

THE INSTITUTION OF ELECTRONICS AND  
TELECOMMUNICATION ENGINEERS

IETE

MEMORIAL LECTURES

50 YEARS  
1953-2003

IN THE SERVICE OF THE NATION

GOLDEN JUBILEE  
COMMEMORATION



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# IETE MEMORIAL LECTURES



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## FOREWORD

*Dissemination of knowledge of Electronics, Telecommunications, Computers and Information Technology is being undertaken regularly by IETE through print media as well as seminars, symposia, technical conventions and lectures. A number of lectures including memorial lectures are organized every year. Memorial lectures in particular are useful to both IETE fraternity and younger generation of scientists and engineers. They serve to perpetuate the memory of our great scientists and engineers and also motivate the younger generation of our field for indulging in constructive and path-breaking inventions. These lectures are very effective as they are delivered by eminent scientists and engineers on the current subjects of interest. During the course of lectures scientific and engineering achievements of the luminaries are also conveyed in simple and effective manner.*

*Realizing the importance of memorial lectures, the Council of IETE decided to publish these in a book form. Dr H S Sharma, Chairman, Golden Jubilee Celebrations Committee and Shri H O Agrawal, Chairman, Publications Committee have done a commendable job in editing the available memorial lectures covering a wide range of electronics, telecommunication, computers and IT topics.*

*I do hope the readership of this publication will benefit a lot from the information stored in the text of lectures and also take inspiration from the inventions, innovative work and the life of the scientists like Homi Bhabha, Vikram Sarabhai, Sir J.C Bose and Sir C V Raman.*

**Sept 30, 2003**  
**New Delhi**

  
**Prof K K Aggarwal**  
**President IETE**  
**&**  
**Vice Chancellor**  
**Guru Gobind Singh Indraprastha University**  
**Delhi**

## PREFACE

To honour India's eminent achievers in the field of science and technology, Council of the IETE decided to add memorial lectures as an important feature of technical conventions and symposia. The first lecture - Bhabha Memorial Lecture was added in 1967 in IETE Annual Technical Convention to commemorate the memory of India's eminent engineer, physicist and administrator, Dr Homi Jehangir Bhabha, with whom IETE identifies itself for two reasons ; firstly, it was Dr Bhabha who started the self-reliant development in electronics instruments required for India's Nuclear Research Programme in 1952, and secondly, electronics industry, R&D and education got the necessary directions through the Bhabha Committee Report which he had completed in record time and submitted just before his untimely death in an air crash in 1966. The first Bhabha Memorial Lecture was delivered by another eminent scientist Dr Vikram Sarabhai who is known for his pioneering work in ISRO and Physical Research Laboratory. It is a tragedy that we, also lost Dr Vikram Sarabhai, another brilliant and illustrious scientist of our country in 1971. IETE, which was associated with Dr Sarabhai, started another Lecture Series in 1973 to perpetuate his memory. This lecture was added as a permanent feature of annual Mid-Term Symposium of IETE. In 1995, IETE started Sir J C Bose Memorial Lecture to mark the centenary of his path-breaking invention - generation and transmission of very short wavelength (mm waves) electro-magnetic energy through a totally self-assembled innovative equipment in the Town Hall of erstwhile Calcutta. Subsequently, in 1997, IETE initiated Sir C V Raman Memorial Lectures in the honour of the first Nobel Laureate Scientist of India.

The IETE Memorial Lectures are delivered by eminent scientists and engineers on current science and engineering topics, relevant to the disciplines of electronics, telecommunications, computers and information technology. The lectures give an overview of the technologies available world over and how they can be implemented in India along with the benefits that would accrue to help in development process. Some of the lectures are on the practical experience of these experts and linked to the pioneering work started by the eminent scientists in the past.

In this issue of Golden Jubilee Commemoration- IETE Memorial Lectures, contributions are from well-known physicists and engineers to name a few; Vikram Sarabhai, S Bhagavantam, S V C Aiya, B D Nag Chaudhari, Thomas Kailath, Raja Ramanna, J Das, A S Rao, U R Rao, Yash Pal and a galaxy of other eminent scientists, engineers and educationists well known for their work in the field of education, R&D, design and manufacturing of high technology electronics and telecommunication systems for nuclear, space, defence and other applications. The ideas of these eminent authors are pertinent even today from the point of view of historical perspective, engineering marvel, scientific knowledge - its applications and as a source of inspiration & motivation.

We are sure this collection of memorial lectures will benefit scientists, technologists and persons from all walks of life immensely.

We would like to thank Council of IETE particularly Prof K K Aggarwal, President IETE, Air Cmde (Retd) P D Badoni, VSM, Managing Editor and his staff of IETE Publications Section for working incessantly towards completion of this publication.

*H O Agrawal*  
*Chairman Publications Committee*

*Dr H S Sharma*  
*Chairman Golden Jubilee*  
*Celebrations Organizing Committee*



1909 – 1966

*DR HOMI JEHANGIR BHABHA needs no introduction. He was a well-known atomic scientist, engineer and administrator. It was unfortunate for the community of scientists and engineers that this genius was suddenly snatched away in an aircrash in January 1966. His versatility was so great that he made monumental contributions to many areas of science and technology including electronics. The setting up of the vast electronics complex at Hyderabad and the preparation of Electronics Committee Report known as Bhabha Committee Report are significant contributions which he made to the development of electronics in this country. His involvement in the development of knowledge of Science and Engineering was so intense that most of the organisations connected with these fields considered his death as their personal loss. The Institution of Electronics and Telecommunication Engineers (IETE) is one of them. It was decided to perpetuate the memory of this great Scientist by institution of a lecture series which is held every year during Annual Technical Convention of IETE.*



# Development through Pace Setting? Horizontal and Vertical Control Systems

VIKRAM A SARABHAI

Chairman, Atomic Energy Commission and Secretary to the Government of India,  
Department of Atomic Energy, New Delhi 110 011, India.

**I**T is fitting that the Institution of Telecommunication Engineers should honour Bhabha by instituting a Memorial Lecture. I deem it a privilege to be invited to deliver the first lecture.

A distinguished civil servant who worked closely with Bhabha for several years remarked to me that, in his opinion, Bhabha was the best administrator he had come across. By this, I am sure, he did not mean that Bhabha was a quick disposer of files or was easily accessible. He was paying tribute to Bhabha's ability to translate into practice insights and attitudes which were based on sound experience and a conceptual background derived as a practising scientist. With this he was able to create organizations and execute projects with elegance and efficiency.

One of the most important tasks that Bhabha completed before his death was the Report of the Electronics Committee which was appointed by the Department of Atomic Energy under his Chairmanship in 1963. This report which is more commonly known as the Bhabha Committee Report has rightly aroused a great deal of interest and is particularly relevant to telecommunication engineers. The role that electronics is destined to play can be judged by comparing the figure of Rs 13,500 crores which represents the value of electronic goods produced in 1965 in the US with the figure of Rs 16,630 crores which represents the gross national product of India in the same year. Moreover the urgency and the enormity of the task can be gauged by the tenfold increase of domestic production from Rs 30 to 300 crores per year which would be required during the next ten years. Its significance to national security as well as to economic growth cannot be over-emphasized. Much publicity has been given to the assessment of the needs during the decade 1965-75 and then targets to be reached in the manufacture of electronic equipment, components and basic raw materials if India has to attain a fair measure of self-reliance. What are not equally well published are the concrete recommendations regarding policy for achieving the objectives. Permit me, therefore, to recapitulate some of these.

The electronics industry has to be considered as a whole

and developed in an integrated and interlocked manner. If the public interest is to be considered, and the interest of the Indian tax payer, it is essential that all equipment, whether for civilian or military use, should be produced in the most economical manner possible, and this requires that the production of this equipment should be organized according to technologies and economics of production, as is done in the highly industrialized countries. If the separation of civil and military production is not required by security consideration even in the technically most advanced countries, it clearly cannot be justified in India. It also follows from technological considerations that production in the public sector cannot be separated from production in the private sector and for optimum development of the industry it is necessary to plan it on an integrated basis taking the public and private sectors together.

Electronics, more than any other, is an industry in which technical persons must be in key positions at all levels, for policy making and for the management of plants down to the individual production operations. In order to develop a self-reliant and largely self-sufficient industry capable of meeting Indian needs and of competing in the world market, the first and most urgent need is to establish in every plant producing electronic equipment, scientific and technical design and development groups with sufficient competence to redesign equipment either being manufactured under license or whose design is readily available in the literature, in order to adapt it to Indian conditions and to use the components available in India. These groups should also bring prototypes developed in the country to the production stage. In all such work a considerable saving in development time can be affected by dismantling imported equipment and copying its design with such modifications as may be necessary to adapt it to Indian requirements. It should be possible within the relatively short period of about a year to redesign equipment or to develop indigenous prototypes from information available in the literature or obtainable from studying foreign models. It is essential that action should be taken simultaneously to design, develop and produce next generation of equipments indigenously.

The very backwardness of the country in electronics and smallness in size of the present electronics industry could be turned into an asset, if early stages in the development of the industry in other countries are bypassed and the industry planned on the basis of the latest ideas and techniques. In no circumstances should India follow step by step the developments of the electronics industry in the more advanced countries, entailing, as this would inevitably, the production of obsolete components and equipments and the use of obsolete and obsolescent techniques and production processes.

The highest priority should be given to establishing the indigenous production of components and establish high grade components required for professional equipments in the country, if the industry is to stand on its own feet and a real substantial saving in foreign exchange is to be effected. It has been found that the economies of scale and the removal of customs duty on imported primary materials for making components or their production in the country, will straightway affect a 40 per cent reduction in the price of certain components, and a further increase in the scale of production will reduce the cost still further.

Expertise is available in the country to design systems, develop equipments and undertake its manufacturing and it is possible to base the next generation of equipment which will come into use between 1970 and 1975, entirely on indigenous designs. It is, therefore, possible to build up a self-sustaining electronics industry in the country within a decade, if development work and progressive switchover of both production and use to indigenously designed and developed equipments is decided upon immediately by government, as an inflexible policy to be followed with determination.

Where the developmental actions are in an advanced stage and where the executive technical authority is satisfied with the ability and capability of the agency to develop and produce the equipment up to desired specifications, then a calculated risk should be taken and firm orders placed on that agency while the equipment is still under development. This will help to telescope considerably the period involved in the procurement of components and the availability of equipment to the users.

It is essential that India should also participate in long range research, and for this purpose strong support should be given by government to such long range research, not directed towards any immediate application, both in government supported laboratories as well as in the universities, and indeed, in any laboratory privately or publicly owned, where there is an outstanding research worker or group. It must be understood that only research workers, who have proved their capabilities and promising young men must be supported for such long range research, which should not be confused with much of the directionless and so called pure research, which is done in

India today. In particular, advanced study and research in the solid state should be strongly supported. It must be emphasized that long range research can and must only be built round outstanding individuals in order to yield any worth while results.

Implicit in the approach which has been outlined is a recognition of the culture in which science and technology thrive, a culture in which one relies on horizontal control systems rather than vertical control systems, a culture in which the role of government is one of pace setting.

I shall try to explain some important characteristics of the two types of control systems. Let us take the example of the preservation of peace in the world. If we succeeded in creating a world government and through its power and control it is able to prevent war from breaking out between hostile groups we would have the successful operation of a Vertical Control System. Here the control is exercised downwards from a higher level. However, take the case of prevention of armed conflict between the USA and the USSR during the last 20 years. Most people would agree that it is not the existence of the UN or the superior power of an organization at a higher level has preserved peace. It has been through the operation of mutual deterrents on what is known as the balance of terror. Each side is aware that to resort to arms for the settlement of a dispute would entail its own population being subjected to unacceptable damage. In consequence peace is preserved by horizontal interaction without anyone from the top ordaining that there should be no war. In every day life we have a number of examples of these successful operation of horizontal controls, e.g., our behaviour with our neighbours or in a community, the manner in which prices are kept down and quality improved through free competition in a situation where there are no shortages. It is in such situations that pace setting by government can be a most powerful instrument for development. Indeed it can be much more effective than through vertical controls.

In our country where we ideologically promote the public sector, government has a wonderful opportunity of priming the process of development by setting up pace setting industries and organizations which through exercising horizontal controls stimulate the overall level of economic development. But this role is impossible if simultaneously one relies on vertical controls which are largely negative in character as in the case of the Industries Development and Regulation Act. We by the worst of both worlds when in a democratically oriented society one relies heavily on Vertical Control Systems most appropriate to monolithic hierarchical structure.

Another important moral that is conveyed in the Bhabha Committee Report relates to the process of leap frogging. Let me give an example. The Indian National Committee for space research recently appointed a group of three experts under the Chairmanship of Dr Rao of the

Central Electronics Research Institute, Pilani, to examine the implications of satellite communications to provide television coverage to India. We clearly require a system of broad band communication for television. To cover the best part of the country about 150 transmitting stations servicing approximately 8000 square mile per station would be needed. If the stations are hooked up through microwave links of the conventional type or coaxial cables we would need an expenditure of about Rs 72 crores. Using a synchronous satellite, the system would cost only Rs 23 crores including the cost of the satellite and its launching. In a developing country such as India the difference between 23 and 72 crores might mean undertaking a project in three years or in ten years. Moreover, one would be bypassing technology, which would be becoming obsolete as time goes on.

In analyzing Bhabha's role in the growth of atomic energy in India Dr Kamla Chowdhry and I made the

following observations: " There is need to understand that there is a shift from simple to complex technologies, from stability to innovation, from experience based knowledge and skills to highly conceptual knowledge. The understanding of this change means the recognition of socio-technical systems rather than a mechanistic organization structure, the recognition that highly trained and professional groups have different needs and motivations, the realization that hierarchical structures and systems need to be minimized and that the concept of control is inherent and contained in professional commitments rather than exercised from outside.

I would suggest that if we are to base the growth of this country on the application of science and technology within the democratic framework we shall have to increasingly rely on horizontal controls. Indeed, State enterprises should primarily be directed at setting the pace. The State should say 'yes' rather than 'no'.

The first part of the report  
 deals with the general  
 situation of the country  
 and the progress of  
 the various branches  
 of industry and  
 commerce. It is  
 followed by a  
 detailed account of  
 the state of the  
 treasury and the  
 public debt. The  
 report concludes  
 with a summary of  
 the principal  
 events of the year.

The second part of the report  
 contains a list of the  
 principal officers of  
 the government and  
 a list of the members  
 of the various  
 departments. It also  
 contains a list of the  
 principal cities and  
 towns of the country.  
 The report is  
 printed in English  
 and French. It is  
 published by the  
 Government Printing  
 Office.

## The Impact of Electronics on Society

S BHAGAVANTAM, HFETE

Scientific Adviser to the Minister of Defence, Government of India, New Delhi, India.

**L**ET me, at the outset, thank you Mr Kanjilal for saying a few nice things about me. It is a pleasure and has always been so in my life to meet any body of professional persons. The Institution of Telecommunication Engineers is a professional body of Telecommunication Engineers. They have been good enough to invite me on earlier occasions. They have elected me as an Honorary Fellow and they have been more than generous to me. I enjoy coming here.

I have accepted the invitation to deliver the Second Bhabha Memorial Lecture because it gives me, in addition to saying what I wish to say to an appreciable gathering of professional men, an opportunity to pay a tribute to one of our greatest scientists, Dr Bhabha. I have some hesitation in deciding on the subject but the fact that you are a group of Telecommunication Engineers and the fact that in the latter years of Dr Bhabha, he devoted a lot of time to telling the government what steps they should take in order to catch up in the field of Electronics with the rest of the world and produced what is now called as Bhabha Committee Report on 'Electronics', I think, the best thing for me would be to talk now on the subject of 'Electronics' as it affects us today in India. So I have not taken any other subject nor have I specifically mentioned the title for that gives me a certain amount of latitude. If we look back on the achievements of science in many fields, I think it will be very widely accepted that one of the greatest triumphs of science and technology in the present century is in the field of electronics.

Electronics for some strange reasons, in particular the past two decades, has been penetrating into almost every aspect of life, public and private. I mean, public, in so far as large organizations are concerned which deal with humanity, communications, Defence, publicity and so on. Private, I mean the domestic life such as gadgets and various other accompaniments. Indeed, two decades ago, this used to be said about plastics. I remember a time when we noticed that plastic entered every aspect of our life except of course food — we cannot make food out of plastic, everything else used to be made. In fact, 20 years ago, I was in a London Restaurant and there was great scarcity of food. It was war time and there was no rice and somebody brought something which looked like rice. I asked him, "What is this?" He said, "This is plastic rice." It was not plastic but it was something which was made of artificial material which looked like rice and it was edible

alright. What I want to convey is, once a thing begins to penetrate our life, it does so with such momentum that almost every aspect gets affected and this is what happened to electronics. If we analyze we find that in many instances our life is tied up with some kind of an electronic gadget or the other. If you take a look of past 30 years, you will find that per capita consumption of electric power would be given in order to show countries at different stages of development or it may be per capita consumption of coal or it may be per capita consumption of steel. For instance, from an earlier book written 20 years ago, I have taken out these figures, that the consumption of electric power per head in the United States was 3000 kW; whereas in India, at that time it was 20kW and different countries varied between these two. This used to be taken as good index of the stages of developments of a country or it may be how much steel does a country produce divided by the population. For example, the per capita consumption of steel, in a country like USA used to be shown as 1100 lb, whereas in a country like India it was 7 lb. Figures must have changed. Nowadays we do not quote these things. The purpose of my saying is to say that at one time such were the indices which gave an idea of the state of development in a country. In 1964-65, I took a book and found that these are no longer being quoted and in order to compare the state of development, here are the figures which give the total production of electronic equipment and components. In the USA, it is given as 13500 crores of rupees worth every year, the amount of material produced by way of electronic equipment and components and so on. As against this in the year 1964-65, India produced 26 crores worth of electronic equipment and components. People have moved away from above comparison, like per capita consumption of electric power. Of course, there are other units too. I often used to compare per capita consumption of milk. For example, I find that if you go to a student hostel in India and ask how much milk does a young man consume, very often you will get an answer which is shocking. Such things do not have an effect on the immediate situation so far as the things are concerned but in the long run, far-reaching effects are there on the nutritional situation regarding the nation as a whole. These factors are gradually moving and the purpose of my saying this is to say that electronics have so much penetrated our life that we have started giving figures in respect of one or the other item, to say, how well we have moved in the modern world. I saw some other statistics which were produced by our own government which show

the number of radio receivers in India. In 1956 it was somewhere like about 11,00,000. In 1966, ten years later — it was roughly about 60,00,000. In ten years, the number of radio receivers, I would like to draw your attention to the fact, has become six fold. But this is a way of putting it. The figures are very deceptive. You must be very careful that a professional statistician does not produce a figure in a manner in which you are taken away. That it has multiplied roughly six times is a statement of fact but even if we had 10 receivers and they became 60, mind you that also is a multiplication of six times. For how many people do we have this number of receivers? This is a question which one would have to ask and it was very low at that time. This was the situation in the field of electronics.

This is one field where considerable amount of interaction has taken place between science and technology. I am sure, you understand why and how I am distinguishing between the technology and science. I am one of those who believe that the two are distinct. They are mutually dependant. Technology depends on science and draw from science for its growth. Science has to flourish only by maintenance of technological prosperity. In other words, it is a sort of mutual dependence and growth of technology and the growth of science are inter-dependent. At one time, I called this a widening spiral of science and technology. Growing technology wants a good scientific base otherwise it will collapse. If science has to grow, technology has to flourish and provide money for science to grow. It is a very sudden interaction and in the field of electronics, this interaction has been most spectacular. I may mention here one example in which this spectacular interaction has taken place. Let us take Defence, various kinds of weapons — may be missiles, may be an aircraft, or may be a kind of radar and so on. In the early days, even now you can see such models, one could not have replaced them by lethal models which are quite heavy. They used to build quite large items with the help of basic things. Now people began to demand lighter ones. As they demand lighter ones, then came the transistor. When the transistor was discovered, immediately the weight and the size and the appearance of a particular instrumentation came tumbling down and the demand increased for reducing it even further and now we talk of integrated circuits, printed circuits and so on. You will see in the past 20 years such radical demands have been made. In fact, demand when it is made almost looks as if it is unreachible and unattainable, but yet the demand is being met by technology and the science is rising to the occasion by introducing something quite radically different from what was obtained at the time. Demand is made and this interaction between the demand on technology and the resources of science is something quite remarkable in that area of electronics. In other fields too, I can mention as examples, Defence as always given rise to such action and re-action in many cases. In the case of weapons, for examples, the same group of scientists who provide a weapon, spend time in finding

out some way of conquering this weapon and after they find out, they again spend the next five years in trying to improve the weapon and modify it in such a way that the new discovery does not work and the next five years again they spend in overcoming this particular drawback to improve the weapon. This has gone on in the history of interaction between Defence and Science. A similar interaction has taken place in the field of electronics between technology and science with the result that today you have what you call miniaturized items in electronics. Every one wants to carry something near his ear which is not seen by others and which will serve as an earpiece. People want to carry, even police wants to carry the receiver, transreceiver or transmitter but they do not want others to see that they are carrying transreceiver. They want it to be so small. They want the aerial not to project outside. In fact, they do not want to be recognized as police-men, of course for other reasons too, apart from electronics reasons. But the point is, that the almost in every phase of life we have demanded quite severe specifications and the miniaturization has gone to such a large extent today. I was addressing a group of physiologists the other day. They want such tiny things which they can put inside the nerve. They want the aerial which would be of the size of pin head which does not want to jet about outside the body and they want signals to be transmitted from the nerves' fibre which they can receive and they can work upon. It is an extraordinary situation by which miniaturized electronics has been pressed into service by different kinds of people and the working requirements which the technology has been demanding have been met by the scientists by the process of miniaturization and today we have the results of this technology and science in one of the most developed branches of electronics. That was the situation in 1963-64 when the Government of India constituted this Committee of Electronics of which Dr Bhabha was the Chairman and in whose memory, I have the honour today to speak to you for a little while.

I had the privilege of working in this Committee and we had many difficulties. However, the report was written and was presented to the government. I do not want to tire you with the details of that report but since you are an Institution vitally concerned with the state of electronics in the country and what is happening to the Report, I would like to express my personal opinion. Take two aspects of that report. If you have to keep reasonable pace with the developmental subjects of the world, you ought to fulfill and provide for our own requirement in a reasonable manner and not at a slow rate of growth which I have mentioned in regard to radio receivers. In regard to the total production of electronic equipment as in 1964-65, the Committee envisaged doubling the rate of production in every three years. This is one important point which was envisaged in the Report. There are many industrialists here who are running production units. They would realize how difficult it is to double your output in three years. In fact, if

you can do that you will be a very flourishing industry. Doubling the production again, there are snags here. You can double your production from Rs 100 a month to Rs 200 a month, you can double your production from three crores to six crores a year. Do not be led away by simple figures. I had to quote too many figures but unfortunately, the subject is such that it has got into some controversy and I had to draw figures to give you but I feel it is the realistic estimate of the situation. Doubling the rate of production every three years was envisaged by the Committee. Various steps have been recommended that we should take in order to achieve this and I will deal with this presently.

The second important recommendation in the Bhabha Committee Report is to be able to attain self-sufficiency to the extent possible, as quickly as possible so that we can meet our needs and attain this doubling every three years until we reach a stage when we would be able to do all that we need in the country. Several steps were suggested in the Report to meet the situation and one of them was that in a large measure, we should encourage the indigenous research and development and do it in a way with the order of magnitude different and higher from what we can see today. Of course, there are research and development units, laboratories, organizations, universities and they have been doing some work but it was recognized that if you make marginal addition, it is not going to produce any difference. We will have to handle the support to research and development in a big way which needs an order of magnitude different from what we do now. In other words, there are only two which I have picked up. Of course it is a very voluminous report and we spent years over it and many details and figures were given, many people were interviewed and many people expressed their views. But I am not taking which are in my opinion subsidiary. I have taken only two major aspects. I will say a few words on these aspects. The first one is doubling the rate of production every three years. Now where are we in regard to this. I have collected here some figures regarding production and I may just as well state my conclusions before I read to you these tiresome figures. My conclusion roughly for some reason or the other may not be true because we have not made any conscious effort but there are other factors in this world which operate. There is great pressure. The demand is more, the industry wants to make profit and so on. May be even as they call the circumstances beyond our control. When we enter into agreements, clauses are provided by which if God interferes and introduces certain parameters, then the contractual obligations do not fall on the individual signing the contract. However many things have happened. In 1962 there was an aggression on this country. In 1965, again, there was an aggression on this country. I often say that some times out of evil comes good. So far as I am concerned as a technical man, out of 1963 and 1965 by many of our friends refusing to supply equipment to India for some reason or the other, classifying them as lethal

weapons and so on, some good has come out because it meant that we had to put fresh efforts into our own production. Whatever the reason may be, my general conclusion is that in many areas in electronics, the production has gone on as envisaged by the Bhabha Committee. I will give you a few figures. The defence equipment produced in 1964-65 was worth Rs 5 crores, in 1966-67 it was 8 crores and in 1967-68 it was 14 crores. Now that finishes three years. 1964 it is 5 crores, and 1967-68 it is 14 crores, one crore short of becoming three times. In 1968-69, the current year, we expect to produce 21 crores worth of defence equipment. These are the figures which I have taken from the published material in regard to the defence equipment. Well, I can take the entertainment equipment also. I have figures here — 1964-65 17 crores, 1965-66 24 crores, 1966-67 32 crores and 1967-68 40 crores. It has not become three times but it has become 2½ times. Very often it is said and the Bhabha Committee Report has mentioned that the components which really go into these equipment are more important and is it alright to give these figures which are simply white washing. The components have to be produced in the country. You cannot import the components and rig up these equipments. These statements are made very belatedly. I have got here the production of components by value. In 1964-65 it was 6 crores, 1965-66 8 crores, 1966-67 10 crores, 1967-68 15 crores — 6 crores to 15 crores is again 2½ times and 1968-69 we expect to produce components worth 29 crores. There is a big spurt now in components. I have seen just now in the exhibition large number of components, some of them cleared by the Inspectorate of Defence have been put up. These are coming in large numbers. We expect the components to be 30 crores in this year which is five times than in 1964-65. I have got figures to show that so far as the production of equipment and components is concerned, we seem to have and I think we have achieved a doubling rate of roughly three years. I must seek an indulgence to spend a few minutes on the production aspects of the major electronic company, namely the Bharat Electronics, which does substantially meet the defence requirements and to a large extent, like valves, transistor and so on. I have not taken on myself the task of advertising Bharat Electronics but there are certain points which I do want to draw out of it. Incidentally, the poor public sector comes under a lot of criticism and justifiably but Bharat Electronics is exempt and should be exempt from that because of the performance which I should presently mention. Very often statement is made how are we interested in Bharat Electronics. They make only defence components. Before the emergency, we used to say how are we interested in Bharat Electronics, they make only civilian components. This is an unfortunate criticism. The fact is that the total production of Bharat Electronics today and so far the past three years is divided in the ratio of 66 per cent for defence and 33 per cent for civilian use which is the actual situation and this has got to be fluid. It will change depending upon the requirement. No Company can afford to put up factories which will for all

times produce defence equipment or civilian equipment. In fact one of the major recommendations of the Bhabha Committee is that in electronics, it will be very unwise to make clear cut distinction between the defence production and civilian production. I may also mention the important fact because those of you who are acquainted with the Electronics Industry would probably accept that if the investment to turnover is in the ratio of 1:2 then the industry would be on sound basis. That in Bharat Electronics during the past three years, the ratio of gross effects to turnover has been increasing from 1:1.3, 1:1.4 and last year it was 1:1.5. Yes, the ideal ratio would be two and the reason for not achieving this is that we are not able to farm out as much work as we should have to outside units, and then undertake the assembly of major equipment. Then the profit should be more and turnover will be more. We have consciously been attempting in Bharat Electronics to farm out what are called Auxiliary Industrial Units which are located inside the Campus itself, as much as possible but the movement is quite slow. There are certain difficulties in this country in attaining the situation of this kind. If I may take a minute to mention that so far as the Bharat Electronics is concerned, I have figures here for four years of which I have been connected with it and I am quite proud to say that after making it quite a flourishing electronic industry and after giving bonus to its workers to the maximum extent permissible under the law, we have been able to give a dividend to the owner, i.e. the President of India. Starting in 1964, the dividend was 5 per cent, in 1965 it was 6 per cent, in 1966 it was 7 per cent and in 1967 it was 8 per cent. Every year, I have been able to increase the dividend by one per cent. But I do not hope to do this too long. May be I may cease to be connected with the Bharat Electronics before it becomes impossible to raise it every year by one per cent. It is possible in India to double your production and we have done that in Bharat Electronics. Many others have done also in electronics and they have shown in figures and yet maintained a proper assets turnover ratio and make profits and meet the requirements of the country. This has been done not simply in the defence field. The production of Bharat Electronics is  $\frac{2}{3}$  in Defence and  $\frac{1}{3}$  in the civilian sector today. At the present moment, it is quite possible that in the country today the point of doubling of production in electronic equipment and components every three years and yet build up a flourishing industry is quite possible. How you do that and what are the weakness in that, I presently come to. Now take the radio receivers. It is much talked of topic and I would like to say a few words. The radio receivers, we were quite worried about it because the number of receivers as I mentioned a little while ago is not indicative of the progressive mass contact. The number of receivers as I mentioned a little while ago is not quite large although it has become six fold in 10 years. In 1965-66, six lakhs of receivers were produced, in 1967-68 16 lakhs. The number has become nearly three times and in 1968-69, i.e. during the current year, it is anticipated to be 2 million. I am told

that one million of that are being produced round about Delhi area by various producers of radio receivers I have seen today a radio receiver which is priced at Rs 165 or something like that with both medium and short wave bands. A radio receiver which will be cheap enough, which will have no foreign exchange content worth mentioning, which can be purchased by our poor man, a simple man, is what is required. Now I have put it very carefully what a cheap receiver means. Scientific inventions and technological developments in this country have fallen because we do not define what is meant by a cheap receiver. I recall 20 years ago, we talked of a solar cooker and a cheap solar cooker. How cheap? Well the trouble comes there, Rs 100, Rs 50 or Rs 20? Nothing can be cheaper than a chap who puts up a mud 'chullah' and a few bricks to build it up. You cannot have a cheap enough solar cooker in this country unless you discuss what you mean by cheap. A cheap radio receiver, I am afraid, Rs 165 is not a cheap radio receiver. How much Rs 100, Rs 50, or Rs. 20. Well, there are different views on this. I should not go very much on that controversial issue.

The only other item before I leave this question of production which I like to touch is the TV receiver. This is very much in the news and have controversies first in regard to foreign know-how. I understand, the present position is that a capacity of 30,000 TV sets per year has been licensed. So we expect these license, if they go into production sooner or later, will be able to supply 30,000 receivers. I also understand that there was some uproar by people who were expecting these sets and there was a meeting recently and it was expected that they will produce sufficient number from January 1969, which is only 15 days ahead. I seldom like to make a prediction which is so close as 15 days. The receivers are expected to be marketed at a selling price of Rs 1800 and will involve an import content of Rs 260 per set. You have seen in the newspapers that Bharat Electronics, only a couple of days ago, have signed an agreement by which they will produce picture tubes and we hope when that production goes 1970 or so, we reduce the foreign exchange content. I am not mentioning these things for any other purpose than to say that here is a TV receiver which is being put up on the exhibition and I have one in my house for my own use. An excellent work has been done and has been put up. For the time and the effort and this country's resources, the work done is commendable and I would strongly suggest in a case like that very soon I am going to raise this slogan of "Indigenous know-how and no foreign import". I have deliberately called it a slogan because I have some reservations for that but in a thing like TV receiver what does it matter if by January 1969, those who are very vociferous have a TV set or not. They may get it in six months. We should certainly take all efforts in our capacity to see that the indigenous development is helped and is processed. No one can produce an ideal thing to start with. The troubles will all be overcome in due course. This is the

position about the TV receiver. I recall that something similar used to exist some 20 years ago when the broadcast receivers were manufactured in this country.

Now let us leave this aspect and let me go back to the second important recommendation of the Bhabha Committee that is self sufficiency without foreign assistance by encouraging indigenous research and development in a big way. A criticism that is made on the production units and the production which I have just referred to, is that this is a licensed production. Now it is unfortunate that uniformed statements are being made like that. I would emphatically deny that. I know from personal knowledge that research laboratories have been designing and developing some most valuable items. We have designed in defence, a reasonably sophisticated radar for motor location that is under production in Bharat Electronics. We have designed some very sophisticated communication equipment which is of a nature that it will not be sold to us by any other countries because it has something to do with deciphering and so on and that is under production in this country. We have designed some excellent equipment sophisticated which may not be miniaturized so as to be able to carry in your pocket as any commercial man would try and convince and I am afraid by senior Defence Officers every time they go abroad. They do see these things there and they come back and they tell us: "Oh, we are worthless fellows, we do not want such things, we want something which can be carried in our pockets". Yes, you can get it, but you will have to wait for a little while until you have the same resources which the other countries have had. We have to give all the chances so that it can survive. The real prick is that it is for a bold decision making authority to decide on what we can wait for a little while and on what we cannot wait for. This decision is more a political decision and it is not a typical decision. It is something which involves risk and which we can take and one should take. That apart, we have produced items which have been designed by our own scientists and they are under production. Unfortunately, since some of them are not well publicized, an uninformed critic often says, "Oh, yes, you have doubled your production in three years and all is satisfied but you have done it under licensed production. What about indigenous know-how". Let me say that I recall a speech made by a very senior administrator who is no more now. The title was "Down with slogans". One young man got up in the audience and said, "Sir, that is a slogan". I do not want myself to submit to such a situation but I do want to say that this statement is often made that we have the indigenous know-how. We can deliver the goods in every electronic item. This is being said so often and so much out of context and without reference to other parameters which also have to come into the picture that it has become a slogan. No country ever makes a statement that we shall not look at any other country or import any know-how from them. This is not possible. Every country considers an item on its own merits. One thing, since you

are a technical group, it is my conviction that there is an enormous amount of technical competence. There are young people who know these things; who can do it but that is not sufficient, if you want to reach the aim. There are other requirements. There is the managerial skill, there is the need for someone who can keep these 100 scientists together. I remember the remark which General Rose who looked after the atomic weapon programme of the United States said. After the closure somebody asked him, "How did you enjoy looking after the scientific group who made the atom bomb?" Pat came the reply, "it was a job to keep six-hundred pots without quarrelling with each other". That was his job. Six-hundred crack pots were put inside a building and General Rose's function was, apart from making the atom bomb, which anyway these fellows were doing and wanted to get out of it, was to keep them looking at each other without quarrelling. Please do not think that to produce three radars every month is all technology. There is a great deal of technology but in addition to this there is managerial skill, there is the need for financing it; there are administrative bottlenecks, somebody has to see that these things are done, these are produced and finally delivered. I have often said that simplifying and over-simplifying the situation to reach a goal, may be a very difficult goal of self-sufficiency. Technologically, we are nearer the goal, but administratively, we are very far from it. Unless the technology management, administration and financial backing all pooled together, one cannot progress very much. What is the use of men of science and technologists making promises that they will do this and they will do that and not fulfilling those promises, even in one case, if it is going to put the technologists in an awful situation. Thereafter no body will believe you. This is the reason why I say take each case on its merits. Certainly you should discuss every item. Others should also come into the picture and if all of them come to the conclusion and the decision makers say yes, you can deliver the goods be all means, take the risk and take the plunge. But I must caution my own friends. Every one knows how a radar may function. That alone is not sufficient to make, manufacture and deliver a number of radars, to the defence and once you do not do it, these people are merciless. They are only waiting to show that the Indian indigenous development cannot deliver the goods because they can purchase from outside and no other hindrance can be put in. I am not saying that they are less patriotic than the technical people. It is an action and reaction. If you want to buy your clothes, why do you go on buying a tie which is made outside. Why do you go on buying clothes which are made outside. You do not buy a fountain pen which is made in India because it does not write and you want to write. It is not the question of lack of patriotism on my part but I certainly want to write my notes and, therefore, I want to buy a pen which writes and, therefore, I want to choose the pen which writes. And you do not want to buy an Indian pen because it is just an Indian. But Defence is a field in which there is no room for such sentiments.

Now research and development. Yes, there is a basic weakness in our whole set up. Bhabha Committee discussed it at great length and came to the conclusion and I fully agree with it that the base of research and development today in the country is in order of magnitude much below what is necessary to achieve these things. The talent is there, but that is not enough. You have to put very much more efforts into these organizations. You have to bring them into the picture, you have to make the young people realize what it is carry the research into design stage, design into the development stage and the development into production stage, otherwise all efforts that are put on research remain in the walls of the Research Laboratory. This is a matter on which the British have today realized and recognized and they are taking many steps to see that there is no break at any one of these points of this cycle. You have a research at a concept stage and then a design and then the development takes place and then the hardware and then the production. Unless, the whole chain goes through without any break, the fruits of research are not being enjoyed by the nation. India cannot afford to spend any money today unless out of it comes something which will add to its gross national income. This is a very vital matter and decision on bigger issues cannot be taken only by the scientists, feeling that he can deliver the goods or by the patriots, feeling that let us get on with what we can design and produce. However, it is fully recognized and I would like to state that while the production has doubled at the rate of each three years, as contemplated by the Bhabha Committee, the support to research, design and development as contemplated in the Bhabha Committee Report has not yet taken place. It is this area where further efforts have to be put in my opinion and the groups have to be strengthened. They have to be given more resources, they have also to be allowed to play the things on a redundancy basis and if it does not succeed, it does not succeed. But at least, they would have learnt that they could not succeed by working in that manner, and failures are only stepping stones to success. This is the thing which one has got to realize very fully.

The Bhabha Committee expects that about 85 crores per year will be spend on research by the year 1975. I do not think we are spending at the present moment anything more than about 10 crores at the outset. 1975, let me see, is not ten but seven years more. Ten crores a year to be stepped up to 85 crores by 1975 is a big job. If you want to spend 85 crores, you can. But you will have to take care to see that extension takes place only after certain requirements are fulfilled. I think there is a big gap and I like to utilize this opportunity of drawing your attention to the fact that more resources have to be put in and more courage has to be put and a bolder attitude has to be taken with regard to the expenditure on research with open eyes that research is something which has got to be promoted if you want to attain ultimately the self-sufficiency which you have aimed at. To believe that you can and you have this

situation with us and to argue that as a slogan, to the extent of its being misunderstood as a slogan, that no item need be imported, we have self-sufficiency, will lead, in my opinion, to disastrous consequences in some major areas. I do not want to pick out individual organizations but there is the CSIR, there is Atomic Energy, there is the Defence R&D, and these agencies have been doing considerable amount of work in electronics. The Universities, for some reason or the other, have been depleted of real talented material, in this area. It is only in the University that one can play about with the freedom that is necessary at that stage for one to play about. The three other organizations which I have mentioned for reasons which may slightly vary in shape but in essence the reasons are the same, there is a certain amount of constraint, there is a certain amount of pressure to do one thing or the other. Therefore, the freedom that is necessary for making a breakthrough on a large national scale and to be able to leapfrog and to get something which would put you right on the map of the electronics of the world, can be expected only in a place like University or the University-like Institutions. I am afraid, I have no time to go into the details by which or lay the finger on the agencies which have been culprits for denuding Universities of all the talents as they did in the past few years. The point is that the Universities have to be strengthened from this point of view. I have dealt with these two major items, which I think constitute the essence of the Bhabha Committee Report.

Coming now to the electronics proper, and electronics production, I want to say that my own contact and knowledge of the talent possessed by the young people is that it is excellent. Of course, today, science in India is passing through a terrible situation. Words like brain-drain, people not wanting to come back to India because those who are in India are all devils and those who are outside India are all angels. This kind of thing is confusing the situation in an awful manner. However, I think they are only passing phases. I have no doubt that no body should run away from the field in which he is asked to deliver the goods. I have no sympathy or respect for those who want to stand out of the place where trouble is and talk in a very patronizing manner. Those who are in the struggle, remain in the area, try to overcome the difficulties, understand them and face them, would achieve the objectives laid down in this Report. It is necessary for this nation to achieve the goal which ought to be achieved and put itself in a comparable position to advanced nations. It is those and the people whom I see everyday in the various electronics laboratories, on whom rests the responsibility. I like to utilize this opportunity to say that I have no doubt that given other support such as the administrative support, financial support and so on, they will deliver the goods.

I thank the Council of the Institution of Telecommunication Engineers for giving me this honour of asking me to deliver the Second Bhabha Memorial Lecture.

## The Electronics Industry in India

A S RAO

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At the outset, I wish to express my sincere thanks to the President Shri Kanjilal and all members of this Institution for providing me this opportunity to participate in your annual convention. As one who has had the happy privilege of working with the late Dr Homi Bhabha for well over 18 years, I deem it as a very special honour to have been asked to deliver this memorial lecture. In our country there has always been a keen appreciation of the value of fundamental knowledge and many of our young graduates show a strong predilection for the pursuit of pure research. Quite a few of our scientists have won international recognition for their outstanding contributions to the basic sciences. Among them, Dr Bhabha's original contributions to the development of nuclear physics, cosmic ray physics and quantum electrodynamics, are very well known. Besides this personal contribution, he advanced the cause of basic research in our country through the creation of centres of excellence such as the Tata Institute of Fundamental Research, which is recognized as a national centre for advanced research in physics and mathematics. The importance of applied research and technology in an emerging country such as ours has not gained the degree of understanding that it deserves. It has been felt only to a very few individuals, who, by dint of their leadership and pioneering efforts, have contributed enormously to a proper appreciation of applied research and technology. Among these individuals again the name of Dr Homi Bhabha will stand at the very forefront. Thanks to his vision, his missionary zeal, organizational ability and guidance, India has found a respectable place on the nuclear map of the world. More importantly than that, he exploded the notion that a developing country must adopt a gradual step-by-step approach in order to catch up with the advanced nations of the world. His achievements point out very poignantly the kind and qualities of technical leadership and the teamwork which are needed for creating modern technological base in a developing country and sustaining it in a rapid pace of growth and development.

Today I wish to talk to you about the development of the electronics industry in India, not only because of my longstanding contact with it but more especially because of the great future role that Dr Bhabha foresaw for this industry in India. It was because of his conviction that this industry could be ushered in our country and sustained in a pace of high growth-rate, and thereby help solve many of

our chronic socioeconomic problems, that he so readily agreed to serve as the Chairman of the Electronics Committee, in spite of his numerous preoccupations within and outside the country. He guided the Committee during the long hours of discussions and, in the words of our Prime Minister, "every page of the report (of the Electronics Committee) bears the imprint of his genius, skill and thoroughness and attention to detail".

### TECHNOLOGICAL EVOLUTION SINCE WORLD WAR II

When one surveys the evolution of the post-World War II industrial scene, one feature that strikes out very prominently is the emergence of science-based industries of high technical content. This evolution has had a revolutionary impact not only on industry itself but also in the society at large, contributing to rapid improvements in standards of living and material well-being of people. It has brought about immense changes in the concepts and patterns of industrial management, leading to the enormous professionalization of industry with technical personnel playing key roles at all facets—from the elaboration of a laboratory concept to the development of a saleable product, from production to marketing and sales. Among these science-based industries the growth of the electronics industry has been very spectacular. Electronics began as a systematic technology with the development of the radio valve early in this century. By the beginning of the thirties, it became a dependable and well-understood science, although it was primarily confined to radio technology. During the thirties, a great variety of transducers were developed to transform various physical parameters into small electric voltages and electronic devices began to be increasingly used in physical research. During this period, the technique of television also was brought to an advanced stage of development. It soon became evident that there was practically unlimited scope for the application of electronics and many brilliant scientists and engineers began to be drawn towards this field. When the Second World War broke out, electronics was called upon to serve a number of military needs. The most noteworthy development during the War was the application of the radar and the technical lead of Britain in radar development over Germany was largely responsible for the final outcome. Thanks to the strong impetus provided by the

War, the electronics industry began to expand at a fabulous rate in all the industrialized nations of the world. Striking progress was achieved in the US electronics industry during the fifties, the most significant achievement being the development of electronic computer. She has ever since continued to maintain technical and commercial lead in this industry, owing not a little to the strong support and vigorous initiatives of her Government under the imperatives of the Cold War and Space venture. Although military demand has somewhat slackened in recent years, the industry has continued to grow at a rapid pace because of the expansion of the civilian market. In 1968 total US sales of electronic products stood at about 25.3 billion dollars, compared to about 2.6 billion dollars in 1950. With a share of about 3.5 per cent of the gross national product, the electronics industry runs fifth among the major industries of this country and is making a strong bid for a higher place.

It is certain that during the seventies the electronics industry will register substantial growth in view of the developments that are now taking place. It is not possible to describe all of these developments in detail. It would be sufficient to mention just a few of them. Significant achievements have already been made in world-wide communication and broadcasting, in whether study and large-area mineral prospecting with the aid of satellites. It may be expected that these achievements would, given a climate of international peace, good will and cooperation, lead to the speeding up of the growth-rates of the economies of the less-developed countries by cutting short some of their inherent obstacles to development, such as illiteracy and inadequacy of technical services. In the field of education, with the aid of electronic teaching aids, it seems possible that high-quality instruction could be provided to large numbers of pupils and paucity of skilled teachers need not any longer be a problem. In business and industry, the computer is taking over many of the operations which have hitherto been performed by human beings—whether it is sorting of mail, invoicing and inventory control or control functions in the operation of a large nuclear power reactor or a large chemical complex. Electronic welding methods and electronic furnaces are increasingly used in metallurgical processes and the laser has become a power tool. In the home also, microwave ovens and ultrasonic liquidizers are becoming fashionable. Computers would be increasingly used in diagnosis and in medical treatment planning. Breathtaking developments are taking place in the field of transportation with the introduction of supersonic transport planes, giant tankers and the use of computerized traffic control in urban areas. These developments would in turn entail substantial increases in the use of electronic hardware. Finally fundamental research, especially high-energy nuclear physics, is itself becoming an important consumer of costly and sophisticated electronic products.

## TECHNO-ECONOMIC CHARACTERISTICS OF THE ELECTRONICS INDUSTRY AND THEIR RELEVANCE TO INDIA

At this stage, it would be appropriate to examine some of the techno-economic features of the electronics industry. Perhaps the most outstanding feature is the low investment needed in equipment and material. Because of this feature, the ratio of the annual production to investment in fixed assets (exclusive of buildings) is high, being as much as 4:1 in the manufacture of electronic consumer goods and about 2:1 in the manufacture of electronic capital goods such as computers. In comparison, in the steel industry, for example, this ratio is as low as 1:2 and is of the same orders in the fertilizer, heavy chemical and petro-chemical industries.

A second feature is the sort gestation time required between setting up of the plant and the commencement of production. Experience at Trombay shows that this gestation time is typically about 12 months for the manufacture of electronic components and about 18 months for the manufacture of electronic capitals goods such as computers. In the case of the steel industry, on the other hand, national experience has been that the gestation period is of the order of 5 years or more and in the case of the fertilizer, heavy-chemical and petro-chemical industries, it is of the order of 3 years.

A third feature of the electronics industry is the high value added by labour. In fact, skilled labour at all stages from design to production is the key commodity in this industry. Because of the high technical content of the products, the ratio of engineers and scientists to production personnel is very high, being typically one engineer for about 15 production personnel. It is also not uncommon that technical personnel are employed not only in research, design, development and production but also in marketing and sales. It is not surprising, therefore, that the wage bill accounts for a sizeable proportion of production cost, being as high as 35-40 per cent.

Yet another feature of the industry is that many sectors of the industry, it is the quality and performance of the product that is the decisive factor for the market, rather than its price tag. This is particularly true in the case of several professional electronic equipment where technical performance is of primary importance.

Finally, the industry is characterized by a fast obsolescence rate of many of the products. This obsolescence is often the result of revolutionary breakthrough in the basic sciences, leading to the development of new components or of the development of new design principles and is also induced by market forces, reflecting changes in users' requirements or the development of new applications. Typically the life of a product is about 7 years in the components sector and 5 years in the capital goods sector.

Both the last two factors underscore the importance of research and development in the industry. About this I shall speak in some detail later on. First I would like to discuss the opportunities that electronics has for our country. I think that these opportunities are tremendous and highly significant in the context of our current economic and social problems, the most important of which is the problem of the educated unemployed. The investment we make in the education of our younger people makes no sense if we are unable to provide opportunities for meaningful employment of their skills. According to estimates provided recently by Mr J R D Tata, the unemployed number about 13 million at present and this number would swell to some 27 million by 1975, despite the creation of some 14 million job openings during the Fourth Plan period. The high employment potential of the electronics industry must be exploited fully, if we are to contain this problem and provide meaningful employment for the majority of our younger generation. The advantages of low per capita investment required, the short gestation period and the high return on investment are also obvious in the light of our present economic conditions of scarce capital and sluggish growth.

#### INDIAN ELECTRONICS INDUSTRY DURING 1947-63

It would be interesting at this stage to trace the growth of our electronics industry since independence and assess its present status. When we became free in 1947, the electronics industry consisted of a total stock of some 2,70,000 radio receiving sets and an annual production of about 4000 sets, six low-power medium wave transmitting stations and a telecommunication network comprising about 83,000 telephones. Conscious of the extreme inadequacy of these equipment, the Government took up a programme of expansion of these industries. The Indian Telephone Industries was set up in 1948 to manufacture telephones, openwire carrier system and related test equipment. The total number of telephones at the fiscal year 1962-63 including extensions and PBX extensions amounted to about 5,70,000. The All India Radio started an expansion of its network and by 1963 the network consisted of 32 stations. An experiment television broadcasting system was set up in New Delhi in 1959. The annual production of radio receivers by the large-scale manufacturing units steadily increased to about 3,60,000 in 1962. In 1954 Bharat Electronics Limited was established mainly to cater to the needs of the Defence Department and All India Radio. The total production of electronic components and equipment from this public sector undertaking touched a figure of about Rs 3 crores during 1962-63. In 1952 a small unit consisting of a handful of electronic engineers and technicians was formed by Dr Bhabha as a nucleus for the independent and self-reliant development of nuclear electronic components and instruments. The unit expanded steadily to become the

Electronics Group of Atomic Energy Establishment Trombay. During 1963 a production of about 18 lakhs worth of nuclear and allied instruments and equipment was achieved.

Impressive as these achievements were, they still represent a rate of growth that was meagre in comparison with what had been achieved in other countries, notably Japan and hardly commensurate with the size and population of our country and the growth-rate of our needs. For example in 1962, our total output of electronic goods amounted to some Rs 21 crores and it increased to about Rs 43 crores in 1966, still representing an insignificant proportion (less than 0.3 per cent) of our GNP for that year. In comparison, the output of electronic goods in Japan amounted to Rs 1350 crores in 1962 and this increased to about Rs 2325 crores in 1966, representing about 3.5 per cent of her GNP for that year. During 1966 alone Japanese export of electronic goods amounted to Rs 600 crores a value that was comparable to our total export earnings from all goods and services for the same year.

These figures would bespeak the importance of electronics to our national economy and the urgency of its rapid development.

#### BHABHA COMMITTEE REPORT

It was partly with a view to stimulate speedier growth and achieve self-reliance in this vital sector of industry that in August 1963, the Government of India set up a technical committee under the Chairmanship of Dr Bhabha to make a comprehensive study of the structure and state of our electronics industry and "to recommend measures for the planned development of electronics so that the country as a whole may become self-sufficient in the shortest possible time and in the most economical manner." The committee recognized from the outset that the task of planning the electronics industry for the next decade was of such proportions and complexity that no full report could be submitted by it within a short time. On the other hand, it realized the urgency of the problem and the need to initiate as much action as possible quickly and without waiting for the final report. It accordingly decided to take up various categories of equipment and components and to deal with them as comprehensively as possible in interim reports, highlighting areas where action could be taken without waiting for the final report of the committee. The committee submitted 21 such interim reports and the final report consolidating the recommendations in these reports with modifications where necessary, was ready towards the end of 1965. It is disappointing that the some of the recommendations, in particular for the development of the professional electronics industry, have not been implemented as expeditiously as would have done justice to the sense of urgency with which the Committee completed its task and as would have been desired by Dr Bhabha, were he alive to-day.

It may summarize the highlights of the Committee's basic recommendations. The Committee assessed the need for electronic equipment over the decade 1966-75 at Rs 1600 crores and recommended a total investment of about 170 crores during this period and the expansion of the manpower base from the then existing level of 15,000 persons, including those engaged in distribution and servicing, to about 4,00,000. These inputs would enable the industry to grow at a linear rate of about 30 crores per annum, thereby meeting the cumulative need over the decade and ending up with a terminal output of Rs 300 crores of electronic products per annum. Considering the sizes of our Fourth and Fifth Year Plans, the recommended investment is indeed very modest and should be easily achieved. It must be pointed out that even with the terminal output of Rs 300 crores reached in 1975, the electronics industry would still have a share of only about 1 per cent of our GNP projected for that year — a share that is considerably less than what it is at present in the advanced countries, namely around 4 per cent.

In the four years which have elapsed since the preparation of the Bhabha Committee Report, the output of our electronics industry has increased from about Rs 29 crores to about Rs 82 crores in 1968. While we may take pride in this substantial growth, there is, however, no room for complacency, for a large proportion of this increase was accounted for by the entertainment electronics industry alone. The professional electronics sector has not shown the rate of growth that is needed. An in-depth study of this sector is urgently called for.

### ROLE AND IMPORTANCE OF R&D IN INDUSTRY

I am convinced that we will not and cannot make any significant headway in the area of professional electronics so long as we continue to depend solely on import of know-how and technology, without establishing a strong and vigorous R&D base within the country. There should be a proper appreciation of the importance of this indigenous R&D effort not only on the part of policy making and financial organs of Government but also, and perhaps more importantly, on the part of management in industry, whether in the public or the large-scale private sector.

Here, I am not speaking of basic research but rather of a product-oriented R&D effort, in which the accent is on development. As I mentioned earlier, technical lead is of vital concern in the field of professional electronics. However, I do not suggest that we should have an R&D base which should be able to invent everything in order to attain a technical lead. Nor do I think that it is feasible at the present juncture of our electronics industry to pursue such an offensive strategy. In fact the experience of US in the early years of development of her electronics industry and the more recent experience of Japan show that such a

strategy is not even absolutely necessary. There could well be some advantages in following deliberately a defensive policy in our development effort, so that we can profit from the mistakes of others. What is needed, however, is to have a strong development and engineering capacity so that inventions made elsewhere may be quickly assimilated, copied, utilized and improved upon.

It is also necessary to see the role of this R&D effort in another light. Because of the complexity of professional electronic equipment and systems, it is virtually impossible to manufacture anything without the right to use a large number of existing patents. For this reason, cross-licensing and patent 'pools' have been characteristic of the industry. The stronger our own R&D efforts are, the greater are the chances of obtaining know-how and licenses from other countries on favourable terms.

I would now like to take up the question of allocation of finance for R&D programmes. The Bhabha Committee has recommended that the annual outlay on R&D should be stepped up so as to reach a figure of Rs 85 crores by 1975. With the projected annual turnover of Rs 300 crores for that year, this R&D outlay would be of the order of 25 per cent of the annual turnover. It has been pointed out that this outlay would be comparable to the investment going directly into production and that this is very unrealistic. It is easier to shoot down a figure on R&D expenditure than to suggest one. I would concede that the problem could be studied in greater detail than was possible for the Bhabha Committee to do within the time that was available. Moreover, periodic reassessments of R&D priorities would be needed in a fast-moving field such as electronics. However I must point out that nothing would be more disastrous to the development of our electronics industry than adoption of a crude yardstick such as a fixed percentage of the annual turnover for R&D expenditure. Management in industry should adopt a more imaginative R&D policy than that and must take due consideration of the nature and amount of the R&D effort needed, the development lead-time to be bridged and the time-scale of the demand for funds. It should be noted that there exists a minimum level of 'defensive' R&D effort, which could be termed the 'threshold'. This threshold is an absolute level of resources input and not a ratio of sales. The value of this threshold is set by the amount of R&D effort put out by others in the field. Needless to say that, because of the nature of the professional electronics market in which quality and technical performance alone count and not the price-tag, the threshold level for R&D effort is high. If our own R&D effort falls short of this threshold, it would be virtually impossible to cut development lead-times short enough to survive, let alone thrive. I feel strongly that we should deliberately avoid any penny-pinching instinct in our R&D budgeting, more especially during the early stages of development of our professional electronics industry. We would just fail to catch up.

## LONG-TERM APPLIED RESEARCH IN ELECTRONICS

I would like to leave the subject of product-oriented R&D at this stage and consider some aspects of long-term applied research in the field of electronics. The objectives in this applied research is to follow the trends in the electronics industry of the advanced countries to design and develop prototypes of the next generation of electronic components, equipment and systems so that technical know-how would be readily available within the country when the need arises for their large-scale manufacture. What should be our guiding policies in the organization of such research? I shall try to summarize my thinking on this question.

First of all, these research laboratories should be built around capable and outstanding individuals and efforts should be made to seek out such individuals. Where necessary, brilliant, Indian scientists and engineers who are now working in foreign countries should be brought back by offering them attractive incentives, and more importantly, proper opportunities for the application and development of their technical expertise. I feel that very often many of our foreign-trained scientists and engineers feel dissatisfied more because of the lack of opportunities for productive use of their talents and skills than because of inadequate salaries and perquisites. We should not grudge the expenditure involved in creating the facilities for their work here in India, for this will be compensated by the expertise, drive and energy that such persons will be able to bring to supplement our efforts. The total staff of any single research and development laboratory should not exceed about 300. Larger organizations pose personnel management problems and would become correspondingly wasteful and non-productive.

Every research and development laboratory must be provided with adequate facilities, particularly pilot plant facilities and the staff should be commensurate with the type of project undertaken. The ratio of the pilot plant staff to total staff, may vary from 25 per cent in the case of work, for example, on computer or radar systems to about 50 per cent in the case of production of components.

The principal aim in setting up such laboratories should be to develop products up to the pilot plant stage so that subsequent industrial exploitations can be taken up with the minimum of delay. It will thus be clear that any such laboratory will have well-defined objectives which are mainly developmental in character. Only in exceptional cases can they have a pure research bias. Thus the main aim of these laboratory should be to produce materials, components and instruments and not necessarily research papers. Project should be well-defined. They should be undertaken only if proper staff, equipment and facilities already exist or can be made available in a reasonable period of time. Responsibility should be backed by

adequate authority at every level. Specializations in particular fields such as micro-wave components and systems, digital computers, material sciences and nuclear instruments and systems should be encouraged.

It is further desirable that some of these laboratories are grouped together in the same location so that the expertise in one laboratory could be readily available to another. This principle should, where necessary, be extended to co-operation between laboratories which may be widely separated. The grouping suggested is, however, not for administrative purposes and the autonomy enjoyed by each individual laboratory should be remain unaffected.

## INDIGENOUS R&D (VIS-À-VIS) IMPORT OF KNOW-HOW

Before leaving the subject of research and development, I should like to touch upon also on the policy implications in regard to import and acquisition of know-how from other countries. We should at the national level make a conscious and deliberate choice of projects in which indigenous R&D effort is to be concentrated, after making a careful study of the scientific and technical manpower which can be marshalled and the material resources which could be made available in a reasonable period of time. Having made the choices, the development end-objectives must be clearly defined and pursued with vigour and determination. It would be advisable to set reasonable time limits for attainment of these end-objectives and completion of a project. It is critical during the interregnum that no party in the country, whether in the public or the private sector, be allowed to enter into licensing arrangements and collaboration agreements with foreign companies for the manufacture of the products to be developed under the selected projects. If this is not done, the indigenous R&D effort would be predestined to failure and need as well be not initiated.

It would, however, be necessary to review the progress of the project from time to time and at the end of the predetermined period, an objective analysis of the results obtained should be made. If the analysis shows that the indigenously generated know-how is not suitable, then and thereafter only, should proposals for the acquisition of know-how from other countries be entertained.

One further point regarding import of know-how from other countries. From the case studies brought out in the Bhabha Committee Report, it is clear that it would be advantageous to centralize at the national level, the acquisition of know-how from other countries for the manufacture of a particular product. This acquired know-how should be considered as a national property and should be made available to as many entrepreneurs as have the requisite organization and capacity for manufacture of the particular product. The present practice of permitting acquisition of know-how for one and the same product,

from different countries by different indigenous manufacturers under various schemes is wasteful of our foreign exchange resources and should be stopped.

### PRODUCTION OF SPECIAL COMPONENTS

Before I conclude I wish to touch upon a special problem that is experienced in the components sector of our electronics industry. Here industrialists have shown some reluctance in undertaking manufacture of certain items mainly because the size of the internal demand at present is not sufficiently high so that manufacture of such items is economically viable. As an example, I may cite the manufacture of components such as connectors. It would be unwise to delay setting up of plants for the manufacture of such components until the demand raises above the break-even point. Clearly there is a need for Government initiative. Government should come forward with suitable incentives so that losses arising from the

deliberate creation of idle capacity in the early stages could be underwritten. This should be done in the interest of our self-sufficiency in this sector of the electronics industry, the importance of which has been underlined by Bhabha Committee.

Finally I wish to thank once again Shri Kanjilal and the Institution of Telecommunication Engineers for this opportunity to meet with all of you and to share my view on the development of the electronics industry in India. Certainly electronics holds vast and tremendous potentialities for our country if we develop the necessary will and marshal our valuable human resources. All of us, scientists and engineers, have the responsibility of bringing these opportunities to the attention of our legislators and policy makers in Government, to our industrialists and to the public at large for their proper understanding and support. I feel that in this task of education your Institution can play an extremely useful and supportive role.

# The Importance of Communication

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**I**T is a great honour for me to deliver the Bhabha Memorial Lecture. Bhabha's contribution to Indian science is particularly significant because of the bias towards technology that he introduced in our thinking and the importance that he gave to the development of close links between science and technology. I met Homi Bhabha at his invitation in Bangalore and had the privilege of spending about 8 or 10 days with him not very long before he was killed in an air plane accident. At that time he was in the process of completing a document which is now known to every body, known as Electronics Report. He had not yet finished it. He was often thinking aloud on various matters and one of the things that was uppermost in his mind at that time was the future expansion of Electronics Industry in the country. He wanted to make certain predictions as to the large increases that might occur in the demand for electronic goods. His colleagues and many people that he consulted said that he was probably overoptimistic. He felt that while he was giving figures, which perhaps were too bold, he felt in his own mind more optimistic that anything that he would be able to set on paper. Between the two choices of being thought too circumspect or too bold he felt that the latter was perhaps the verdict of history that he would not mind. If his associates consider that he was walking with his head in the clouds he hoped they would also think that his feet were on the ground.

We all know what has happened in the remarkably short span of hardly five years. What was considered overoptimistic we now realize was an underestimate. This is a lesson in the rate of growth of Technology and the role of Science which we should not underestimate. Particularly, I would appeal to this body (The Institute of Telecommunication Engineers) which is composed of the best technologists of the country in this particular field that this lesson do not go unnoticed. The time span of development is becoming extremely short and the challenge of modern technology is how closely can we follow scientific development into technological spin offs. Between Faraday's generator or dynamo and the commercial electric generator was a span of 40 years. A story is told of Faraday that Prince Albert visited his Royal Institution to attend his lecture and see his demonstration. Prince Albert asked at the end of his visit whether there was any benefit to England from his work and Faraday answered, Your Highness, I do not know what benefit are going to happen in next few years but I am quite certain that

your Highness Government will eventually tax it and get revenue out of one of these. The time span in the case of dynamo was 40 years. It had shortened to about six years in the case of Bardeen's discovery of the transistor in the middle 1940's as most of you know. Our technologists have to run very fast today to stay where they are nowadays and they have to run faster in order to move forward. I would like to make another small point before I go to the topic of my address. I have a feeling that not only the time span of development but also the laws of investment and growth of industries in the highly science oriented areas of technology may not follow classical textbooks of economics. The area of technology, i.e. electronics, with which we are mainly concerned in telecommunication do not in some sense follow those of capital intensive and labour intensive industries described in textbooks. Some of these new industries are the brain intensive industries where the added value of the products are due to the application of intelligence and highly professionalized skills and not only because of highly expensive capital equipment. The new technology in the telecommunication industries have an important role to play because you as engineers and technologies can generate industries where you can generate a lot of products and services, add substantial value to your products by developing what I have referred as the brain intensive industries in which the capital needed will be low in proportion while employment of professional and skilled people will be high. This is a great challenge for the future to our scientists and technologists in the telecommunication and electronics area.

The world population today is increasing at a very rapid rate and modern civilization depends basically on communications; whether it is education, industry, business or politics. In fact, I have done little arithmetic while Gen. Verma was giving his talk and calculated that with 3000 million people we would require roughly a bandwidth of around  $5 \times 10^{18}$  for a fully universal, worldwide communication system. The problem is very serious. It is only limited as present because most of the world population, including ours, is too poor, too ignorant and too isolated to ask for their share of the communication system. If we will all to communicate, send or receive data, television, carry out business, industries, scientific and all sort of things, the pressure on bandwidths, as all of you realize, becomes enormously large, absurdly so if we pursue it to its logical conclusion in an arithmetical way.

This problem that arise from the enumerated number of frequencies available and the large number of possible communication channels due to increasing demand might have posed a difficulty if we were more advanced. It is not of much significance today in our country but I think that ten years from now many people in Gen Verma's position or the telephone people will be tearing their hair about this sort of problem. This decade, I venture to think, will witness roughly 10:1 increase in traffic capacity and this might be an underestimate just as Bhabha made an underestimate. However, the finite width of the radio frequency spectrum available below 12 kHz make a traffic increase of this magnitude almost impossible to face with equanimity. Any currently viewed system using 10 kHz frequency provides capacity for only about 15,000 telephones or 8 TV channels. As you need more TV, Radio or high speed computer or data links the problem becomes more and more intractable. One possible answer lies in increasing the frequency which increases the information carrying capacity, i.e. if you have high frequency you have automatically higher bandwidth capability. This is one of the reasons why we go progressively to higher and higher frequencies. However, there are technical problems as you go to higher and higher frequencies. Since the communication capacity becomes reduced if there is no time and space coherence in the electromagnetic waves generated, simple communication systems get highly restricted and ineffective. Therefore, the problem is not only to go to higher frequencies but also at the same time to generate what is essentially coherent radiation at those frequencies. Experience shows that although high frequency, high bandwidth systems cost much more than low frequency ones, the cost for such systems become bearable and eventually less per unit information capacity because of large bandwidth. There is, however, the difficulty that generation of coherent electromagnetic radiation becomes difficult and under present technologies impossible beyond visible radiation. There is another type of limitation on this that although in principle one can think of going to higher and higher frequencies there is a scientific limitation imposed by rectilinear propagation of light and, therefore, as we go to higher frequencies we cannot get them to bend over the earth's circumferences. Therefore, we have to use line of sight communication which increases the cost and poses other problems.

As you are aware in line of sight communication, rain, cloud and fog causes problems. These becomes even greater when we go to submillimeter waves or to higher frequencies such as optical frequencies. The millimeter wave region between 30 and 300 GHz is quite attractive for wide band communication systems we have been thinking about. It is attractive because of the large bandwidth that you get which will more than outweigh the difficulties at these high frequencies as technology progress. With these frequencies it is not at all unreasonable to think in terms of a GHz bandwidths. It

could surely accommodate something like 200 thousand voice channels. Of course, you have technical problems and scientific problems. One hundred thousand GHz frequency is likely to be higher attenuated even by fog. But, of course, when we talk of satellite communication, the picture is in some respects different because here you are not restricted to line of sight communication in the conventional sense of the world although it is also line of sight. You are restricted only to a finite and calculable depth of atmosphere and, therefore, some of the frequencies which get ruled out by ordinary arguments can come into our consideration again in considering satellite communication. The next order of challenge is when you go from these very high frequency submillimeter waves to light or near light frequencies, there we have in the laser and the master, possibilities of considering coherent radiation of very high frequencies. The problem of the laser I shall discuss a little later. The problem is again not about the coherent light which the laser does produce but the amount of information that it can carry under present limitations of technology and the possible future restrictions that might arise. The other point which I would like to discuss briefly before I go into the lasers in more detail is that if we take up submillimeter waves how would we transmit and use it, since there is a restriction in propagating in the atmosphere? It is possible to think in terms of tubes, fairly thin tubes but still nevertheless tubes which will be a sort of a waveguide for these frequencies. As the frequency increases such long waveguides may once again be economically be technically feasible. There are two fundamental approaches for doing this. One is the dielectric guides and thin film dielectric waveguides. The other is the helical form of laser guides. It may be of interest if some studies are initiated which will be futuristic which look forward and investigate the relative possibilities of these or other systems which are not yet been either mentioned or investigated.

Coming back to the laser problem you know perhaps that a great deal of very interesting and very basic work has been done in recent years. Particularly the fact we have semiconductor lasers today has been a great step forward. Both binary alloys, such as GaSb and GaAs lasers and the more recent ternary GaAlAs lasers remove the earlier restriction of having to use gas-filled lasers which are cumbersome and difficult to use. However, for a long time, in fact until few months ago, the binary alloys, for example, GaAs suffered from the disadvantage that these have to be used at a liquid air temperature somewhere round 77 K°. Quite recently sandwiches made out of GaAs and GaAlAs sandwiches have been operated at ordinary temperature, they lased well and they have been found to generate sufficient intensity of power to permit fairly long distance communication. Now this is one aspect in which a breakthrough has occurred and we will rapidly advance because of the tremendous convenience of lasers operating at room temperatures.

A second interesting development is that of the injection lasers. In the injection semiconductors the problem of modulation becomes much simpler and a larger bandwidth becomes available. The third point of interest is the transmission systems for lasers. Again, the limitations of line of sight communication that of high attenuation is a problem. The use of light conductors or light pipes is an alternative solution of low loss transmission system. In other words, fibre optics consisting of very thin fibers of glass can be used to conduct light over large distances. Here, again, an interesting breakthrough has occurred during the last year or so using very high quality glass fibres which are produced by a new technique of drawing the glass fibres in such a way that it is composed of two kinds of glasses. An inner core of higher refractive index glass with an outer coat of lower refractive index glass both drawn together in order to form one composite glass fibre where the refractive indices are so matched that for all practical purposes this becomes a waveguide for transmission of light in the optical region with little attenuation or loss. In fact, with such fibres a figure of loss somewhere around 1.2 or less per kilometer has been found possible. If now we add all these possibilities together we find that we may not be too far away from an optical system of say  $10^{10}$  or  $10^{11}$  channels. Even so we are several magnitudes away from the theoretical needs that might arise in the future. However, what has happened in this kind of trying to project our mind to the future is that we have certainly increased by few orders of magnitude our limitations of the number of channels that we normally think about as possible under current technology. At the same time many of the very difficult limitations of large power handling systems and so forth have been overcome because injection lasers large powers are not necessary to be able to control large coherent sources of radiations.

There are other approaches or methods which are possible in principle and which people have considered. Where coherent light is passing through a piece of glass fibre and a transverse electric field is applied to it of sufficiently large magnitude, the light becomes electrically polarized and this polarization can be used also to induce modulations of various kinds. However, again here we are in realm of, let us say speculations, and we do not know what can be done or what the future has in store for us. I only quoted this to show that the way we are attempting problems today may not necessarily be the way in which the solutions for the future will become apparent. The solutions may be in an entirely different direction and, therefore, it is appropriate for highly professionalized organizations, competent scientists and technologists to consider what are the areas of options that should be kept open so that our future and the future on Indian technology in certain directions are not foreclosed by things that we have not done in the intervening years.

I would like to conclude on the subject with a small thought. Our Hon'ble Minister of Education, Prof V K R V

Rao, pointed out that the demands that would be made on communication systems, whether it is satellite or other methods of communication, would be tremendously great from even one particular consideration that of education. Perhaps, in the future every child would like to read at home through his radio or TV or things of this sort and, therefore, communication for education is itself a great challenge for quickening the pace of education for all. The child who cannot come to the school, the child who needs help from his home which is not available through his teachers. All this will challenge the ingenuity of our technologists to meet our communication tasks in education in the context of a country which is poor and which cannot use the most expensive and the most perfect methods of communication but would be willing to give up the better for the sake of good and the cheap.

The last point which I would like to take up before I conclude is the problem that has bothered me in more ways than one. It is more a philosophical problem at this stage but in a forum like this I hope I can open my mind to a little speculation. I hope Gen Verma and the audience will forgive me for being speculative. If, one looks at the fantastic number of channels that are necessary and the bandwidths that will be called for in the next century one can feel very frightened. We talk today of problems of populations density or environmental degradation which really arise from high average consumption of energy and by high density of population because both tend to create problems of pollution. But there is one kind of pollution or rather environmental degradation which people have not yet bothered about. The tremendous impact of increasingly large and tremendous amount of communication will have its effect on the individual. We are yet unfamiliar with the psychological and the social pressures and stresses that may result from large pressures of communication. In fact the question whether there is a limit of communication density beyond which human beings cannot tolerate is largely unanswered. Although in another sense, but not in any way as an argument, we do know that there is a limit to human tolerance to a number of coincidental but arbitrary frequencies. The transition occurs after a certain stage, not the same for everybody, beyond which the number of frequencies are not distinguished but become noise. Let me put it in this way: if communication is going to produce stresses on individuals, these stresses in a certain sense will be proportional to the square the number of individuals because of the need of people to communicate with each other if such facilities are available. That is, people will want to talk with each other, people will want to ring up on the telephone if one has a telephone. Communication increases as the economic status of people increase. It is also proportional to the square of the number of people involved. Now, this really means a tremendous amount of social and psychosocial stresses which is brought about by increasing communication availability and increasing number of people. Such stresses generate challenges to

science and education which we cannot fully foresee today. In this sense education has only a narrow bandwidth which we accept for the child. But quite soon we impress on him wider bands of communication for which he has no rejection mechanism and thereby we subject him to even greater stresses than on adults who have rejection mechanisms limit into them after years of training and education.

May I would end on this note: The tremendous and increasing density of communication that we feel are certain to come in the future and which lie in store for our children and for our grandchildren will be because

communication will be cheaper, easier and more necessary. Unhappily it is also going to produce tremendous amount of social and psychological stresses about which we have at this stage no knowledge or information. It poses a new kind of a problem of environmental degradation unlike in some respects to the pollution due to energy consumption but perhaps not entirely unlike the environmental degradation that arises from high densities of population. It is probably correct to say at this stage that there should be at least a few of us, not very many perhaps, who should get a little more concerned about a problem which might emerge in our country much more quickly than we see happening at present.

## Satellite Communications – A Case Study

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**I**N the early 40's, closely following on the developments carried out in a War time R & D work, microwaves opened a new medium for communications links. With increasing reliability and decreasing costs, microwave system route miles rapidly surpassed the coaxial networks both in Europe and United States. With communications literally bursting at the seams in these continents, there was, however, still a vast stretch of water where the only medium of transmission possible was the comparably low reliability HF or the extremely expensive low capacity submarine cable.

It was at this time that a man of great vision came out with a brilliant idea. This was A C Clarke - whom at that time one would have called a science fiction writer - who in an article entitled "Extra terrestrial relays - Can rocket stations give world-wide radio coverage?" in the October 1945 issues of the *Wireless World* postulated that a microwave link between United States and Europe was possible, provided an intermediate repeater between the land masses could be supported sufficiently high, a matter of a few thousand miles. His solution on how to do this impossible task was brilliant - he suggested that the repeater was placed on an orbiting satellite placed 22,000 miles above the surface of the earth, so that it virtually became geostationary.

In the history of science, we often come across solutions without the means of achieving them. Rocketry was still in its infancy - the most developed one being the V2 missile with a 55,000 lb thrust turbo pump propellant system rocket engine that rose to a hundred miles to come down with its 1 ton warhead of high explosives at supersonic speed.

### Sputnik Launched

In 1957, a most significant development took place when, on October 4, as part of the IGY programme, USSR launched Sputnik 1, the first orbiting satellite in history. The 23 lb spacecraft measured air density, temperature, cosmic ray and meteoroid data which it transmitted to the ground - and it gave the first indication that Arthur Clarke's prophecy, made 12 years earlier, was no mad man's dream after all. And therein lies the first ingredient to any scientific venture: an inspired vision. All important milestone in technological development were laid by

visionaries well in advance of people who kept pushing the frontiers of sciences. This is equally true of nuclear physics, electrical power generation or the computer field. And in satellite communications, it was Clarke who was the visionary.

John Pierce of Bell started the first study of what was needed to make a working communication satellite. There was an array of new brilliant devices that he could count upon; the high gain low noise horn reflector antenna, the travelling wavetube, the transistor, solar cells and the solid state maser. There were, at the same time, some exotic experiments taking place in the field. In 1946, in Project Diana, the US Army Signal Corps bounced radar signals back from the moon. In 1958, Air Force launched the first communication satellite, SCORE, which transmitted down to earth a prerecorded message. In 1959, live voice transmission was accomplished by Bell Laboratories from the New Jersey to California, again using the moon as a passive reflector. In 1960, Echo-I was launched. This was not a satellite as we now know, but a 100 ft balloon made of aluminium coated mylar. For many years, people through out the world could see Echo sailing across the sky in its 1000 mile high circular orbit. The project made available valuable data that were to be made use of in future work in satellite communications. It proved that communication was possible of a passive reflector between points as far apart as in USA and Europe. A horn reflector proved itself and, for the first time, frequency modulation with feedback was tried out. New types of low noise amplifiers using solid state masers gave good results - and finally tracking of satellite by computers, radars and telescopes proved extremely reliable. There were many other developments, some brilliantly successful, others not so brilliant - and quite a few others that were tragic failures. Two years later, the most outstanding event in the history of satellites took place. This was the launching of the TELSTAR in July 1962 by the AT and T. It proved beyond doubt that a broad band communication satellites could transmit voice, data and television and that the electronics package could survive the stresses of launching and the hazards of space.

### Telstar Project

Before proceedings further, I wish to briefly dwell on the Telstar project and a fascinating event that took place in the short life span of the satellite. Telstar was a 34 in.

sphere, with 72 flat facets used for solar cells. The inside was mostly occupied by command and telemetry systems - a package of over 1000 transistors, and 1500 diodes plus a single travelling wave tube for communications. In the early hours of 10 July, a Thor delta rocket took off from Cape Canaveral and placed the sphere directly in orbit. Three hours later, transmission to and from the satellite took place. Thereafter commenced a series of experiments started and stopped by commands from ground stations. As this was the most important function of the satellite, the command circuitry chains in the spaceship were duplicated: about 4 months later, in November, Chain 1 began to show erratic response and a few days later, Chain 2 also went out of commission. For all purposes, that was the end of the satellite. It was then that a masterpiece of technical investigation took place in the Bell Laboratories. Various reasons were postulated and logically eliminated till finally it was concluded that the failure could be attributed to the failure of an electronic component due to excessive radiation bombardment. A series of ground experiments with prototype electronic packages laid the suspicion on a zero gate in the decoder. Each of the 15 satellites commands was a binary of 7 pulses of which the start pulse was 3 units wide, followed by six, made of 1s and 0s, the 1s being of two units and 0s of 1 unit. When the zero gate failed, the Bell engineers devised a notched pulse that could pass the 1 gate and advance the counter and still be unlike as 1 as not to be stored. The commands were taped and, when the Telstar made a pass over Andover on 20 December, the command was given and Telstar came back to life perhaps the first instance of long distance diagnosis and treatment. Later investigations proved that every perigee pass took the satellite through the heavy radiation in the Van Allen belt and perhaps made worse by the extra radiation as a result of man-made high altitude nuclear explosions, one of which had taken place the day before Telstar was launched.

### **Billion Dollar R&D Programme of NASA**

I have related these incidents to bring out the second of the ingredients of a successful break through, namely patient, persistent and systematic research and development work, often in the face of impossible difficulties. Apart from the billion dollar R&D programme of NASA, there is practically no large industry in the US which does not have substantial R&D backing - either in house or through contract. Projects like the Apollo programme and the orbiting observatories involved literally thousands of R&D contracts. Of course, there were some carried out in the highly advanced laboratories in US. But at the same time there were others literally carried out by the backroom personnel. In other words, R&D effort need not necessarily mean setting up of large facilities. What is necessary is that the total effort has to be increased and whatever is available is made meaningful and purposeful - there is nothing more frustrating to an

R&D man than to have his work pigeonholed. The return on R&D investment is indirect but manifold.

Recently, I visited a microwave factory in Budapest and was rather surprised to see that their investment on R & D worked out to nearly 15 per cent - and the results were amply borne out by the manner they kept up to date in a field where obsolescence is so very rapid. Perhaps a lesson could be taken from this by our country where R&D work is treated with indifference or impatience and expenditure thereon considered as infructuous.

Early in 1960, the United States began exploring with other nations the feasibility of a global communications satellite system. At this time, synchronous satellites were still on the drawing board. The only practicable satellites were the random orbiting ones which were simpler to design, cheaper to build and launch. But they required more elaborate tracking, multiple access was difficult and the intense radiation in the Van Allen belt seriously curtailed their effective life. In 1963, the first synchronous satellite, SYCNOM, was launched by NASA. It was a 28 in. cylinder weighing 86 lb which could handle only a one two-way conversation with no television capability. The weight was necessarily low because of the orbital height and limitations of launch vehicles. This was the position when the INTELSAT was formed on 1964.

### **INTELSAT**

INTELSAT at its very inception had to face competition from another well-established communication media, the submarine cable. The first trans Atlantic cable was laid in 1956 and had been followed by others of higher capacities and involving a high financial outlay. The cable capacity was considered by some to be adequate to meet the trans Atlantic traffic and any large investment on a satellite system was held to be wasteful and superfluous. And, as though to lend force to the opponents' arguments, the only synchronous satellites that the state-of-art could provide the INTELSAT were low powered ones, with low capacities - which meant a high cost per satellite channel and an excessive investment on the earth stations. If INTELSAT had decided to wait for further developments in satellite technology, when more powerful satellites would be available, the Atlantic would have been crossed by more cables to meet the growing demand of traffic and thereby once for all inhibiting the introduction of a satellite system. Perhaps the most striking feature of the INTELSAT system was the manner in which the decision was taken to use the low capacity satellite and the swiftness with which the INTELSAT satellites were deployed in increasingly larger sizes. The first satellite called 'the Early Bird' was launched in June 1965. It had an orbital weight of 42 kg and a capacity of 240 channels. The expected life was 1½ years. It had a toroid shaped beam tilted upwards primarily to serve the northern hemisphere. A crash programme INTELSAT II with same channel capacity, a

single wide band amplifier and a beam to cover both the hemispheres in October 1966 - by any standards a remarkable achievement to meet the express needs of NASA for its Apollo programme. The INTELSAT III series with 1200 channel capacity and 5 years life expectancy started in 1969 and INTELSAT IV with 6000 channels and 7 years life expectancy in 1971. The investments per circuit year of capacity was \$ 15000 for INTELSAT I, \$ 8400 for INTELSAT II, \$ 1450 for III and only \$ 500 for the IV series. It is true that, at the commencement of the INTELSAT series, the developing countries were most effected by the high cost of earth stations. It is argued that if INTELSAT had waited longer, the later generation of satellites would have permitted cheaper earth stations and greater participation by developing countries but it is equally probable and perhaps more than likely that if INTELSAT had waited, increasing competition from cable carrier would never have let the satellite system take off from the ground. All this points out to the next great ingredient in our recipe for success; prompt and considered decision making in the face of conflicting arguments. Perhaps there was just a shade of gamble in it - but there have been few great decisions without calculated risks. Time and again we come across incidents where the course of history in the scientific field or politics was changed by our powerful decisions. Decisions need not necessarily be great but are essential for the successful execution of any schemes large or small. We can cite hundreds of examples where lack of timely decisions have ruined these projects. The increasing size and life expectancy of the INTELSAT series was made possible by the work that was going on space in NASA on launch vehicles and partly by the developments and innovations in the satellite field. Today, launch weight limitations are technically no problem, only their cost is. From a satellite design point of view, the only constraints is that the capability for various vehicles of the Delta, Atlas, Titan and Saturn series increase in well-defined quantum steps and impose serious limitations in the flexibilities of design.

Incidentally, from cost considerations, the launch vehicle by itself does not place the satellite in synchronous orbit. It leaves it in a transfer orbit with an apogee roughly equal to 22,000 miles. The satellite carries with it the mounted axially a solid propellant apogee motor. At the appropriate time, the motor is fired which boosts the velocities of the satellite and converts the orbit into a circular and a synchronous one. The apogee motor did fail once in the first of INTELSAT II series. It failed to fire and left the spacecraft in a highly elliptic orbit. I have earlier referred to the innovations in the satellite design. These were two principal ones, the first one was to increase the bandwidth and the second one was to increase the EIRP by using a focused beam that perpetually kept pointing to the earth. The INTELSAT IV for example has a spinning motor about 8 ft in diameter and nearly 10 ft tall. Its cylindrical

surface carries the solar arrays. Inside are the house keeping sub-systems like power and propulsion. Mounted on a shaft in the centre is a despin platform containing the communication payload and the antenna farm. The despin sub-system provides a rotating mechanical interface between the despin communication platform and the spinning section of the space craft. It also provides for the transfer of power and telemetry and telecommand signals across the spinning interface. A brushless d.c. motor reacts against the spinning housing to despin the shaft. The shaft is supported by two angular contact ball bearings which spin round the shaft at nearly 60 revolutions per minute without a moment's stop for over 7 years without maintenance or repair. This, to me, is indeed a marvel of mechanical perfection.

Perhaps I should qualify my statement about maintenance and repair if only to relate another fascinating instance of telerepair. The INTELSAT IV was not the first one to use a despin antenna - it was there in the INTELSAT III also, though the latter had only a single global beam and no large spot antenna. In 1969, in an INTELSAT III, perhaps the second in the series, suddenly communications failed. Scientists immediately got into a huddle and tried to figure out what have gone wrong. During the spring and fall equinoxes each year the satellite traverse the earth's shadow for short periods every day of nearly six weeks, the longest eclipse being nearly 70 minutes. At this time, the solar cells are no more operative and the entire power is from a bank of extra long life nickel cadmium storage batteries. The scientists concluded that, on one of these passes, through the eclipse, with the sudden drop in temperature, the despin system bearing had frozen stiff and put the satellite out of commission. Since telecommand was still effective, when the spaceship came into the sun, its attitude was alerted on command from the ground, so that the full effect of sun was on the bearing and the despin motor came back to life. Incidentally, the subsequent satellites were provided with electrical heating for the bearing. Perhaps I have dealt with this at some length if only to give an illustration of what I consider another essential ingredient for success-innovation. I have mentioned only one, but there were some scores of them. Without these innovations, the global system would never have expanded to its present size and with such remarkable success. Without innovations there is no dynamism, and without dynamism any system or organization becomes static and dies.

I have so far dealt with the basic requisites for the success of any technical or scientific project. Since, however, no such project is taken in isolation and has to share with others - scarce material and financial resources, a total cost consciousness of the project as a whole is essential. Perhaps in no other field is this total cost concept so directly amenable to assessment as in a communication satellite system. In our own country, we had had some

excellent studies made during the last two years for the DAE-NASA SITE experiment and for the on-going satellite project. The latter in dealing with TV broadcasts has compared the costs of direct broadcasts from satellites with terrestrial microwave networks and also with a hybrid system made up of terrestrial microwave links and a distribution satellite. My remarks for the present will be confined to the total cost concept applied to a global satellite system and in particular satellite design. I have earlier referred to the life of a satellite apart from a catastrophic failure, the life is limited by the degradation of the solar array, the deterioration of the storage batteries and the depletion of the fuel. The last one is generally the controlling factor. Even after the spacecraft is placed in its final location there is a continuous house keeping necessary for altitude control, rate of spinning and orbital position.

At synchronous orbit, there are external perturbations acting on the satellite : these are lunar/solar perturbations on the orbit inclination, perturbation caused by the triaxiality of the earth and solar torques. Each of these produces systematic disturbances which have to be periodically reduced in order to meet overall pointing objectives. This is accomplished through reaction jets placed in axial, radial and tangential directions. The jets are fed by hydrazine propellant contained in four titanium tanks and controlled by latching valves operated on ground command. The INTEL SAT IV carries nearly 270 lb of hydrazine at the commencement of the mission. With every operation, there

is a depletion of fuel. The life of the satellite could be stretched by keeping the house keeping chores to the minimum. But this would mean greater deviation in the orbit coordinates and the need for larger antennas and closer tracking at the earth stations. The cost reduction by stretching the effective life span has an immediate echo in greater investment in the ground segment.

Another instance of total cost concept applications is in the use of orbital space. Since the land masses are not uniformly spread round the globe, only certain segments of the orbit will be used for locating the satellites. This then becomes a limited resource that has to be utilized with great care. How close should it be packed with satellites ? Their proximity depends upon the power of the satellites. If the power is more, the orbit separation should be greater and if less, the spacecraft can be placed closer. In other words, the power density per degree, the orbital path, is limited unless of course the earth station antennas are made more and more directive. Here again, an attempt at greater utilization in the space segment results in increased investment on the ground.

The savings and increases in expenditure are fortunately not equal and there is always a solution wherein the inputs give an optimum output. This of course is well known but it will be useful if we sit back and ponder in how many of the projects that we ourselves are associated at some time or other, have time, money and material been put to optimum use.

## A Review of the Work on Electronic Materials and Components at NPL

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**I**T is indeed a privilege to have been honoured by the Institution of Electronics and Telecommunication Engineers to deliver this Memorial Lecture. I have accepted this honour with a great deal of trepidation particularly when we look at the list of eminent scientists and engineers who have delivered it in the previous years.

My pleasure is greatly enhanced as I was privileged to enjoy the confidence of Dr Bhabha with whom I have had discussions and correspondence on various matters connected with electronics including the manufacture of instruments and components by the Department of Atomic Energy. Some of you may remember that the Electronics Committee Report was issued in the form of chapters before the final compilation. He was good enough to send them to me for comments and many of them were incorporated in the final Report. As early as 1949 when I happened to be in Bombay at the time, he wanted me to join TIFR but I felt diffident as I was only an engineers by training and not a physicist or mathematician to deserve a job in a fundamental research institute.

My deep interest in materials and components ever since the 40's was known to him and he realized as Professor Meghnad Saha, Dr Bhatnagar and Dr Krishnan did, that R&D work must be undertaken in this field immediately, if we are to achieve self-sufficiency ultimately. After all, components are the building blocks of any electronic equipment or system, and their reliability and performance depends on the quality of materials of which the components are made. I may recall the remark of Dr Bhatnagar when the proposal for an Electronic Engineering Institute was mooted at Pilani, he said, "Ramamurti, there will be only one National Physical Laboratory but the country will require many more than one electronics". This remark was made in 1951 and that too by a chemist by training!

This was the primary motivation that resulted in the setting up of a Radio Components Unit at the National Physical Laboratory as early as 1950, which was not in the original plans of NPL. The type of work envisaged was mainly experimental and developmental research in the field of import substitution both of raw materials and components, learning the process technology thereof, and to carryout pilot experiments before passing on the processes to industrial entrepreneurs. I propose to discuss

the steps that were taken to achieve the objectives, the shortfalls and what appear to be the reasons for them so that it may serve as guide-lines to enhance R&D effort in this field and see such efforts are fruitful. I am confining my observations only to the activities and experiences of the Radio Components Unit. NPL has subsequently entered the field of microwave components but I am not touching on this activity as they do not strictly come under process technology. Electronics industry and its progress is very much of a live subject. There have been many forums at which this has been and is being discussed, the latest being the Asian Electronics Seminar held in Delhi from 5th to 10th December 1973. IEEE and IETE in their technical sessions had this aspect on their programme for discussions.

When proposals for setting up an Electronic Components Unit was first mooted, the guidelines were defined broadly as follows:

- (1) The choice of the area on which investigations should be conducted should have relevance to the normal activities of the organizations concerned.
- (2) It should be based on a technology which is not likely to become obsolescent in the near future.
- (3) Initial R & D effort may be based on imported raw materials of known quality while the process technology is mastered.
- (4) Parallel investigations to be carried out to find substitutes for the raw materials from indigenous sources failing which, to initiate action to prepare materials of requisite quality either from the mineral ores or commercial grade materials.
- (5) After successful experimentation on the process, to initiate and undertake pilot plant studies for the manufacture of the components, and offer the product after careful evaluation of their properties, to actual users in the industry for field trials of their equipment.
- (6) To take remedial steps in processing and quality control based on the information fed back by the users by the performance of the concerned component.
- (7) To invite entrepreneurs to takeover the manufacture by exposing them to the pilot plant activities.

- (8) To inculcate cost consciousness and commercial viability, a Cost Accountant to be associated during the pilot plant operations and records maintained to enable an entrepreneur to decide on the production capacity he has to establish and inputs required.

These guidelines were followed in their entirety in setting up two projects in the 50's at NPL, one for Glass Technology and another for the electronic components. In this forum we are concerned only with the activity on Electronic Components and Materials.

Ceramic technology was chosen as one of promises as it is used for the manufacture of a vast range of ferroelectric and ferromagnetic ceramic materials. The relevance of the choice is reflected in the spate of new devices such as electro-optic and piezomagnetic ceramic components that have come into use today.

In judging the success or otherwise of the projects, one has to look at the over-all impact it has had not only by way of direct import substitution but also by way of the technicians that have been trained, the production of the machinery and processing equipment which has created opportunities to a number of small scale and medium scale industries, the creation of an infrastructure which is able to absorb any imported technology in this area, if that is necessitated from the point of the time factor involved.

I propose to present in some detail the different approaches that were attempted to fulfil the objectives.

The first experiment that was tried was the passing on of the process for manufacture of silver mica capacitors to a public sector undertaking which set up a cell at NPL with its own staff of thirteen workers and a qualified engineer as supervisor. This cell produced a few lakhs of silver mica films under the scientific guidance of NPL and got them tested at their research centre in Delhi, and later, at the factory at Bangalore, by user trials. On the completion of a year, the cell with its entire staff moved to its parent factory and commenced production. As the output of the cell supplied only their own in-house demands, the process was licensed to another entrepreneur who happened to be a mica mine owner and exporter. The license stipulated the specific condition of exporting the products. The firm was exporting cut and sorted condenser grade mica films to the United States and were hopeful of exporting processed films and finished capacitors.

In order to commence manufacture as early as possible, a scientist from the NPL was employed by the firm to organize and run the firm. This was successfully done and the firm supplied capacitor films and finished capacitors to the radio industry and to the public sector undertaking too, when their demand exceeded in-house production capacity. However, export of processed films did not materialize for reasons other than the technical quality of the product.

The second experiment was that of licensing the process on an exclusive basis for manufacture of ceramic capacitors to a public sector undertaking. In this case, three key technicians heading the material processing; pressing, sintering & finishing; and testing, respectively, were absorbed by the licensee, again to ensure smooth flow of transfer of technology. Before doing so, the pilot plant operating in the NPL premises was handed over to the firm for over a year for running it under their supervision and financial control. Scientific guidance was that of NPL. The transfer was effected in two phases viz., pressed, sintered and silvered discs were sent to the factory for encapsulation, testing and sale. The orders booked by NPL pilot plant was transferred to the firm. In the second phase the entire processing was done at the factory premises.

The third experiment was one of licensing several parties. Generally, the choice was made on the basis of the technical competence of entrepreneurs. The process was that of entertainment grade ferrites used mainly in radio receivers as antenna rods, coil and IF cores, etc. Out of 17 licensees for soft ferrites four have set up production within a period of two years. All of them sent their technicians for training in the pilot plant for varying periods. One of them spent nearly seven months in NPL participating in all the activities of the pilot plant in solving processing problems. In another case, a seasoned scientist of NPL with seven years standing in the field of ferrites who has been closely associated with the R & D work, joined the entrepreneur and thus was able to establish production quickly. Technicians from NPL were sent to erect tunnel kilns and batch furnaces. These were designed by NPL scientists and have been in operation for years in the pilot plant. In a few cases semi-processed compositions of ferrites were supplied to the entrepreneur to be shaped and sintered by him. In the second phase the firms established full production starting from raw materials.

In the case of electronic or white ceramics, as it is called, the same procedure of training the technicians and engineers of the entrepreneurs was followed. There was no necessity to transfer a scientist from NPL. Production started within a period of two years.

In all cases there was never a problem of searching for an entrepreneur. In fact it proved very difficult to limit the number who wanted to take the components under development at the time. Even in the case of the public sector firms both were very eager to takeover the process even at the development stage. NPL persuaded them to await pilot trials before taking over.

One significant point is that, everyone of the components have been developed and produced in our country for the first time; they are basic processes which led to production of a number of devices of various shapes, sizes and characteristics, the technology being the same.

For example, the process for ceramic capacitors is the same for piezoelectric and pyroelectric ceramics. Again the basic processes of mixing, milling, calcining shaping and sintering are common to white and black ceramics viz., ferroelectric and ferrimagnetic ceramic materials. Different types of electronic grade ceramics require the same processing equipment as, for example, ceramic and steatite rods used for carbon film resistors.

The laboratory concentrated on the basic issue of developing the processes for manufacture of these items using indigenous sources of raw materials, and machinery. In cases where equipments were not readily available such as tunnel kilns and box electric furnaces, they were fabricated. It was explained to the entrepreneurs that shaping them into rods, tubes or pressing into different shapes is a question of fabrication of the dies for which expertise has to be sought from manufacturers of dies and tools. NPL offered full cooperation in giving all information regarding physical properties of the material for fabrication of the tools and dies. Lists of equipment, machinery and raw materials and their sources (more than one) were provided.

Our activities were limited to pilot plant scale studies which can only form the guidelines. The data collected on pilot operations were provided to the entrepreneurs and it was emphasized they will meet with problems in upscaling and these can be tackled if they were referred to the laboratory. We certainly did not have the engineering expertise for designing dies, tools and fixtures or production equipment. It was felt that this should be left to the entrepreneurs to seek help if needed from a firm of consultants.

I would like to report on how far these attempts have succeeded in fulfilling the objectives. On the credit side one would like to mention that the annual turnover of the entrepreneurs exceeds Rs 4 crores as of today, being the value of passive components produced. Indirectly the turnover of raw materials and machinery have increased fourfold, quite a few ancillary industries have been set up such as silver oxide production, high purity raw materials, vacuum extrusion machines, high temperature box furnaces and tunnel kilns, lapping machines and production testing equipment. It is not possible to estimate their value but what is significant is that their products are not only useful to the electronic industry but to many other industries. For example, the lapping machines are used by manufacturers of slip gauges, piston rings, fuel injection systems, to mention a few. The vacuum extrusion machine manufacturer has branched into making of thermoplastic extrusion machines. What is most rewarding to us is that, all these entrepreneurs have started new industries on their own initiative without seeking foreign collaborations. NPL just gave the initial encouragement and subjected their machines to trials and suggested improvements in the early stages. They are now entirely on their own.

The manufacturer of the lapping machine has not only produced improved versions of the original design but has built machines which can lap on both sides simultaneously. Similarly more sophisticated extruding machines are being built now.

Now I would like to deal with the criticisms voiced most often and attempt to analyze the causes:

**(a) The R&D effort does not offer a turn-key job which one can get with foreign collaboration**

The R&D effort was never intended to produce a turn-key job. The research institution has neither the wherewithal nor the expertise in production engineering to offer a complete commercial unit. In the words of Professor Biackett when he delivered the first Nehru Memorial Lecture in 1963, the scale of inputs required for R&D to pilot plant and a commercial production respectively, are in the ratio of 1:10:100. It should be realized that, what one gets by way of know how on a collaboration, when conditions are stipulated that it should be a tried and tested process with its products being well established in the market means, ipso facto, one gets an old technology particularly in electronics where progress is so rapid. In almost all instances where foreign collaboration has been obtained. For the next generation of products, fresh collaboration are entered into. It has gone to the ridiculous extent that for the same component but with slightly different characteristics fresh collaboration has been sought. If there had been an active in-house R&D group which had learnt the basis on which the technology has been built up or, in the alternative, if an R&D institution had been associated working in the same or allied field, the new generation of components could have been developed in the country itself.

**(b) The process technology, even after a pilot plant operation requires a sizeable effort to be put in to make it commercially viable**

This is necessarily so. The pilot plant operation, when run on proper lines with a qualified cost accountant provides the necessary infrastructure and data which will be useful for engineers to upscale the plant to a commercially viable unit. The entrepreneurs have to put in some effort but this is not wholly unrewarding as they acquire considerable amount of information and expertise which enables them to expand without outside help. It is perplexing and unfortunate that even in the cases of public sector undertakings further communication completely ceased, once the production had commenced. The scientists were only too eager to learn from the experience of the entrepreneur the problems of production and try to solve them. In processing of materials as distinct from fabricating an instrument, the approach is multi-disciplinary. The electronics engineer is concerned only with the end-product for testing the characteristics of the component. The processing involves, in the case under study, physicists

ceramists, metallurgists, mechanical and electrical engineers who have all to cooperate to evolve a successful process. The lack of rapport resulted in mutual misunderstandings and the merits of the basic process suffered.

This attitude is not universal. Two of the entrepreneurs for entertainment ferrites have multiplied their output manifold with ingeniously designed equipment, tools, dies add fabricated machines of their own. In one case tunnel kilns have been duplicated, spray drying plant has been built and rotary kilns for calcining have been fabricated. The increased capacity that has been created is based solely on their own efforts.

Instances are there even with foreign collaboration where, if the entrepreneur is enterprising expansion has been effected by duplicating and building new equipment on their own marginal import content. This is true generally of enterprises in the private sector but regrettably has not been very much in evidence in the public sector undertakings. Is it because private entrepreneurs have to face many hurdles and delays before foreign exchange is released and import licenses are available? Does not this apply to the same extent to public sector enterprises? There are of course some notable exceptions in the public sector which deserves a word of praise.

**(c) Since the process is offered on a non-exclusive basis it inhibits the entrepreneur from approaching freely the scientists with problems arising out of upscaling**

This is primarily because the market is limited and the entrepreneur is afraid of competition. The policy of secrecy which the licence tries to maintain is rather short sighted. In fact what actually happens is that there has been migration of key personnel from one to another licensee and that way the competitor has been able to cash in on the experience gained. If the scientists of the parent laboratory had been trusted and full freedom of discussion maintained, more R&D effort would have gone in. The entrepreneurs are not in a position to undertake nor do they have the funds or facilities for R&D. This would result in all round benefit to the entrepreneurs and to the industry in general. After all the ultimate objective of the laboratory and the entrepreneurs are the same.

**(d) Licensing of the process is indiscriminate and has no relevance to the economic viability of the capacity licensed**

This is true, and NPL had tried to convince NRDC on limiting the number of licensees based on the country's requirements but other forces including political pressures come to play. Now that the Electronics Commission has taken on the job of forecasting the national requirements there may be a more realistic approach.

**(e) The research institutions continue to work in the same field and operate a pilot plant. This means that the institution is a competitor to its own licensees**

This has been a very sore point and has created considerable tension between NPL and the licensees. Invariably, they want NPL to stop all pilot plant activity once the process is licensed. This really means putting a stop to further development effort which ultimately hurts the licensee.

In process development it is necessary to continue experiments on reasonably large batches to study the problems of variation in process parameters and also to be able to supply in sizeable quantities to users, for feed-back of information from field trials. To explain more clearly I give two examples.

One was where, the laboratory was asked to stop further R&D that particular field with the assurance the licensee will set up his own in-house R&D, and develop products with improved characteristics and new ones of the same family. This did not materialize and the firm decided after eight years of production to go in for foreign collaboration. This has not only caused great disappointment to the concerned scientists but a set back to science and technology effort too, as R&D effort ceased in this particular field while rest of the world have advanced considerably both in technology and in production of a variety of products and new applications.

Let us examine whether the country has at least gained by total import substitution. This too has not come about as only 20 to 25 % of the requirements of the electronic industry are met and the balance is imported today even (Source : Passive Components Panel).

In the other example of entertainment grade ferrites NPL refused to stop its pilot plant and R&D activities, even though there was incessant cry from the entrepreneurs. Consequently, it was able to substitute to a considerable extent a scarce imported raw material, nickel oxide with indigenous manganese oxide even for short-wave operation, where nickel oxide was earlier considered to be essential. These have the same characteristics as nickel based ferrites. What is significant is, the raw material cost was reduced to a tenth without any need for foreign exchange. The antenna rods and coil cores made of this composition were used in radio receiver exported to the developed countries and did not call forth any adverse comments on their performance.

In the case of the first experiment on mica capacitors the criterion of total import substitution was satisfied. Between the two entrepreneurs the requirements of the industry was fully met. The more important from a national point of view, viz., export of electroded films and finished capacitors failed to materialize. About 1500 tonnes of condenser grade ruby muscovite mica films are being

exported as raw material for the manufacture of capacitors. If at least part of this could be converted into capacitors and sold abroad, the foreign exchange earnings may be considerable. Though new synthetic dielectric and ferroelectric ceramics have replaced mica to a considerable extent, there are applications where mica capacitors cannot be matched.

A manufacturing unit has now been established for making tapes from scrap mica based on a process developed by RDOEI in Bhopal. This is an extremely gratifying development. However, the firm proposes to reach a maximum production of 300 tonnes and there is need for more manufacturers to come into this field as it is a good foreign exchange earner. Though this is not strictly electronic it has its uses.

The multi-licensing policy, particularly in the case of entertainment grade ferrites has proved quite rewarding in that a virile industry has grown without any foreign collaboration with many improvements to its credit both in processing technology, design and building of machinery, dies, tools, etc.

The electronic grade ceramics, unfortunately has not proliferated though one or two of the entrepreneurs are well qualified academically and otherwise. They have not shown much initiative in expanding or acquiring adequate capacity in installing modern machinery and equipment. The result is that there has been little impact on the market and imports in substantial quantities continue. The entrepreneurs' complaint is that the requirements of electronic ceramics is to diverse both in material composition and shape each of them being quantitatively small that, they are unable to set up economically viable production.

As compared to process transfer, know how transfer for instruments or equipments is comparatively easier and generally speaking more successful. There is usually prototype available which is handed over to the entrepreneur who can then redesign the externals if need be from an aesthetic point of view, or even relay the circuitry and check the components for its performance under stringent operating conditions and yet conform to the basic design. This has been done successfully by many research institutions. Nuclear instrumentation, television receivers, various pressure rate of flow and strain measuring instruments are some notable examples. The photocopying machine is almost a perfect example of knowledge transfer where the licensees have successfully marketed a product within an year of its development and that too at a price substantially cheaper than the imported equipment. Though the machine is not grouped strictly under electronics, it is a close cousin to it.

There is a very successful joint effort by four different organizations. One, the user which posed the problem of developing a sophisticated equipment to a research

laboratory, the laboratory produced prototypes for field trials in collaboration with another organization which produced some of the circle components finally, after successful completion of field trials a fourth one has undertaken its manufacture in numbers. All problems of a well engineered product will be tackled by the production unit. In this almost classic example, the main user had made up its mind to utilize indigenous expertise, to the exclusion of foreign collaboration and the R&D laboratory worked enthusiastically without a Democle's sword hanging over its head all the time threatening foreign collaboration. A production organization in the public sector was prepared to tackle the production problems and undertake quantity production.

In fairness to users, it must be stated that development of a process is far more complicated and invariably the user is not knowledgeable in the technology associated with processing. He can only evaluate the end-product and hence finds it difficult to appreciate the problems that scientists are faced with. More often than not, the enthusiasm of the scientists lead them to underestimate the time required to overcome all the problems of production. This is compounded by lack of standard equipment.

It is learnt that the Department of Electronics siezed of the vital need for intensifying manifold, R&D effort on materials and components, are proposing to support financially R&D efforts at appropriate institutions. The National Research and Development Corporation has decided to play a very constructive role in bringing up the R&D effort of research institutions to a stage where it can be readily taken up by industrialist, i.e., a turnkey project will be offered to the industry. Ever since its inception in 1953 it has only played a passive role of acting as an agent for signing an agreement and the onus of satisfying the industrialist was entirely the responsibility of the research group. While that responsibility continues to be that of the institution. NRDC will step in with funds either jointly with a sponsor or on its own, to prove the viability and commercial success of the R&D efforts. This is a most welcome, specially for process and materials development.

There has not been enough appreciation of the fact that, to assimilate any process technology and understand the numerous problems involved, one has to go through and work on the process from its inception. Then only it is possible to appreciate the many variables and study its effect on one another, before a viable process can be developed. In one recent report it has been stated that this approach of systematic study of the effect of varying one parameter on the other when many conflicting properties are to be satisfied, reveals a lack of understanding of the problems and is an empirical approach. It will be interesting to know what other way is there by which it is possible to analyze scientifically the many problems that confront production and to solve them.

We have planned to achieve a lot more in 1950 than what has been possible. We had hope perhaps rather naively, that we will be able to build a close link and establish a joint collaborative effort in producing the components with entrepreneurs in public and private sectors. In the fields we have worked we expected to establish total self-reliance and import substitution. We also hoped we would be accepted as genuine in our objectives and efforts if there had been drawbacks it has not been intentional. Posterity will perhaps judge dispassionately, that what was set in motion in 1950 has snowballed now and practically on every platform where electronics is debated the need for considerable R&D on materials and components is emphasised. I recalled Dr Bhatnagar's prediction viz., "there has to be many more laboratories for electronics than one."

It is hope the three-pronged approach viz., identification of the problem and assignment to an R&D group in an appropriate research institution by the Department of Electronics, a time-targeted R&D effort by the scientist, fruition of the project through NRDC as a

pilot plant or as an economically viable commercial unit with or without a sponsor, should, to a very large extent, dissipate the fears of scientists and engineers and encourage them to concentrate single-mindedly on the problems.

Electronics Corporation of India Limited, a child of the Bhabha Atomic Research Centre is an example of the very gratifying success achieved in a short span of six years by the nation's scientific and engineering talent for evolving production know how without any foreign collaboration. It is apposite to quote from an article written by Shri AS Rao, Managing Director of ECIL. "... Perhaps ECIL's performance is suggestive of how immensely the nation can gain if it can expand the concept of ECIL in electronics to other technological fields as well, infusing a high degree of self-reliance to our industrialization programme and in turn, to general development."

What a pity it is that Bhabha the visionary and the most practical of practical men is not with us today to bask in the glory of the fruition of his foresight!

## Science and Social Consciousness

K C PANT

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**P**AYING homage to Homi Bhabha is by no means easy. But it is certainly rewarding – as it always is when we pause to ponder over the life and laurels of one who has been a colossus of his time. What Homi Bhabha was and what all he did, would be impossible to capsule within the confines of a short speech. But we can always try and draw in broad strokes the main thrusts of his attitudes and achievements – not as an exercise in eulogy – but as an aid for seeing more clearly our own unfinished tasks for the future.

Homi Bhabha was a great scientist and commanded respect and admiration both in India and abroad. He pursued the intricacies of fundamental physics in the “thrilling thirties”. He walked with confidence the world of Blackett and Cockcroft, Heitler and Rutherford, Bohr and Pauli. At the age of thirty-one, he was elected a Fellow of the Royal Society of London. In fact, even as late as 1953 when he was overwhelmed with diverse responsibilities, he found time to write an important paper on the Multiple Production of Mesons which has been published in the Proceedings of the Royal Society of London.

But Bhabha did not seek science for its own sake. He sought science for what it could do for the larger cause of humanity. In fact, when he conceived of what later became the Tata Institute of Fundamental Research, he said: -

“It is absolutely in the interest of India to have a vigorous school of research and fundamental physics; for such a school forms the spearhead of research, not only in the less advanced branches of physics but also in the problems of immediate practical application to industry. If much of the applied research done in India is disappointing and of very inferior quality it is entirely due to the absence of a sufficient number of outstanding pure research workers who could set the standards of good research”.

He added, with characteristic foresight, that “when nuclear energy has been successfully applied to power production, in say a couple of decades from now, India will not look abroad for its experts but will find them ready at home”.

Bhabha was a strong nationalist and a staunch patriot. He had spent 12 years of his life, from 1927 to 1939, in England and Europe. With his academic attainments he could have got, for the asking, the best of berths in

Cambridge or Princeton. But he chose to return to India as he felt “It is one’s duty to stay in one’s own country and build up schools comparable with those which other countries are fortunate in possessing”. If Bhabha was conscious of the deleterious effects of brain drain, he was not oblivious of some of its more fundamental casual aspects. He wanted our scientists and engineers to stay in India but he made it amply clear that the right work environment and work facilities must be made available to them. This is exemplified by the institutions set up by him which are, in the truest sense, standing memorials to Bhabha’s thought and action.

It has been my privilege to have known Bhabha. I first met him when he came to see my father. I was only a student at that time. Later he invited me to what became the Bhabha Atomic Research Centre. I was also a member, along with him on the Governing Body of the Indian Institute of Science at Bangalore. I have always held Bhabha in the highest esteem. I still have a vivid memory of the last occasion when I met him. This was just before he left on his ill-fated trip. He talked to me for more than an hour. He was as warm and vibrant as ever and his eyes full of visions for India’s future. He saw far ahead – whether it be the potentialities of fundamental research, the finiteness of the fossil fuels or the possibilities of energy from controlled fusion. Bhabha was not a mere dreamer. He had his head in the clouds, and his feet firmly planted on the ground.

Whoever came into contact with him did not fail to marvel at his many-sided virtuosity. He was himself an artist and he assembled for his institutes a fine collection of art from all over the world. He was also a great lover of music. Indeed, Bhabha’s life and personality bring to mind the following well-known lines:

*His life was gentle; and the elements  
So mix'd in him that Nature might stand up  
And say to all the world 'This was a man!'*

Whether it was the Atomic Research Station at Trombay juxtaposed to the Elephanta Caves across the water or the Atomic Power Station at Kalpakkam adjacent to the temples of Mahabalipuram, Bhabha drove home the point that the might of the machine shall always be tempered by the finer aspects of man and nature.

Above all, I believe that the greatest contribution of

Bhabha was the manner in which he sought to prove that science and technology were not the close preserves of the affluent nations. The relatively poor have the inherent powers to mould their own science and technology. In his last public address in January, 1966 he stated "What the developed countries have and the under-developed lack is modern science and an economy based on modern technology. The problem of developing the under-developed countries is, therefore, the problem of establishing modern science in them and transforming their economy to one based on modern science and technology". In this we find the germs of the concept of national self-reliance in concert with the larger strategy for the removal of poverty. We would be paying the most opposite tribute to Bhabha if as collective bodies of scientists and engineers, we could pause and consider to what extent Bhabha's dreams have been realized and how we can enhance the role that science and technology can play in the tasks of nation-building.

## II

What India has achieved in the field of science and technology since independence is not, by any standards, something to be cavilled at. Under the enlightened leadership of Pt. Jawaharlal Nehru, education and research received a tremendous fillip. The number of universities grew from 27 in 1950 to 80 in 1965 and to 120 in 1975. In the field of technical education, the Indian Institutes of Technology and other engineering institutes sprung up in different parts of the country. The Council of Scientific and Industrial Research which had been set up in 1942 emerged as the focal point of research in a variety of fields. Equally significant were the setting up of national laboratories in physical and chemical sciences, metallurgy, glass, leather, roads and building etc. The Indian Council of Medical Research was established in 1949 to promote and co-ordinate research in the fields of health, sanitation and related areas. The map of India came to be dotted with the laboratories of the Indian Council of Agricultural Research. India was one of the first countries to enunciate the Science Policy Resolution in 1958, which declared that "it is an inherent obligation of a country like India with its traditions of scholarship and original thinking and its great cultural heritage to participate fully in the march of science which is probably mankind's greatest enterprise today". Along with the development of research potential in the universities and organised research institutes under national agencies, a beginning has also been made in research and development activities in industrial units, especially in drugs, pharmaceuticals, textiles, electrical machinery etc. One of the important steps taken in the fields of industrial utilization of R&D results was the establishment of the National Research Development Corporation in 1973.

Science and technology have received tremendous inspiration and a clear sense of direction, under the leadership of Shrimati Indira Gandhi. Her purposeful

interaction with the scientific community has been instrumental in appropriately orienting research programmes not only in the frontier areas of science such as nuclear energy, space and electronics, but also in research and development geared to improve the everyday life of the ordinary man. In 1971, the National Committee on Science and Technology was set up with the main objective of preparing and up-dating the national plans for the development of science policy, resource and manpower utilization and the institutional needs for the rational growth of scientific endeavour. The Committee set up various sub-committees in different areas of science and technology and, with the participation of 2000 active scientists, prepared the document entitled 'The National Plan for Science and Technology'. "The Prime Minister's deep involvement in the futuristic concerns of the world at large has been reflected by the setting up of the National Committee on Environmental Planning and Co-ordination. In her own words "just as man has sublimated his cannibalistic and predatory instincts, he has to overcome his habits of wasteful consumption of energy and of non-replenish-able resources".

You are all aware of the catalogue of achievements. The Technology breakthrough in high-yielding and high quality varieties of cereals has brought about what is popularly called the Green Revolution. A number of strides have been made in the areas of electronics, drugs and pharmaceuticals, pesticides, food and energy. The recent atomic explosion has opened new vistas for the peaceful uses of atomic energy for creative developmental purposes. Aryabhata has launched India into the space age. Space exploration and operation of space satellites have made possible the percolation of television communication to distant villages. In the field of steel, engineering and chemical technology, our expertise is such that we are in a position to participate constructively in the developmental programmes of the Third World. We have at present the third largest cadre of scientists and technologists who have within their grasp the potential to transform our economy into one of prosperity and plenty.

## III

The question is : why are we still dogged by vast pockets of poverty and backwardness? How can science and technology play a more perceptible potent role in raising the levels and quality of living of the Indian masses?

It is now almost a cliché that science and technology are concerned with means – how best to reach certain ends – and cannot tell us what we must pursue. To merely stop with this statement would tantamount to a unidimensional view of the problem. If science has proved beneficial in the fields of nuclear power, microbiology, space technology, desalination of water or plant and animal breeding – to name but a few of the many boons of science – it has equally exposed mankind to the threats of

nuclear destruction, ecological imbalance, depletion of natural resources, or aberrations like the Thalidomide disaster. What is clearly called for is that science and technology should be underpinned by a sound value system. This cannot be brought about by a mere academic exercise. The development of a science of ethics has been considered in the past but, as Henry Poincare observed "it can be no more a substitute for mortality than a treatise on the physiology of digestion can be a substitute for a good dinner". Nor is it necessary that every scientist or engineer should also be a part politician or social philosopher. That would possibly only lead to the worst of both the worlds. You would be aware of the fact that Isaac Newton was a Member of Parliament, and legend has it that he spoke only once, to have a window closed. But there is no reason why scientists and technologists should not be imbued with the emerging social consciousness, be aware of the realities and aspirations of the people at large and see for themselves how best their skills could be bent towards the attainment of the larger national objectives.

One factor which is perhaps common to all under-developed countries, has been the process of technology transfer. It is often argued that, as "late comers in development" these countries can reap the advantages of what has evolved in the advanced countries. There is no need, they say, to re-invent the wheel. Such a generalization tends to sweep under the carpet the fact that transfer of technologies is a very complex phenomenon. It needs to be recognised that the potential impact of major technological programmes on the recipient societies may go beyond those that are traditionally contemplated through economic analysis and technical feasibility studies. It has now come to be accepted that technology is a driving force and a determinant not only of the rate of growth but also of the pattern of development. Technological dependence has resulted in instances of inappropriate technologies in the under-developed countries. Broadly speaking, this has occurred in two ways. Firstly, the technologies which are transferred from the advanced countries are generally capital intensive whereas the factor endowment patterns in under-developed countries require labour intensive techniques. Secondly, it has resulted in the manufacture of 'inappropriate products'. It promotes an ethos of consumerism where the electric shaver is sought when the ordinary razor would do or common thirst is translated into the desire for a popular brand of soft drink. In fact, it leads to social disruption especially in countries where inequalities exist but are no longer accepted as legitimate. The greatest insight into this problem was provided by Mahatma Gandhi when he prescribed to the Afro-Asian countries his simple formula: "Supply the needs and reduce the wants".

There is now the talk of appropriate or intermediate technology for the developing countries. There is a notion in some quarters that intermediate technology is only a

cover for so designing the international division of labour that high technology and high added value production is confined to a few nations and low technology and low added value of production becomes the mainstay of the poorer nations. We firmly reject such a position. By appropriate technology we do not imply backward or second grade science or technology. As you know, India has many sophisticated and large scale industries but vast areas and groups of people are left untouched by them. The small scale industries and the village crafts would need to be made more viable and efficient. Far from being incompatible with modernization, appropriate technology is a step in that direction. What it really calls for is a clear perception of what is desirable and what is feasible. We need innovation not for inventing markets for non-essential goods but to produce essential goods at lower costs within the reach of the vast majority of the people and without diminishing employment opportunities.

To cite an illustration closer to this audience, let us take the case of computer technology. Future historians will perhaps match the importance of the computer with the invention of writing. While the steam engine and its mechanical successors have enabled man to accomplish physical feats, the computer opens pathways to achievements in the realm of information and ideas previously denied to us. When we talk of appropriate technology it does not mean that we should deprive ourselves of the advantages of sophisticated technology like the computer technology. What is more important is that we should clearly chalk out the areas where and the manner in which this technology can be of relevance to the developing countries. Economic planning for development demands the collection and analysis of a considerable volume of reliable data and often within a short period of time. In this context, computer technology emerges as a remarkably useful planning and management tool. There are also several possible sectoral applications. One example that has been cited relates to the applications of the systems approach to the designing and placing of wells in Punjab so that the water table could be lowered with most effectiveness at the minimum possible cost. Similarly on the organisational side what would be required is to evolve the most suitable concepts of time sharing or the installation of a large number of mini computers.

If indigenous science and technology are to emerge as a more creative force, our scientists should perceive their role as agents of change and canalise efforts towards socially relevant areas. Those who are in the field of applied research must concentrate on problems that are closer to domestic reliance. Standards of excellence, however high, in dealing with esoteric problems that gain acclaim abroad will not pass the touchstone of social relevance. There should also be a manifest resistance to the temptations of what the Prime Minister described as "academic tourism". In the ultimate analysis there is no alternative to a sense of

commitment and dedication. To touch a slightly lighter vein, you may have heard the story of a visiting journalist who asked the Director of a famous laboratory "How many scientists work in your laboratory?" The Director reflected for a moment and replied "Less than half."

#### IV

What are the tasks for the future? The Prime Minister has already given the call. While addressing the engineers recently she said:

"Today villages need and demand the discoveries of science. It is of the utmost urgency that technology should reach the villages. In the past much attention was paid to develop equipment which would suit our agro-climate conditions and the economic state of our cultivators. Rural industrialization also poses certain basic technological problems which have not so far attracted the attention they deserve. Whether the poverty of India can be eradicated smoothly in future will depend largely upon whether or not we can achieve a real breakthrough in these directions".

It is now increasingly recognized that the battle against poverty has to be won overwhelmingly on the agrarian front. The rationale for the priority accorded to integrated rural development is not far to seek. In terms of pure economics, the statistics relating to the percentage of population living in rural areas, the structural composition of the national economy, the rate at which employment in the manufacturing sector is likely to grow over time, the rate of population increase etc speak for themselves. On the social side, there is the problem posed by inordinate urbanisation. In absolute terms, the urban population of India increased from 25.86 million in 1901 to 108.79 million in 1971. The ratio of urban to rural population which was 1 : 7.5 in 1921 is 1 : 4 today. The increase in the urban population is 2.5 times the increase in general population and over three times that the rural population. A significant aspect of urbanisation of India has been the heavy concentration of the population in cities with a population of 100 thousand or more. The problem created by uncontrolled migration to the cities are well known. Calcutta and Bombay are already bursting at the seams. Delhi and Madras may well join these ranks. The crucial fact is that the abnormal growth of the metropolitan areas in developing countries has been more a "push" effect from the villages rather than "pull" from the cities. This is borne out by data showing that urbanisation has grown considerably faster than industrial employment in under-developed countries. If this spectre of urban explosion is to be laid to rest, problems of the rural economy should be faced and overcome in the rural environment.

The priority areas for science and technology in this momentous task are many. The first and foremost would naturally be the extension of higher productivity techniques to the whole range of crops. Provision of other inputs especially irrigation, on an economical and efficient basis,

would be part of the package approach. Fulfillment of the energy needs through more cost effective bio-gas plants or through non-traditional sources like wind or solar power would also demand intense research and development work. The National Commission on Agriculture has calculated that at least 30 per cent of the rural force may have to be employed in the non-agricultural rural sector, including processing, textiles and other village industries. This, automatically poses the need for evolving appropriate technologies.

It is not as if we are breaking ground in entirely virgin territory. Many of you would be aware of experiments like the one undertaken in Karim Nagar District of Andhra Pradesh. This experiment has brought out in bold relief how scientific and technological inputs can make a vital impact on the everyday life of the rural masses. It has also demonstrated that the Indian farmer, however, tradition-bound he is, is responsive to changes whose profitability is proved on the ground. Above all, it has brought home as to how through the maximum use of local resources it is possible to generate gainful employment and stem the exodus to urban areas. A similar experiment is being undertaken in Chandrapur District of Maharashtra. What we have to aim at is the systematic proliferation of these ideas across the length and breadth of our countryside. This would mean that the innovation process should not be dependant on the initiative and drive of an individual or two but should be carefully institutionalized. The district would, no doubt, be the right base for operation. It would call for the undertaking of an integrated inventory of the natural resources and the development of scientific resource-use plans. There is scope for fruitfully involving the colleges in this task. There is much to be said in favour of the idea of having Vigyan Mandirs in each block which spread the message of science to rural youth with models and other educative aids like the planetarium. Considerable thought is required in this direction. What we need is not a ripple here or there. We have to develop, at every level, the capacity to interpret the world around in scientific terms and the will and determination to work steadily towards the unfinished task of nation building.

#### V

I would not like to take more of your time. I am really grateful to the Institution of Electronics and Telecommunication Engineers for this opportunity to be here with you. I would only like to end on an apocryphal anecdote about an emperor who once said to his gardener: "Plant a tree tomorrow". The gardener replied, "It won't bear fruit for thirty years." "In that case", the emperor retorted, "Plant it this afternoon." That is what Bhabha did and are today reaping the fruits. It is up to us to resolve to afforest the world of science and technology - with the right species, right now — so that the coming generations could lead a fuller and richer life.

# Component Progress and Computer Development

B NAG

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**T**HE development of computers has been inextricably linked with the development of components, particularly, microelectronic devices ever since the invention of the transistor in 1948. As a matter of fact the two have interacted so closely in their evolution that they can virtually be regarded as symbiotic. While the first large stored programme computers were based on vacuum tubes with switching speeds of  $1\mu\text{s}$ , their successors were based on discrete transistors where both switching speed and reliability improved by an order of magnitude. However, it was the invention of the integrated circuit in 1959 and the evolution of semiconductor component technology which was to have an unprecedented impact on computing, resulting in an improvement of 4 orders of magnitude in cost/performance till now. These improvements in computer hardware have been important not only for 'high end' or 'mainframe' computers, the largest and fastest machines, which provided the initial stimulus for these developments, but advances in microelectronics, particularly, in large scale integration (LSI) led first, to development of the minicomputer in the mid 60's followed more recently by the new smaller microcomputer. With this latter development, in 1971, there has been an almost Darwinian Speciation of computers into machines of different sizes and organizations, each tailored to a different range of functions.

In order to comprehend these developments, it is essential to review developments both past and present and understand the limits to the performance, cost and reliability improvements in semiconductor components, as well as the likely rate of technological progress in the future as compared with the past. These increased capabilities in components can cause and create new approaches in systems architecture and machine design; new and improved memory and storage hierarchies coupled with declining costs with their consequential impact on both low and high end computing; the development of the microprocessor and related to these developments the role of distributed processing.

## SEMICONDUCTOR TECHNOLOGY

The major driving forces within semiconductor technology have been improvements in the area of materials, processes and tooling, which has led to major improvements in both component density as well as

performance. Silicon is and will continue to remain for quite sometime the predominant material in microelectronics and the improvements in silicon a technology are summarized below:

- The defect density in silicon material has improved by three orders of magnitude since 1967 and this trend is likely to continue in future (see Fig 1). This has been coupled with an increase in wafer size from 25 mm in the 1950s to 100-125 mm today. As a consequence the chip size has increased from  $0.5\text{ mm}^2$  in the early 60s to  $40\text{ mm}^2$  today, and this is likely to increase to  $150\text{ mm}^2$  in the next few years.
- Mask Line width has decreased from tens of microns in the 60s to the practical optical limit of 1.5 microns, through use of projection optical systems and this is likely to decrease further to 0.25 microns by the use of direct writing on a wafer using Electron Beam systems currently under development (see Fig 2). Further improvements in line width will be possible in future through the use of X-ray lithography.
- These improvements in materials and optics have necessitated corresponding developments in process techniques like dry etching using plasmas in place of chemical etching and the use of ion implantation in place of thermal diffusion, which has resulted in more precise control of impurity concentration and distribution at lower temperatures.
- As a consequence of these developments the level of integration has followed a trend which was first noted by Gordon Moore in 1964 and is exhibited in his famous

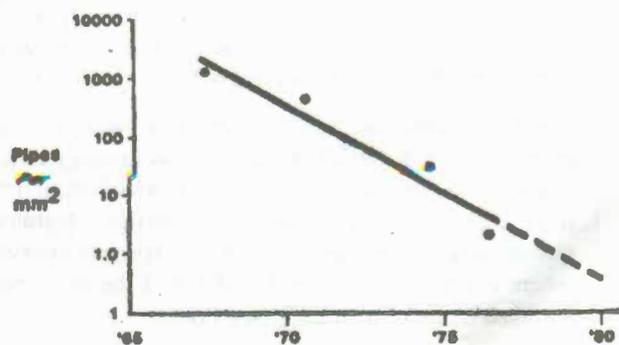


Fig 1 Defect density

graph (see Fig 3). According to this, device complexity has been doubling every year since 1959 and today circuits contain  $2^{18}$  or 262144 elements. There is some evidence that this increase in complexity is likely to begin tapering in the 80s due to physical limits. Figure 4 is prophetic projection made by Petritz<sup>1</sup> which summarises device and technology trends and the nature of some of these devices.

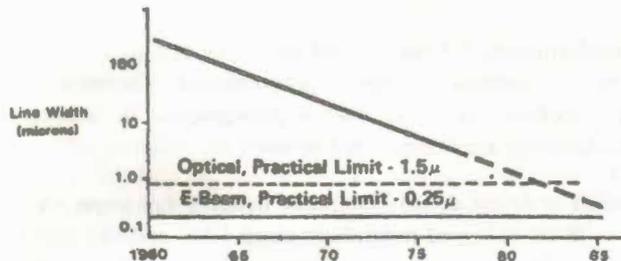


Fig 2 Minimum line width

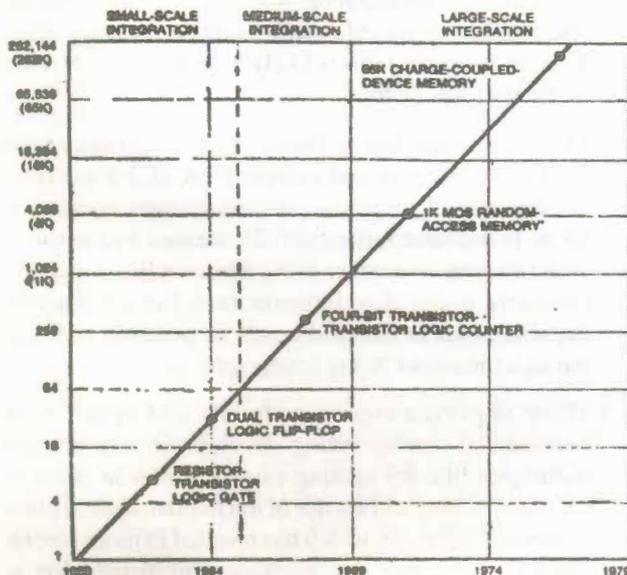


Fig 3 Number of components per circuit in the most advanced integrated circuits has doubled every year since 1959, when the planner transistor was developed. Gordon E. Moore, then at Fairchild Semiconductor, noted the trend in 1964 and predicted that it would continue

- (e) The different elements contributing to increasing complexity, namely, die size, pattern dimensions and circuit cleverness are shown in Fig 5.
- (f) The above increase in complexity as well as the improvements in 'yields' for a given technology have resulted in a remarkable decline in the price/function in integrated circuits. This decline in costs in integrated circuits is best illustrated by the price-experience curve, where every time volume has doubled the price has declined by more than 25% (see Fig 6).
- (g) In terms of a historical perspective, bipolar technology was the first to be developed and it was indeed the 54/

74 series of TTL integrated circuits, which by the end of the 1960 had achieved an almost complete domination of the design of new systems. Although, basic TTL technology is over 10 years old the addition of Schottky diodes has enabled higher speeds to be obtained with lower power, with very little increase in surface area usage, thus considerably extending the useful life of this technology. This evolution is illustrated in Table 1 which summarizes past, present and future trends.

- (h) It is worth noting, however, that for the largest and fastest machines like the CRAY-1 with a CPU cycle time of 12.5 ns, ECL technology continues to dominate. ECL has passed through three generations of development, the most advanced of which is the 100,00 series (see Table 2). An implementation of these devices in a 'Master-Slice' technique is being used on new mainframe 'Super Computers'.
- (i) However, it was MOS technology which became the vehicle for large scale integration (LSI) in 1970 with the advent of the single chip calculator. Particularly, exciting is the future of a variant of MOS technology, namely, silicon gate NMOS, which is particularly relevant for the development of VLSI. A perspective of the evolution of this technology from 1972 to 1980 is illustrated in Table 3. It is predicted that MOS devices in the 1980's will show sub-nanosecond and sub-milliwatt characteristics with the speed power product down to 0.2 pJ. The realization of this performance has been achieved through the concept of 'scaling' as Table 3 clearly illustrates.

**MEMORY**

The above developments in semiconductor technology have produced a major impact on the development of mainframe memories. A summary of the cost/bit together with access time for different memory technologies can be

TABLE 1 Evolution of transistor-transistor

LOGIC (TTL)			
Series	Delay Time	Power	Speed-Power
Standard	10 ns	10 mW	100 pJ
Low power (L)	33 ns	1 mW	33 pJ
High speed (H)	6 ns	22 mW	132 pJ
BASIC (TTL)			
Low Power Schottky(LS)	9.5 ns	2 mW	19 pJ
Schottky(S)	3.0 ns	19 mW	57 pJ
SCHOTTKY TTL			
Super Low Power Schottky (SLS)	5 ns	2 mW	10 pJ
Super Schottky (SS)	1 ns	10 mW	10 pJ

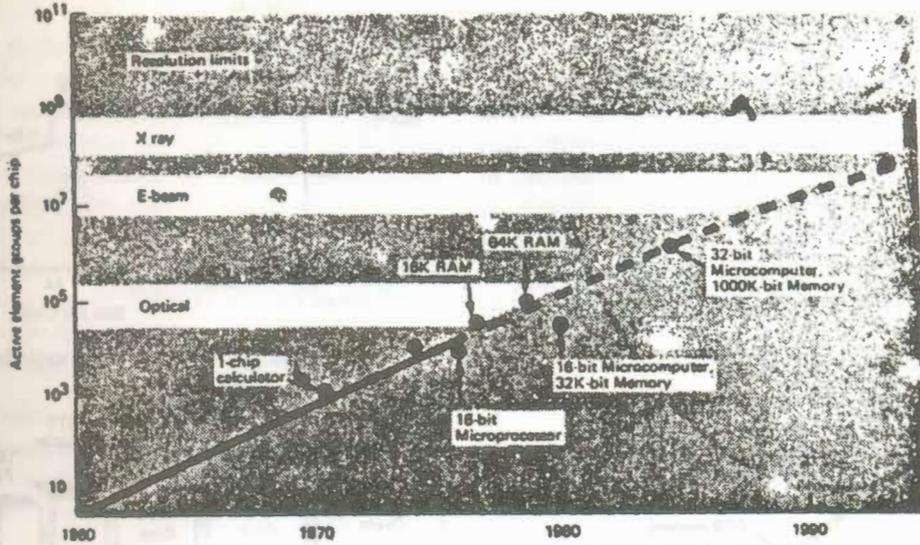


Fig 4 Device and technology trends

TABLE 2 ECL Technology

	ECL I	ECL II	10,000	100,000
Gate delay	8 ns	4 ns	2 ns	0.75 ns
Gate power	31 mW	22 mW	25 mW	20 mW
Speed power	250 pJ	88 pJ	50 pJ	15 pJ

TABLE 3 Evolution of MOS device performance

Device/Circuit Parameter	Enhancement mode		Depletion mode		N-MOS	H-MOS	N-MOS
	N-MOS	N-MOS	N-MOS	N-MOS			
	1972	1976	1977	1977			
Channel length, $L$ ( $\mu\text{m}$ )	6	6	5.0	3.5	2		
Lateral diffusion $L_0$ ( $\mu\text{m}$ )	1.4	1.4	0.6	0.6	0.4		
Junction Depth, $x_j$ ( $\mu\text{m}$ )	2.0	2.0	1.0	0.8	0.8		
Gate-oxide thickness, $T_{ox}$ (Å)	1,200	1,200	800	700	400		
Power Supply Voltage, $V_{CC}$ (V)	4-15	4-8	12	3-7	2-4		
Shortest gate delay, (ns)	12-15	4	6	1	0.5		
Gate power, P-(mW)	1.5	1	1	1	0.4		
Speed-power product (pJ)	18	4	6	1	0.2		

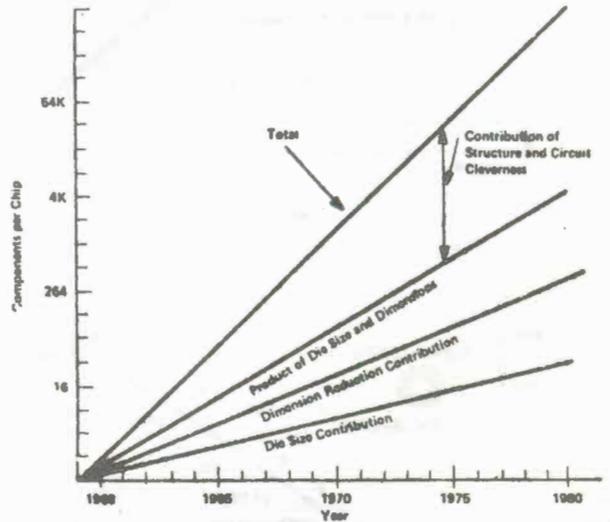


Fig 5 Elements of increasing complexity as a function of die size, pattern-dimension and circuit cleverness

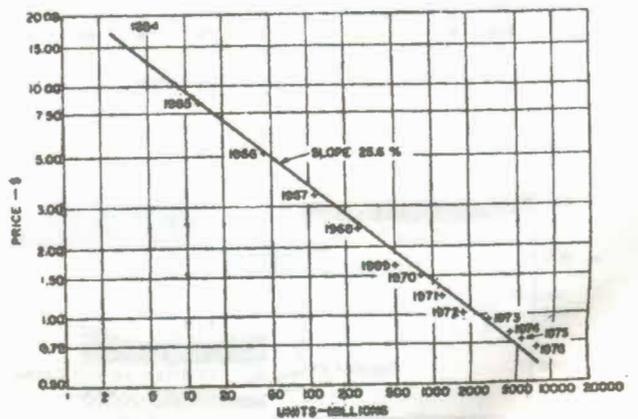


Fig 6 Price-experience curve for ICs. Every time volume has doubled, prices have declined by more than 25%

seen in Fig 7. In terms of mainframe memory MOS technology dominates, where present production technology remains at the 16K dynamic RAM level, while the 64K RAM is under development. Figure 8 illustrates the evolution of memory technology. Since the dynamic RAM represents the leading edge of technology, the improvement of main memory access time can be seen in Fig 9 and the evolution of memory cell size can be seen in Fig 10. It is interesting to make a comparison of physical size between the relative volumes of different memory hierarchies and technologies. As can be clearly seen from

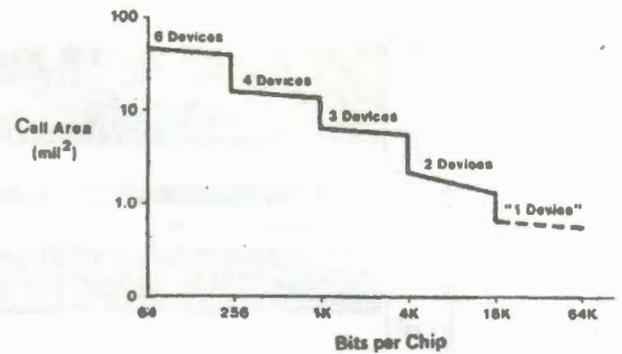


Fig 10 Memory cell size evolution

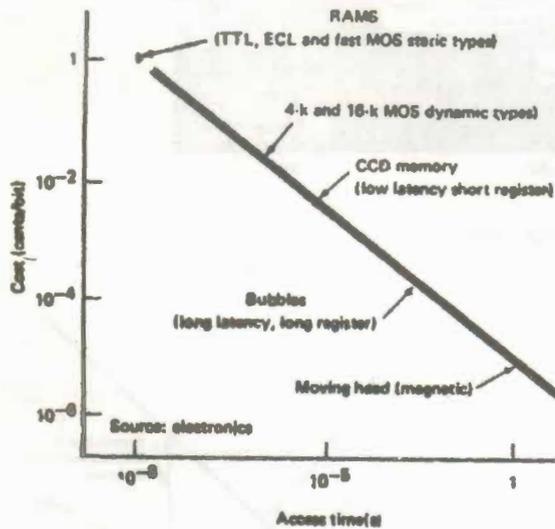


Fig 7 Economics of memory devices

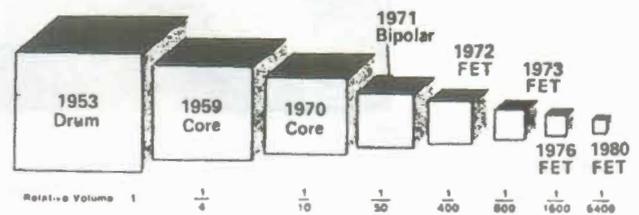


Fig 11 Main memory trends - physical size comparison

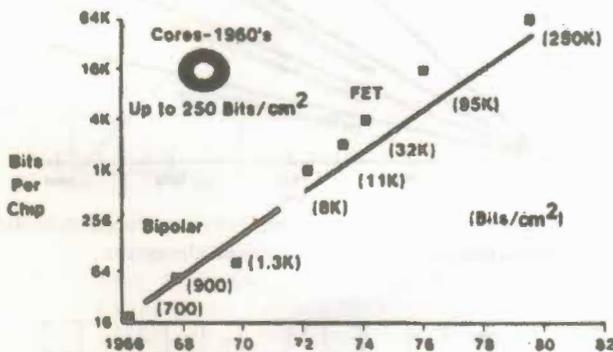


Fig 8 Memory technology evolution

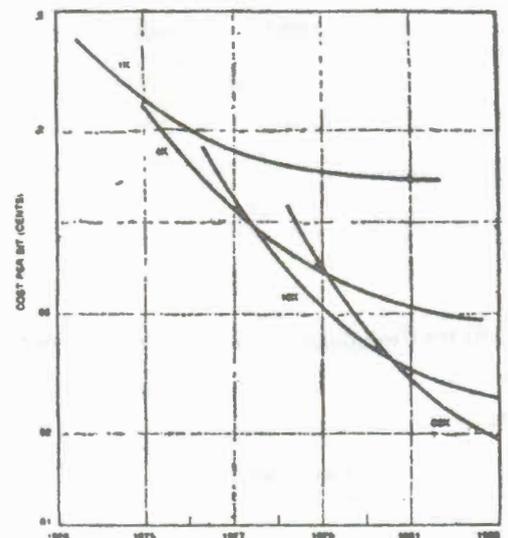


Fig 12 Cost-experience curve

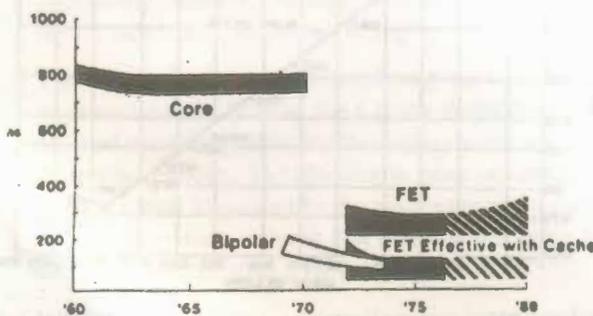


Fig 9 Main memory access time

Fig 11 an improvement of three orders of magnitude in mainframe memory volume will have taken place from the core memory of 1959 to the dynamic MOS memory in 1980.

Semiconductor memory has one particularly valuable characteristic, namely, the cost/bit of the memory is more or less independent of the size of the memory. In the past, with core memories the cost/bit of the system was much higher with a smaller memory due to the high cost of support circuitry. With the advent of semiconductor memories the cost/bit is primarily in the chips and their packaging and not in the support circuits. Hence the cost of a computer system is proportional only to the size of the

memory. This factor has been quite important in making economically viable today's low end minicomputer or microcomputer. In the case of MOS memory, the effect of the cost experience curve has been shown chronologically as a function of memory generation with time, in Fig 12. It can thus be seen that even at the level of the 64K bit RAM the cost will come down to only  $10^{-2}$  cent/bit which would still be substantially higher than cost/bit for disc and tape storage, which is  $10^{-5}$  cent/bit. It is likely that this trend will persist into the foreseeable future. This large spread in cost/bit as well as access time for different memory technologies militates in favour of a structured memory hierarchy, particularly in the case of mainframe computers.

The use of lesser performance FET memories in high performance systems has been made possible by the use of the buffer or cache concept, thus giving major improvements in memory access time (see Fig 9).

**PACKAGING, INTERCONNECTION AND RELIABILITY**

The improvements in semiconductor technology which have occurred in terms of performance and in terms of power dissipation and complexity have naturally put new demands on packaging technologies. Thus, improvements at the chip level have reduced the higher level packaging required in (cards/boards) for a particular system design. At the same time, these improvements have also placed new demands on packaging technologies for greater input/output connection density, improved reliability, power distribution and cooling.

**Package Interconnection Aspects**

As the level of integration increases the ratio of the number of circuits to the number of input/output connections improves. However, this rate is not sufficient to avoid the required total number of communication lines to this group of circuits to increase. Thus,  $P = K.C^b$  expresses a historically derived relationship between the number of circuits in a package and the number of pins ( $0.5 \leq b \leq 0.7$ ). Improved machine design can minimize the total number of connections; similarly, as the number of circuits in a package begin to approach a total function, a more favourable pin count than that predicted by the historical relationship emerges. However, physical size restrictions due to considerations like time of flight increase connection density, either at pads of the chip or at the connection to the next level package. The increased performance places a demand on improved impedance control of interconnecting lines. In addition, stub length and loading must be carefully controlled if electrical reflections are to be minimized. Curiously enough it is the double sided PCB where these parameters can be best controlled for the fastest machines though at the expense of density.

Increased levels of integration have also caused problems in terms of power dissipation at the package level.

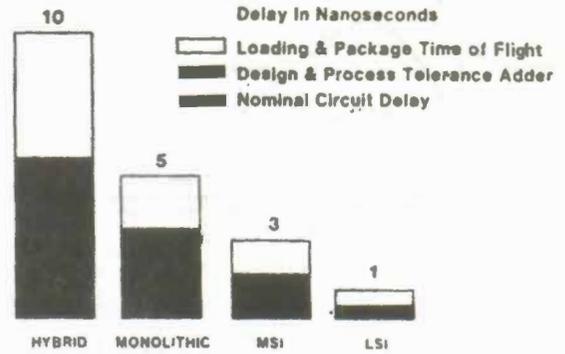


Fig 13 Logic circuit delay per stage

Advances in packaging have not occurred at the same rate as improvements at the chip level. As a result the circuit speed proper is the parameter that provides the largest per cent improvement in total delay/stage (see Fig 13). Packaging and loading delay, as well as tolerance adders for design and process variation, are first order factors to fix in the future, as progress in high performance logic continues.

**Reliability Factors**

Clearly, the present mainframe computers would not have been possible if all the improvements discussed above had not occurred together with equivalent improvements in the reliability of integrated circuits. The evolution of the almost every generation of technology has been accompanied by an order of magnitude improvements in reliability. This has been possible due to better process control, fewer external physical connections per circuit, increased circuit tolerances and improved protection of the

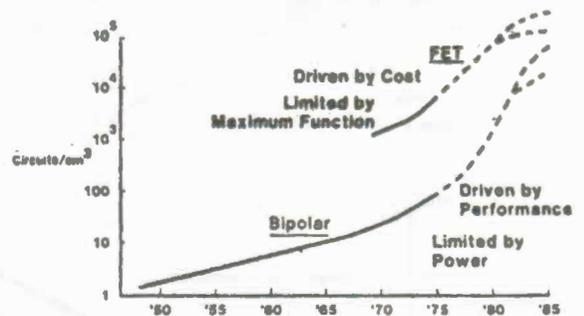


Fig 14 Packaged logic circuits (Board level)

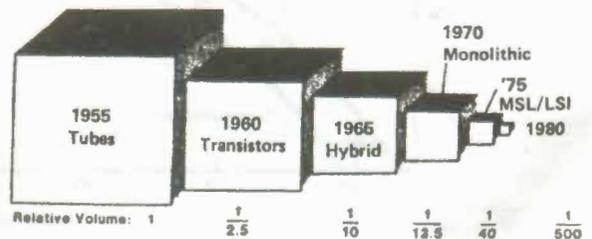


Fig 15 Logic circuits : volumetric evolution

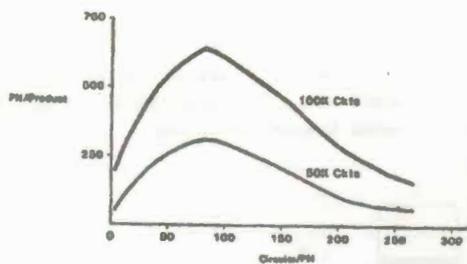


Fig 16 Part number trend

chip surface from environmental contamination. Figures 14 and 15 illustrate increasing package density and decreasing size, respectively. However, the advent of LSI has resulted in a proliferation of part numbers at the chip level (see Fig 16). This problem will either demand a very flexible design and manufacturing system or it could very well mean that in deliberate kind of way (by creating high-levels of universal functional parts such as microprocessors) the exploitation of LSI will be suboptimised. It could also be a mean of the two approaches, namely, the use of a large number of part numbers, together with clever exploitation of multi-use of high-level functions.

In summary, since 1960 to the present, the integration level in high performance logic has increased by a factor of 1000 and this trend is likely to follow Moore's law till well into 1980s, before physical limitations slow down this trend.

**COMPUTERS**

Figure 17 shows the 'whole world' in one diagram and covers the entire spectrum from the calculator to the super-computer. There is, similarly, a corresponding range in the cost of such systems : the largest mainframe machines cost \$10 million, while a complete microcomputer system costs

as little as a few hundred dollars. In a more quantitative sense, a large mainframe computer system may consist of 100,000 logic circuits and between 4 and 8 million bytes of memory. A small mainframe system might have 20,000 logic circuits and 128,000 bytes of memory. A typical minicomputer system might have between 5000 and 10,000 logic circuits and 16,000 to 32,000 bytes of memory. A microcomputer system might have 1000 to 2000 logic circuits and a few hundred to a few thousand bytes of memory. While the bulk of the data processing market in 1976 of \$20 billion arose, primarily, from mainframes and to a lesser extent minis, it is estimated that the market for microprocessors which is growing most rapidly, would exceed \$ 5 billion by 1985. It is, therefore, necessary not only to examine systems development in case of high end computers, but even more important to understand some of the consequences and implications of the developments in micros whose effect both on semiconductor technology as well as society is likely to become more profound and pervasive with the passage of time.

**THE MICROPROCESSOR**

The development of the microprocessor evolved out a need to manufacture a general purpose integrated electronic component. In 1971, INTEL was facing the problem of having to design a customized chip for a family of calculators, which being required in low volume, was not cost effective. To overcome this they produced the microprocessor which, by programming the on-chip memory, could be customized for each application. The first device produced was the INTEL 4004. From this they went on to develop the 8080, an N-channel 8 bit microprocessor. Since then a great proliferation has taken place and there can be found something like 50 substantially different microprocessor architectures.

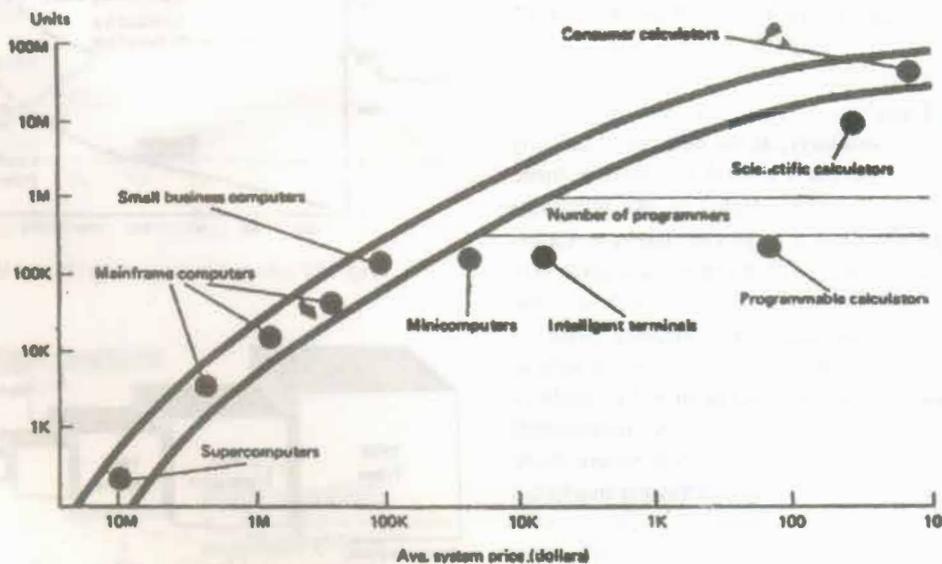


Fig 17 US installed computer base-1976

However, it is probable that only about 4 of them have any real significance. The microprocessor as it has evolved can be divided into 3 distinct classes of product:

- (a) The microprocessor which requires external storage, peripherals and other devices to make it a viable device.
- (b) The combination circuit which will have a microprocessor and some storage or some peripheral on the chip, but requires other circuits for a viable system to be made, thus reducing the external circuitry from 8-10 devices to 4 or 5.
- (c) The complete microcomputer with processor, storage and interface on chip, which allows, at least in simple systems, a complete processing device using just a single component.

In terms of complexity a mid-range 8 bit microcomputer has 5000 transistors, while a more advanced product, like the 8086, will have 15000 transistors. Similarly, of the single chip microcomputers the 8048 has around 9000 transistors and the MOSTEK 3870 which has a 2K-ROM (which will increase to 4K) has some 15000 transistors per chip. Looking into 1980-82 it is reasonable to expect a 16 bit microcomputer with 32K bit memory. All this will happen at highly competitive prices. Already the price of a microprocessor can be as low as \$ 5 and by the 1980's the industry will be aiming to ship microprocessors to high volume customers for as little as \$ 1.

In fact, the implications of the effect of a processor on memory developments where the 3870 is being called by MOSTEK, an intelligent memory, may be even more profound. Indeed, Barron predicts "that within a 10 year period the microprocessor will become the dominant means of marketing LSI." Further, microprocessors will also effect the custom design approach to markets. As these high volume, low cost microprocessors become available the difficulty and high cost of producing a special design on silicon to meet a customer's requirements and bring it to the market will render this solution progressively less attractive. The semiconductor industry is more and more becoming a high design cost, high volume industry, so there will be fewer custom design products at competitive prices. These factors are going to have significant implications for IC manufactures in terms of the market they can address, particularly, if they are hoping to complete in LSI without offering microprocessor capability.

**SYSTEMS PROGRESS IN HIGH SPEED COMPUTING**

Advances in computer systems have also come up as a result of significant improvements in many of the supporting system elements. Thus, printing speed has increased from 150 lines per minute to over 10,000 lines

per minute. Similar ratios of improvements have taken place in Disc access times and tape data rates. In software one has seen a progression from assemblers through compilers to complex control programmes, including data management, queue handling, and other features. Advances in architecture and machine design techniques such as virtual machine and concurrency in toto produce high performance systems with improved reliability along with reduced cost and space.

These improvements have resulted in systems whose performance is measured in MIPs (Millions of instructions/second) whereas in the early sixties, they were measured in KIPs (thousands of instructions/second). In scientific applications even greater improvements have taken place, particularly, in those special applications areas where parallel/array processors or multiple interconnected processors (see Fig 18) can be used, where performances will approach the BIPs (billions of instructions /second range).

**Machine Organisation**

Figure 19 shows the improvement in machine cycle time, which has been achieved from 1960 to the present day. This improved performance has been achieved while maintaining the ability to do complex functions within that cycle.

Another well known technique for using hardware concurrently is that of pipelining. Here a much used

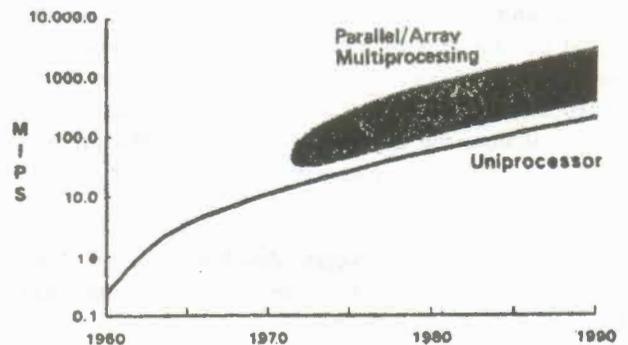


Fig 18 Uniprocessor and advanced configuration performance

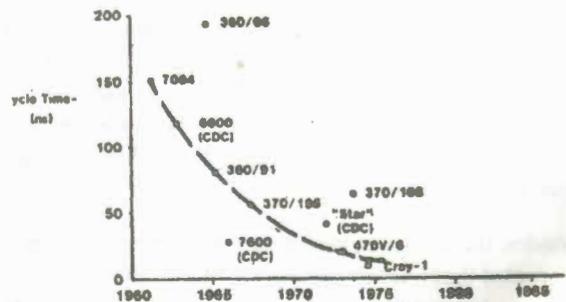


Fig 19 Machine cycle time

process, such as utilized in executing instructions is subdivided into its key elements. (Fetch, Decode, Address Generation, Operand Fetch, and Execution). This provides a means by which a pipeline flow is established, where each stage can be operating concurrently on a different instruction. Thus, when working well, instructions will complete at a rate determined by the dedicated function design rather than the time required to execute a single instruction.

### Operational Techniques

Additional/techniques had to be developed to allow these concurrent approaches to operate efficiently, within the confines to the code being executed. Look ahead and buffering techniques were established to isolate these mechanisms from the effects of a main memory request. An instruction stack with the appropriate mechanisms to keep it full provides a inventory of instructions and a series of store buffers isolates operands from memory. Buffering units allow a queue of work to develop thereby improving concurrency and smoothing overall work flow.

Disruptions to the flow in highly overlapped, pipelined machines can reduce the benefits possible from hardware design. Thus, branching and interrupt can cause disruption, for which suitable techniques for circumventing the problem are being developed.

### Impact of Evolution

Evolution in machine design has enabled the utilization of more and more circuits to efficiently increase the internal performance of a general purpose uniprocessor, from the straightforward use of wider data paths to the sophisticated use of pipelining, concurrency, and branch table prediction, the designer is advancing the product performance range compared with what simpler designs can provide.

Over the past 20 years developments in both components and systems have resulted in a greater than 100 times reduction in the processing time and cost of a given unit of work. In turn, there has been a 16000 fold improvement in cost/performance over this period. This progress will continue in the future as the productivity improvements referred to above are realised.

It is interesting to note that while improvements in commercial processing can be mainly attributed to improvements in semiconductor component technology, high-compute processors have advanced by combining this same technology with advances in machine design previously mentioned.

Besides, the advances in software described above, it is also expected that microprocessors will also make inroads into high-end computing. While today, the microprocessor is limited to relatively low performance, the use of bipolar

technologies will significantly enhance this performance. The extent to which they will penetrate high-end computing is uncertain, but it is likely that at least in parts of high performance systems their use could be both expedient and useful. Similarly, in other parts of the system, such as the communication area, the printing subsystem, and terminal system the use of LSI in the form of microprocessors, as well as directly in memory and random logic has given rise to increased capabilities which are replacing older electro-mechanical techniques.

### FUTURE DEVELOPMENTS

Technology will proceed in two directions-low cost and high performance. These two approaches are not mutually exclusive. In fact, the same design parameters determining success in one area are fundamental in the evolution of the other. To achieve lower cost, chip density must increase and therefore linear dimension must decrease. The same is true to achieve performance, but the design points are different for the two application areas, for example, power and circuit configurations.

It can be shown that for minimum cycle time the critical path should be all on a single chip. Today's high performance machines have about 20% of a critical path on a chip and the integration level must increase by one or two orders of magnitude before this design criterion can be achieved.

Similarly, component optimization and selection for higher performance systems to meet fast cycle times is complex. Many factors will inter into this process. Some key ones are speed-power product for a given technology, along with the preferred packaging & cooling approaches to follow.

### TRENDS

As in the past, future product advances are most likely to occur in areas where an overlap of both technology and system improvements is beginning to take shape. In technology, substantial progress is being made in logic density, lower cost memory and new serial storage devices. High-performance system design techniques continue to evolve, and experience with operating array/vector and parallel processors has started.

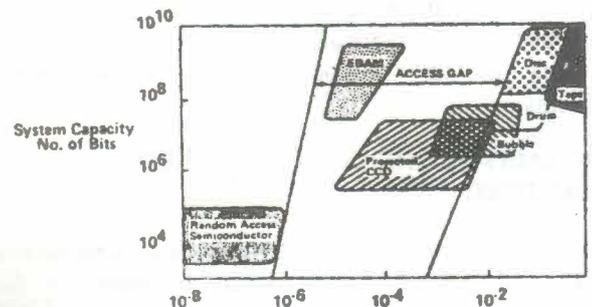


Fig 20 Storage technology comparisons

I would like to say a few words on serial storage technology like CCD, magnetic bubbles, and electron beam addressable memory.

Both CCD's & Magnetic bubbles are dependent on the manufacturing capabilities established for semiconductors. Therefore, progress in silicon technology will directly affect progress in these technologies. Projections are being made that the cost/bit will decline rapidly and offer a cost *advantage* of 3 to 10 over semiconductor RAM. These new technologies may make different storage hierarchies more economical than the structures of today and provide simpler approaches to managing overall storage. A comparison of different storage technologies can be seen in Fig 20.

## CONCLUSION

The symbiotic relationship between semiconductor component technology and computer development has resulted over the past twenty years in remarkable changes in both these fields. This dynamic interaction between the two will continue both in the field of low-end as well as high-end computing till well into the future. Development in silicon technology is likely to continue at the same pace

before physical limits set in, some time in the late 80s. Possibilities of even higher performance circuits using Josephson junctions may become practical in about a decade from now. The effect which the microprocessor is likely to produce on society will be both profound and pervasive. As mentioned earlier this development will be mutually supportive to development in high performance machines. Altogether these developments will combine to provide new and wider applications on an unprecedented basis in time to come.

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# Multi-Institutional Projects for Development of Electronics in India

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## INTRODUCTION

I am honoured by the invitation which the President of the Institution of Electronics and Telecommunication Engineers has extended to me for delivering the 12th Bhabha Memorial Lecture.

I had the privilege of associating with Dr Bhabha in the Bhabha Committee, which prepared the first blue-print for action to develop electronics in India. He was a man of unique vision not only in the field of nuclear and cosmic ray physics, in which he made his mark as a scientist, but also in the broader sphere of scientific and technological development.

Having been a creative scientist himself, he had a passionate belief and abiding faith in the creative energies of the Indian scientists and engineers. As Dag Hammarskjöld has said in his posthumously published book, "Markings", "Our secret creative will, defines its counterparts in others, experiencing its own universality, and this institution builds roads towards knowledge of the power which is itself a spark within us."

It was this empathy for the creative spirit in the newly independent Indian nation, that led him to take on challenging tasks in advanced areas of technology. In fact, his multi-faceted personality extended beyond science and technology into art and aesthetics. Paintings and sculptures inside the Tata Institute of Fundamental Research, and the garden outside, stand testimony to his aesthetic sensitivities. Referring to his diversified talents, once the late Dr S S Bhatnagar, jokingly remarked in a meeting in the presence of Dr Bhabha, "*Sab kuchh diya Bhabha ko siwai bhabi ke*" (God has given everything to Dr. Bhabha except a wife). Indeed he applied his great talents to all the tasks that he undertook with single-minded zeal and devotion.

## Dr Bhabha's Philosophy of Self-reliant Development

One of the outstanding features of the Bhabha Committee Report was its stress on the need and advantages of self-reliant development of technology. With specific case histories, it was brought out that import of technology often has a built-in element of obsolescence.

The technology of today is either not available or is too expensive.

Import of know-how as well as indigenous R&D have a fine structure within each grouping. For instance; technology transfer from abroad can be in the form of (a) licensing of patents, (b) import of machinery, (c) exchange of scientists and engineers under bilateral or multilateral programmes, (d) equity participation, (e) consultancy, etc. In the earlier phases of India's development, there was a greater stress on turnkey projects. However, as the indigenous capability grows, turnkey projects would not be the preferred choice. Optimisation choices would be the right approach at each point of time, and would represent the golden mean between a total dependence either on imported know-how or indigenous R&D.

Another recurrent theme, in the Bhabha Committee Report, was a technique for bridging the technology gap, through "leap frogging". It was recognised that technology does not necessarily develop in a simple linear fashion, but quite often has a meandering path. Nations that come on the scene later, can take advantage of this and bypass some of the intermediate stages of technology, thus picking up the latest trends of technology which are on the upswing. This can be done only when there are active research and development teams, which not only monitor the progress elsewhere, but also develop a basic competence of their own. They can in this way take advantage of any new technological breakthrough, and also generate new ideas of their own.

For each development effort, it is generally considered desirable to have a certain minimum critical level. This level is a function of the degree of sophistication of the product. Keeping this in view many advances in the areas of consumer electronics, agro, medical and industrial instrumentation can be taken in hand by industry through their in-house R&D. This will make it possible for the national laboratories and other Government funded organisations to move into such areas of research, where industry may not be able to put in the requisite level of funding. In this way, the industry would find it easier to move into them later on, with the help of public support received through the laboratories.

For a country like India, with an advanced

infrastructures of research and development and of industry, there are many options. It is also to be recalled that in most countries, an investment of 10-15% of turnover in R&D, is the usual practice in the field of Electronics. For a turn over of 1500 crores/year, this would mean an investment of 225 crores/year in R&D, and for 3000 crores/year, this figure would be 450 crores/year. Thus viable efforts can be put into fairly sophisticated areas.

In advanced countries, know-how transfer is often by rights on patents, and where patents are not involved, by recruitment of personnel and horizontal transfer of technology. The United Nations Development Programme has also such features as make it possible to procure equipment, experts and training facilities. These along with multi-institutional projects offer many options.

Let us look at a few cases of what has been possible and what could be achieved in the future.

### THE ROLE OF MULTI-INSTITUTIONAL PROJECTS

Such collaborative projects open up a way for achieving larger objectives than can be achieved by single institutions. One of the achievements mentioned for the programme of landing a man on the Moon, was the methodology of combining the efforts of a large number of institutions, to achieve challenging technological objectives in a given time frame. On a smaller scale, there are some examples of multi-institutional collaboration in our country. There is scope for many more such collaborative projects. First of all, I would like to share our experience on some, that I know about.

#### Electronic Control System for Diesel Electric Locomotives

This was collaborative project sponsored by the Bharat Heavy Electricals Ltd. (BHEL) at CEERI. The testing and

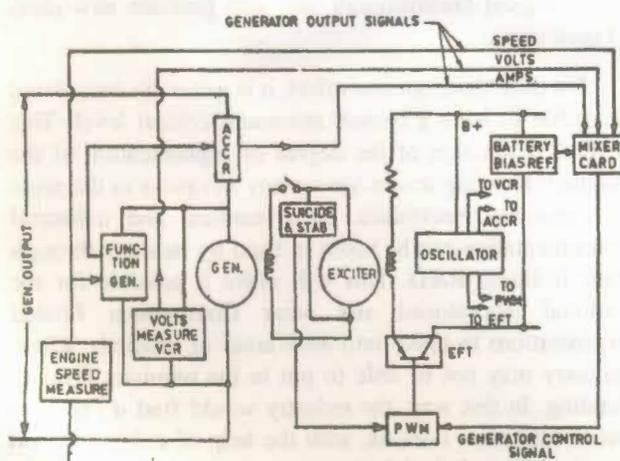


Fig. 1 Schematic diagram of excitation control system for diesel electric locomotive – a multi-institutional project

field trials of the equipment developed at CEERI, were done by Diesel Locomotive Works, Varanasi, and it was manufactured by Electronics Corporation of India Limited, Hyderabad. The development project involved indigenisation of an imported design, in which the electric generator of a diesel locomotive is controlled through its exciter field, which is in turn controlled through the current passing in the field coil of the exciter, as shown in Fig1. The various parameters like voltage, current, engine speed, etc are fed into a pulse width modulator, which controls the field current through a power transistor.

A measure of the success of this project, was the confidence generated among the users. The Railways sponsored a further project on Thyristor Inverter for electric locomotives, which is now nearly complete, and undergoing trials with the help of the Railways Design and Standards Organization. It will be given to Central Electronics Ltd. (CEL) for manufacture.

BHEL has sponsored a project on Inverters for Mining Locomotives. This development can also be used subsequently in electric cars.

#### Instrumentation for Sugar Industry

In the formulation of this project, right from the start, there was association between CEERI, National Sugar Institute, Electronics Commission, Ministry of Food and Agriculture and the sugar industry. The areas where electronic instrumentation would be most fruitful were chosen by the sugar technologists. Priority was given to juice clarification stage and the pan boiling stage. Schematic diagrams of the two sub-systems are shown in Figs 2&3. Field tests show the closer control over pH achieved by the instrumentation at the juice clarification stage and the reduced time for the pan boiling stage achieved through conductivity meters. Industry has participated enthusiastically in the field trials. The programme is being extended to temperature monitoring and controls relating to other functions in sugar industry.

There are other promising areas for similar work. For instance, instrumentation for Tea industry can have a large impact. A proposal for this has been prepared in collaboration with the Tea Research Association by the Central Scientific Instruments Organisation.

Electronic instrumentation can be used to improve quality and productivity in jute industry, leather industry, steel industry, textile industry and chemical industry. It would be advisable to form collaborative teams, which include the design and consultancy organisations of these industries, as well as design, development and manufacturing organisations of electronic instruments.

#### Scanning Electron Microscope (SEM)

As the name implies, an SEM has a finely focused

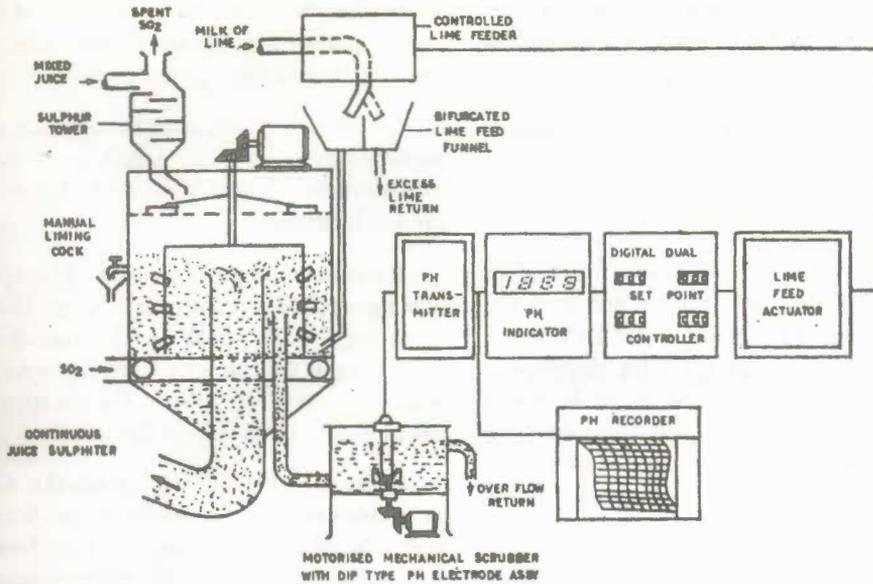


Fig 2 Automatic liming and pH control system for continuous juice sulphitation process in sugar industry

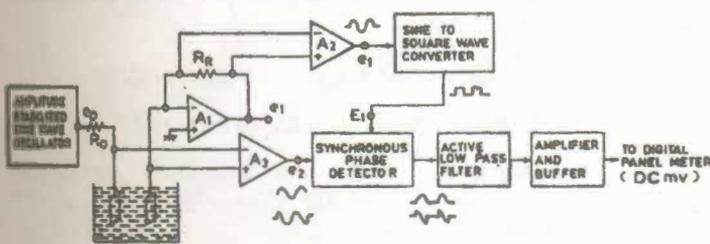


Fig 3 Block diagram of the modified bridge method of conductivity measurement with direct reading capability for use in PAN boiling stage in sugar industry

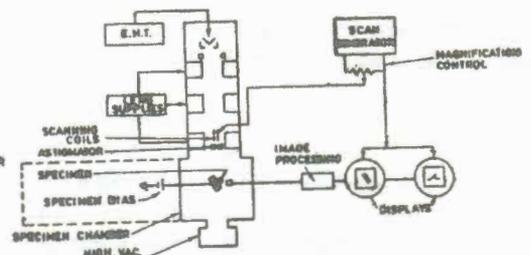


Fig 4 Schematic diagram of a scanning microscope being developed as a multi-institutional project

electron beam, scanning the sample. Figure 4 shows a schematic diagram of an SEM. Secondary electrons, or X-rays or other varieties of radiation given off by the sample, are detected, suitably amplified and presented on a TV like screen for viewing or photography. Not only does the instrument have higher capabilities of resolution than an optical microscope, but also it has much larger depth of focus for the same magnification. It is being put to many uses in research and industry.

A proposal for developing an SEM with the combined efforts of three national laboratories, was first prepared in the Coordination Council of Physical and Earth Sciences Group of CSIR Laboratories. There was a division of tasks proposed between CEERI, CSIO and NPL.

The project received a considerable boost as a result of support by the Department of Science and Technology through its Science and Engineering Research Council. At that stage, there was also induction of new members of the team, namely, the Banaras Hindu University and Central Electronics Limited. The inclusion of CEL was a notable feature, in that an industry that was later to productionise

the model, was associated with the development work right from the start. In subsequent phases, active co-operation from IIT (Delhi) and BARC was also obtained.

The first model was assembled at CSIO. Now others models are being assembled.

The fabrication of these models has also opened up further directions of development. These have been identified by the Co-ordination Committee, as X-ray Micro-Probe Analyser, Auger Scanning Electron Microscope, use of TV scan rate, etc.

Furthermore, an opening has been made into the field of electron and ion beam techniques. But of this, more later on.

### ACTIVE DEVICES

The two broad families, namely, electron tubes and semiconductor devices, are often referred to as active devices. It has been our experience that current technology of active devices is generally more difficult to obtain, and also more costly than for other electronic items. Active

devices perform key roles in all electronic systems. This is a critical area in which we do not have much of an option except to be self-reliant.

A few examples of alternative approaches and possible collaborative projects are mentioned next.

### Hybrid Integrated Circuits

This represents an example of leap frogging in technology, with support from Government and from the United Nations Development Programme (UNDP). In the past, people often referred to the need for developing professional grade components for use in professional equipments. As far as most resistors and capacitors are concerned, this requirement is now susceptible to a fresh look in the light of the development of hybrid circuit technology.

Thick-film circuits provide good reliability, and in fact, can be used in the most exacting environment such as that of space. Furthermore, thin-film circuits can give accuracy and stability of the highest order, such as may be required in instrumentation. Thick-film circuits can handle small signals as well as medium power levels.

The variety of inventory to be maintained in the case of discrete devices is largely cut down, and only a few varieties of substrates and thick-film pastes have to be maintained. Keeping in mind the cost of holding multiple inventory, this approach also holds promise for cost reduction. This is an opportunity for India for leap frogging of the type mentioned earlier.

It is also an example of technology transfer through the purchase of equipment and through bilateral and multilateral exchange programmes. For instance, facilities for thick film circuits were set up in Bharat Electronics Limited and Indian Telephone Industries with imported equipment, with financial support from the Department of Electronics. At CEERI, the facilities have been set up partly through Government funds, and largely through the assistance of a United Nations Development Programme project. Apart from fairly modern facilities, the technology at CEERI has been updated by acquiring services of 4 consultants who came from UK, Germany, France, and Japan. Training was arranged for its scientists in Europe and USA.

Thus, with all this, CEERI is able and willing to assist industries, in setting up their own facilities. Alternatively, circuits can be developed, and pilot runs made for them. This area of technology is an example of how the next steps can be taken without the need for import of turnkey know-how.

### Large Scale Integrated Circuits (LSI)

Developments in integrated circuit technology, have resulted in a doubling of number of components per chip

every year. With this, the complexity of the functions that can be performed, has been increasing, and the cost per function decreasing rapidly.

Consequently, integrated circuits are having increasing applications. Electronic watches, hand-held calculators, micro-processors and semiconductor memories are high growth industries.

It has been pointed out by the Managing Director of a leading public sector company that purchase of technology in the field of LSI, turned out to be rather frustrating as the amounts asked for, were very high, of the order of millions of Dollars. The question which arises, is, has India missed the bus in this field?

In my personal opinion, I think that the situation is not as irretrievable as one might think. What it needs is to make use of the initiatives that have been already taken, and pool the resources of the different institutions to which inputs have been provided. For instance, the Technology Development Council of the Department of Electronics has provided the following support to forward-looking projects in this area:

1. Computer-aided design-Rs. 3 lakhs to TIFR.
2. Mask making facilities-Rs. 79 lakhs to BEL.
3. Integrated circuits and manpower development programmes at the IIT Kanpur, IIT Madras and IIT Delhi.
4. UNDP project on "Advanced Technology in Semiconductor Devices at CEERI: \$ 1.7 million by UNDP and counterpart funds by the Govt. of India.

There is a great potential for development of this technology if manufacturing organizations such as the Semiconductor Complex Limited (SCL), Bharat Electronics Limited and Electronics Corporation of India Limited work hand in hand with the research and development organisations in the country. An example of such proposed co-ordination is between SCL, IIT (Delhi), TIFR and CEERI. Many more such possibilities exist and are under negotiation. These efforts could be supplemented by import of technology, where there are gaps.

### Ion-implantation

New breakthroughs in technology are taking place in the area of semiconductor devices, so as to improve the yields and the performance capabilities of a variety of devices. One of the main ones is ion-implantation as a means of doping. Its advantages are a close control over the profile, greater uniformity, a clean vacuum environment for the wafer during the process of doping, ability to implant through thin passivating layers, lack of lateral spread, and availability of a variety of dopants. After implantation, the substrates have to be annealed in

order to remove lattice damage and bring the dopant atoms to active sites.

There is competence available in the country for development of ion sources, such as at the University of Kurukshetra, high voltage supplies at BARC, deflection systems at CEERI and vacuum system at NPL. Some experimental machines and sub-systems have already been developed in the TIFR and BARC. With this as a base, industrially engineered machines could be developed for various areas, especially for those engaged in research and development.

CEERI is willing to ion-implant samples for research groups in the country, on its ion-implantation machine. It has a capability of accelerating ions upto 200 keV, with beam currents of the order of 50 to 100  $\mu$ A. Presently a Boron and Phosphorous are available as dopants.

### Electron Beam Pattern Generation

This represents another front line area of development in the field of semiconductor devices, which falls in the general heading of ion and electron beam techniques. Use of electron beams makes it possible to define features in a mask, down to sub-micron dimensions. This is not possible with the help of light beams because of diffraction effects. Apart from fine resolution, this technique has the possibility of ensuring fast turn-around time for generating masks for newer devices.

Apart from generating masks, this method is now being used for direct writing of patterns on wafers. This makes it possible to correct for distortion which a wafer may suffer, in going through a heat treatment process such as diffusion. In order to make the process economical, it is necessary to complete the exposure in a very short time. The time depends upon the degree of complexity of the pattern. It can be reduced to a minute or even less, for wafers of the order of 10 cm diameter, through the use of special techniques of beam shaping. Basically this involves the use of beams of variable dimensions or shapes of commonly used cross-sections.

Using the masks which may be generated by an electron beam apparatus, duplication of the pattern on to wafers can be achieved by the use of X-ray lithography. This gets around the problem of diffraction of light, by using wavelengths of the order of 8 Angstrom units.

In order to stay abreast of developments, this is one of the areas in which work can be very fruitful in the long run.

At CEERI, a beginning has been made in studies of electron beam pattern generation. Thus first steps have been taken in developing hardware for generating a menu of shapes.

### Charge Coupled Devices

These devices are becoming important for signal processing, for memories and as imaging devices. By

applying a sequence of voltages to a set of electrodes deposited on the surface of the devices, charge is transferred from one potential well into another. The charge carries either digital or analog information. Each individual potential well can be made very small. The technology is constantly progressing, for making the efficiency of transfer and the speed of functioning of these devices higher and higher. There is competence at the Solid State Physics Laboratory, the Indian Institute of Technology, Delhi and other places for development of such devices.

### Surface Acoustic Wave Devices (SAW's)

In analog signal processing, this is another promising area of development. SAW's are being used in communications, radar and in colour television sets. Studies in this area have been done at IIT, Delhi; IISc, Bangalore and CEERI, Pilani, among other places.

### Solidstate Microwave Devices

This is listed as another area of critical importance. The expertise exists at SPL, TIFR, CEERI, and IISc. There is a proposal for a combined project between IISc and CEERI, which is under consideration by the Department of Science and Technology. In the area of Impatt Diodes, there is already a co-operative programme between CEERI and the Institute of Radiophysics and Electronics, Calcutta.

### Fibre Optics and Integrated Optics

Developments in this area have opened up new vistas for communication of data, telephone and television signals. This is a promising area for a coordinated project of development, through collaboration of materials-oriented laboratories, such as CGCRI; semiconductor devices-oriented laboratories for developing the integrated optics, such as CEERI, SPL, TIFR and communications systems organizations, such as TRC. Such systems are now coming into increasing use, not only for public communications of both high density and low density, but also in specialized applications such as telemetry in industrial controls power systems, data communications in aircraft and ships, submarines, etc. The system offers advantages of reduction in materials cost, immunity against interference due to induction effects, greater security and increased distance between repeaters.

### Semiconductor Devices for Power Engineering

With the development of high power rectifiers, thyristors, etc for high efficiency handling of electric power, the needs and applications of these devices, have been growing rapidly. They are being used over a whole range of equipment starting from home appliances, to high voltage power transmission, power drives, transportation, industrial controls etc. The technology of fabrication of such devices involves a series of critical stages starting

with high purity semiconductor materials such as high resistivity silicon slices of large diameters. The processing steps involve deep diffusion over long periods or newer techniques such as thermomigration. This is a challenging area of technology opening up an opportunity for collaboration between industries such as BHEL and research organizations such as CEERI, to build up on the base of technology import that has been planned already. The opportunities for leap frogging in this area are presented by newer developments of uniform doping such as by neutron irradiation (resulting in nuclear transformations which end up by transforming a specific proportion of silicon atoms into phosphorous), life time control through irradiation with electron beams or gamma rays. Besides this, these devices are large area devices and require facilities for growing near-perfect single crystals of silicon with large diameter.

### Electronics for Transportation

Energy crisis also focuses attention on another area, namely, that of transportation. Here, there is a heavy dependence on fossil fuels whose resources are depleting rapidly. A dual pronged attack has to be launched on this problem. One is that of conservation of fuel in conventional vehicles through electronic control of ignition. Micro-processors can control the various parameters of combustion in internal combustion engines, so as to minimise consumption under varying conditions.

The second important task is the development of electric vehicles. In this, some of the tasks which would fall in the domain of electronics, would be inverters and control systems. They would provide an efficient means of drawing energy from the mains or from storage cells, to drive the motors which will be the prime movers for such vehicles.

### Photo-voltaic Cells as a Renewable Source of Energy

Because of the rapidly increasing cost of crude oil, there would be increasing need to develop renewable energy resources, such as solar energy. The development of photo-voltaic cells for converting solar energy into electricity, is a technology which has a great deal in common with the technology of the semiconductor devices.

Concerted action will have to be taken at several levels, namely, materials technology, device technology, sub-systems, and field trials of total systems. Coordinated plans of action will pay rich dividends.

Fortunately, considerable work has been taken up in a number of institutions in the country under the sponsorship of the Department of Science and Technology and the Department of Electronics. For instance, low-cost solar-cell-grade silicon material is being developed at

NPL, Fresnel lenses at the Indian Institute of Science, Bangalore and CSIO, concentrator type cells and tracking systems at CEERI. Large-scale field trials and use are being initiated by CEL and BHEL.

### Travelling Wave Tubes

CEERI has been developing expertise in the area of microwave tubes over two decades. A variety of magnetrons and power tubes have been developed and a beginning made on travelling wave tubes. Now the Indian Space Research Organisation has sponsored a project at CEERI. Coupling also exists with CEL for production of microwave tubes. In this area, a new industrial unit is likely to be set up. This will also provide an opportunity for implementation of a policy which has been often mentioned as the right way to combine utility of imported know-how with indigenous R & D. This involves association of R & D organisations with the import of know-how. In this way, based on the imported know-how further product diversification can be done.

### Millimetre Wave Tubes

These are acquiring new importance in respect of applications in remote sensing, radar, and plasma heating. Conventional tubes find it difficult to provide sufficient power and efficiency at millimetre and sub-millimetre wave lengths. The situation has been strikingly modified by developments of what are referred to as 'Electron Cyclotron Masers' (Some special members of the family are referred to as 'Gyrotrons'). In these, relativistic changes in the mass of electrons interacting with fast waves propagating in smooth bore guides, give rise to amplification and power generation in millimetre and sub-millimetre wave regions. Powers of the order of hundreds of kilowatts have been obtained.

### Many Other Areas of Fruitful Collaboration among Institutions

There are many other areas in which multi-institutional projects will ensure striking progress. These would include, radar and navigational aids, computers, laser systems, etc. A lot of detailed work would be needed for planning coordinated projects in respect of each of the systems. As a general philosophy, one could say that system analysis and synthesis could be left to the user groups. Sub-systems and special components can be given to laboratories which specialise in particular disciplines.

### An Opportunity and a Responsibility

A few days ago, we entered the decade of the 80's. This new decade would bring about a quantitative as well as a qualitative change in the electronics scene in India. In turn, because electronics is entering practically all facets of national life, this can be a substantial aid in bringing about economic and social upliftment.

It is well recognised that for a given amount of capital investment, electronics has a much larger turn-over and employment potential as compared to other industries, such as steel, petrochemicals, etc. It also has a vast untapped potential for developing exports. It is to be recalled that Japan built up its post-war economy initially on the basis of development of electronics and optimal industries.

The potential of a situation is realised only if we act in order to convert it into reality. In choosing our actual plan of action, we have to assess our strengths and weaknesses and the opportunities and threats that the environment projects. This is an exercise that has to be continuously updated.

A lot of ground work has been done on requirements and projections of the current Five Year Plan. Apart from the Plan Document generated by the Department of Electronics in September 1978, the Electronics Components Industries Association (ELCINA) has brought out some projections for a growth rate of a higher magnitude. Based on these, it is possible to work out detailed plans for the priority areas.

A finely tuned plan of action would be an essential ingredient for meeting the objectives not only of the Sixth Plan but also of further growth. The Science and Technology Plan of the Department of Electronics has identified 70 areas of research which need special attention. It is seen that in each of these areas, one would need to go through a further exercise of identifying the actual products and techniques to be developed. For instance, having identified high power electron tubes as an area, an actual action plan would further need the identification of the kind of specifications and performance that would be needed on a priority basis.

### Concluding Remarks

A systems approach in which the impact of our combined skills and resources in different institutions is maximised, will be the challenge of eighties. It will test not only our professional competence, but also our ability to

work in a coordinated way with team spirit. There have been successes in the past in this field and more will come. Example of Japan, which has some times been referred to as "Japan Incorporated" comes to mind. Their ability to work cohesively among various organisations including the Government, is one of the reasons for their spectacular success in post-World-War recovery. Furthermore, many companies there, get ahead with new products, through use of published literature, and recruitment of staff who have experience in that area.

India has the opportunity to create another economic miracle. In this, its developments in electronics will have a major role to play. It will be an even more significant example than Japan, for it will have relevance to the third world countries. The impact of its success will be felt in many other countries of the world.

The first half of the 20th century was a period of political struggle for independence. Political freedom was the most cherished objective and was achieved through the hard work and sacrifices of leaders as well as citizens. The outstanding personality and integrity of the national leaders and the self-effacing hard work of hundreds of thousands of our countrymen led to the achievement of political freedom.

The third quarter of this century was a phase of building up the infrastructure for our becoming a technologically developed nation with a self-generating economy. The last two decades of this century represent a unique challenge for bringing India to the front-line of developed nations. Those who work for such a Renaissance would no doubt earn glory and the gratitude of the nation. An example of such honour given in a foreign nation, can be seen in the numerous roads in Paris that are named after scientists and men of letters.

Dr Bhabha was in the forefront of the new revolution which has to come in India, if the success in the political field is to reach its true fulfilment. There is no better way to remember this talented son of India, than to dedicate ourselves to bring about the kind of technological revolution that he had envisaged.

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## Energy For The Future

HOMI N SETHNA

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**C**VILIZATION of man received its primary spark from the first fire lit by a primeval caveman. His subconscious realization that his life on earth was made possible by the energy received from the sun, made him pay obeisance to the sun through religious rites. The Sun God was worshipped by different races spread over the Eurasian Continent—the goddess Arinna of the Hittites in Japan in the East, to God Zeus in Greece in the West. The native legends of New Zealand describes that fire was borrowed from the gods. Greek mythology, which identifies Prometheus the Titan as the originator and supporter of mankind, cites his important act of stealing the fire from heaven, and giving it to man for sustaining his existence. Thus veneration of fire, simultaneously with the sun, was widespread in earlier civilizations. It is common knowledge, that fire is one of the important elements cited, both in the Hindu, Greek & Zoroastrian religious scriptures. Man realized, right from the start, that fire, or in modern terms, heat, played an important role in helping him to achieve a more comfortable mortal existence. Today's civilization is perhaps remaining at the same level, only the means for harnessing fire for its convenience being different described by the adjective 'Modern'.

Man's requirement of heat has continuously increased decade to decade. The caveman, at best, used 2000 kilocalories in a day. Soon man learnt to cook his food over a fire, and the early Hunting Man needed 5000 kilocalories per day, some of it in the form of firewood. The first agricultural man who lived around 5000 B.C. grew his crops with energy from the sun, as well as muscle power from domesticated animals he used to plough and level his field. Rough estimates place his daily heat requirement at 12,000 kilocalories. The advanced agricultural man of the middle ages aggregated a daily heat consumption of 27,000 kilocalories, 7000 for food, 12,000 in his home and commerce, and 7000 for his vocation. Compared to this, the per capita daily consumption of the modern European was 70,000 kilocalories, and that of an American 230,000 kilocalories in 1970, an astounding increase in requirement. If the trend in increase in energy consumption is maintained at the 1960-1973 rate of 5% per annum, all the presently known resources of fossil fuel in the world will be exhausted by the year 2010. Even if one assumes that the energy consumption remains stagnant at the 1976 level, the period can be stretched only to 2066.

Energy management experts have conducted extensive studies on the pattern of energy consumption in many countries. Several conclusions have been arrived at, which, if practiced, will stretch the use of fossil energy resources over a considerably longer period. For example, an average American utilises 41.5% of his energy requirement for his car. A doubling of the efficiency of his car, both by reduction in weight, as well as, advanced design, will save a considerable amount of fuel for his country. Similarly, if consensus is created in the public mind to employ mass transportation systems in preference to individual vehicles, a large quantity of fuel can be saved. A study in Germany has revealed that in transporting a single person over 100 km, the relative energy consumption of an automobile is 4 times that of a bus, twice that of a street car, 1.5 times that of a train, and nearly two thirds of that of an airplane. Thus bus travel appears to be least energy consuming for human transportation. One should keep in mind that one of the prime factors that dictates the volume and pattern of energy consumption is the lifestyle. A ton of aluminium needs 60 million BTUs for its production, whereas the same quantity of glass can be produced by the expenditure of only 17.5 million BTUs. Thus if instead of throw-away aluminium cans, glass containers are used, which can easily be recycled, a substantial energy saving can result. Another apparent area where energy consumption can be reduced is the field of illumination. The tungsten filament lamp which is used extensively in all house holds as well as decorative lighting has an efficiency of 5% as compared to more than 60% of Gallium Arsenide light-emitting diodes. If a breakthrough to reduce costs of this semiconductor device and to improve the spectrum are achieved, one could easily imagine the savings in energy.

An interesting aspect to note in passing is the close correlation between per capita energy consumption and the gross domestic product. In the USA, for the year 1972, per capita gross domestic product was, 5643 dollars, and the per capita consumption of energy was equivalent to 61 barrels of oil, both per annum. As compared to this, the GDP in Japan was 3423 dollars, and the equivalent energy consumption 21.2 barrels. If we take the ratio of energy consumption to GDP one finds that the ratio for USA is about 1.7 times that of Japan. The difference is an indication of the style of living but in an overall sense, the GDP and the energy consumption are closely related.

One can go on conserving energy by intelligent exploitation, but it is not possible to escape the fact that energy sources which are orders of magnitude higher are necessary for the existence of modern civilization. Some of these have been identified. As all of us are aware, energy from sunshine, geothermal sources, tidal and wave motions, ocean winds, and nuclear reactions can be usefully exploited for the long-term solution of man's energy problems. I propose to deal with nuclear sources in some detail, and examine in passing the others for completeness.

We shall first consider the utilization of solar energy. The solar energy reaching the outer layers of the earth's atmosphere is about 0.17 million million megawatts which is a staggering quantity. Around 30% of this energy is reflected back into space as light. Another 47% is absorbed by the atmosphere, land and ocean surfaces and converted into heat. The remaining 23% is used for the hydrologic cycle which is responsible for the process of evaporation, precipitation, winds, ocean currents and waves. A very small fraction supplies the energy for photosynthesis.

Solar energy is indirectly utilized in hydroelectric and wind power generation, extraction of energy from waves, and use of fuels such as wood. However, direct use of solar energy is at its infancy. Considerable progress has been made in the use of solar energy for low quality heat needed for heating homes and for hot water supply. Prototype power generating equipment, using good quality steam produced in solar concentrators have been built and studied. Direct energy conversion by use of Silicon Solar Cells has been experimented with and developed.

The most important drawback of solar energy is that it is not continuously available on the surface of the earth. Hence a storage device is a must if the collectors are located on the ground. The capital costs of such systems, irrespective of whether these are based on the heat cycle, or on the direct photovoltaic conversion, are very high as compared to fossil or nuclear systems. There are proposals to build synchronous satellite-based solar cell arrays, convert the power to microwave frequency by amplitrons, and transmit the same to earth at a fixed location. Two solar cell arrays, each 5 miles square, will ensure a continuous output of 10,000 MW at the earth's surface. Though the proposal looks rosy one can see the herculian efforts required to erect such a system in space. It is estimated that the cost of merely placing the components in space will amount to \$200,000 per kilowatt based on \$4000 per pound in orbit. It will require one Titan Rocket Flight every hour for 100 years to carry the components to the location. It is hence amply clear that such a proposal is impractical based on present day technology. To sum up, one could say that significant breakthroughs are necessary before solar energy can be made economical especially for the generation of electric power.

Geothermal energy sources are massive, and if

efficiently exploited can easily solve man's energy problems for all time to come. The heat is contained in the magma, which is molten rock deep below the earth's crust. Scientists have estimated that a total energy of  $6 \times 10^{21}$  kilocalories are stored under the USA assuming only a small gradient of 20°C per kilometre for 10 kilometres. If all this energy is fully tapped, it could supply USA with electrical energy for several hundred billion years. The main problem in exploiting geothermal energy is the identification of large heat reservoirs which can be economically tapped. The most notable of these are the steam fields in Lardello, Italy. The Geysers in California, and Matsukwa in Japan. The Geysers in California, which are being exploited for power production intensely, provide the feed requirement for the continuous generation of 522 MW of electricity which is being doubled shortly.

Hot water reservoirs are also available underground with temperatures reaching up to 380°C. These could be passed through heat exchangers to generate process steam. Low temperature water reservoirs can be used to power vapour turbines at reduced efficiencies.

There are hundreds of square miles of hot rock at temperatures between 300°C to 600°C at relatively shallow depths of less than 3 km. It is estimated that USA can be supplied power at the existing rate by use of this rock heat for a period of 50,000 to 500,000 years. However, the technology to harness this immense potential is not yet developed. One may have to employ nuclear explosives to create underground reservoirs where water can be pumped in to extract the rock heat.

Hydroelectric power, which contributes about 30% to the world's electric energy supply has a total potential of around 5.6 million megawatts. Only 8.5% of this potential has been tapped. It is, however, seen that even with 100% exploitation, if at all feasible, it is not possible to meet the total energy demands of future generations. Similarly, the world's total tidal power is estimated to be around 3 million megawatts, and only a small fraction of it is economically exploitable. Thus tidal power cannot be the problem solver for the future. Harnessing of wave power is a far cry, since the volumes to be handled are very large, as compared to the power output obtained.

Harnessing of wind power for generation of electricity, or to do mechanical work will not contribute greatly towards the enormous energy requirements of the future. A rough estimate of the total wind power available in the world is 100,000 MW. One cannot obviously cover the surface of our planet with wind mills to tap this energy.

Another important source of energy which should not be omitted from this discussion is the output one can get from heat engines which utilise the temperature difference between deep sea water and surface water. It will be advantageous to locate these stations above regions which have hot or cold ocean currents in order to increase the

temperature difference between the source and the sink. Typical temperature differences obtained will be around 40° F. At least one experimental station of a few megawatts capacity is being built in the USA. The large amounts of water to be handled may contribute enormously towards the capital cost for generating equipment.

I would now like to discuss the generation of power from nuclear heat. Nuclear heat is generated in fission reactors by the fission of a heavy nucleus like  $U^{235}$ ,  $Pu^{239}$ , or  $U^{233}$ . The fissile nucleus first absorbs a neutron, and the resulting excited nucleus splits into two lighter nuclei and releases about 2 to 3 free neutrons. The free neutrons can be absorbed by other fissile nuclei which again undergo fission, thereby initiating a chain reaction. If the rate of fission is maintained at a steady value by removing from the system free neutrons in excess of one per fission, a steady chain reaction results. If, more than one neutron per fission is allowed to contribute to the chain reaction a diverging chain reaction results. On the contrary, if less than one neutron per fission on the average takes part in a chain reacting system, the reaction dies down and the system gets shut down.

Enormous quantities of energy are released in the fission process. A single fission releases an energy of nearly 200 million electron volts. To get an idea of the enormity of this figure, a single gram of  $U^{235}$  which completely fissions will release an energy of one megawatt day. Several thousand kilograms of coal are required to produce the same amount of energy.

The basic materials used in a reactor consists of the fissile material called the fuel, a suitable coolant to remove the heat produced in the reactor, and controlled nonfissile neutron absorbers called control rods, which control the absorption of the excess neutrons, and hence the reaction stability. In thermal reactors, which are the most common types of reactors in the world, an additional material called the moderator is present in large quantities. The function of the moderator is to slow down, the fast neutrons which are generated in the fission process. The slowed down neutrons spend more time in the vicinity of the fuel due to their lower speed, and thus the fuel has a better chance to absorb these neutrons. Moderation has tremendous benefits, and cuts down the fissile fuel inventory required for assembling a critical system. In many cases, the moderator itself is the coolant.

A typical reactor system like ours at Rana Pratap Sagar, employs natural uranium as fuel, and heavy water as moderator and coolant. Each unit of this reactor is rated around 200 MWe, and needs roughly 30 tons of fuel to keep the reactor operating for a year. As the  $U^{235}$  in the fuel gets burnt to produce power, some of the  $U^{238}$  gets converted into  $Pu^{239}$  which is again a good fissile material. Depending on conditions, the discharged fuel can contain from 1 to 2.5 kg of  $Pu^{239}$  per tonne. Since  $Pu^{239}$  is a highly fissile

material, one has the option to use this fuel, either in a thermal or a fast reactor system.

A fast reactor system contains no moderator and the chain reaction is maintained purely by fast neutrons. Since fast neutrons stay near the fuel nuclei for much shorter times than a thermal neutron, it is necessary to increase the fissile material to increase the probability of their capture by fissile atoms. A reactor like the one at Rana Pratap Sagar could be built using natural uranium, which contains only 0.7% of the fissionable isotope  $U^{235}$ , because of the slowing down of neutrons by heavy water. On the other hand, a fast reactor will need a highly enriched fuel to sustain a chain reaction. Plutonium is a suitable material for fuelling fast reactors, and the heavy water moderated reactors are efficient producers of  $Pu^{239}$ .

A reactor needs structural materials to hold together the different components of the system like the fuel, coolant channels and control absorbers. The structural materials absorb some of the neutrons thereby reducing the number available for the chain reaction. In a fast system, because of the great speed of the neutrons, their absorption by the structural materials is low. Thus more neutrons are available for absorption in preferred materials. One class of such materials, called fertile materials, are extremely important. These materials are non-fissile, but generate a fissile material after absorbing a neutron, and undergoing radioactive decay. Examples of such materials are thorium and  $U^{238}$ . Thorium converts itself into  $U^{233}$ , which is a highly fissile material, and  $U^{238}$  becomes  $Pu^{239}$ . A fast reactor system can be designed so as to produce more fuel than it burns. These are called fast breeder reactors. The Indian Atomic Energy Programme envisages the creation of sufficient quantities of  $Pu^{239}$  from heavy water reactors built in the first stage. The plutonium so generated will be used to feed fast breeders in the second stage, and these will generate sufficient fuel to feed the reactors continuously. Thus breeder nuclear reactors can solve the energy problems for all time to come. The technology of breeder reactors, has not yet been perfected, but there is good hope of gathering the necessary expertise in this field before the turn of the century.

One may also breed fuel in thermal reactors, but with the type of thermal systems available, the breeding obtained is less than that of a fast reactor.

A discussion of fission reactors is incomplete without referring to the safety aspects of reactors. The Three Mile Island accident has opened a veritable Pandora's box of reactions against nuclear power. Many of the critics have indicated no solution except the banning of reactors for power generation. One can classify the risks of any system into two broad areas, the operation risk, and the public risk. The man days lost due to occupational risks in descending order for some systems and industries are as follows. Methanol, Wind, Solar thermal, Solar photovoltaic, Coal,

ocean thermal, hydroelectricity, oil, nuclear and gas. Contrary to popular belief, the occupational risk of a nuclear reactor is much lower than the one for many familiar industries. Again, in public risk, nuclear energy occupies a very low place. Coal and oil lead the list because of the emissions produced by burning of the fuel. Wind, solar thermal, solar photovoltaic, hydroelectricity, solar space heating, ocean thermal, nuclear, methanol and natural gas follow. The list for combined risk is again topped by coal and oil. The combined risk for nuclear systems is only more than that for natural gas.

There is not even one documented fatality from the nuclear industry because the volume of fuel handled is very small as compared to that of coal, and nuclear stations have extensive built-in safety systems to prevent casualties in the event of an accident. The fatalities in the coal industry in USA were around 120 per annum averaged over the last four years. The Three Mile Island accident has also brought out the fact that the radiation releases, actually taking place after a nuclear accident are indeed well within the statutory limits.

Looking at all these aspects one could conclude that exploitation of nuclear energy is almost a must for meeting the world's energy demands. The contribution of nuclear energy for electric power generation is increasing steadily, and is around 20% level in some countries like Switzerland, France and Japan. The USA and UK are close followers.

We will now discuss thermonuclear fusion reactors which hold great promise for meeting the energy requirements of mankind for all time to come. As you may be aware, nuclear energy released in a fission or a fusion reaction is the equivalent energy of the mass defect of the final products formed. In the fusion reaction, two light element nuclei, or two nuclei of a light element fuse to form a nucleus of a heavier element. The mass defect which results from this reaction manifests itself as an energy release. This is the basic energy source of the universe and its stars, including the sun.

The fusion reactions which can be exploited for generation of fusion power are confined to the fusion of the various isotopes of hydrogen. Two deuterium nuclei can fuse to yield a helium 3 nucleus and a neutron, and releases 1 MeV of energy. Or a deuterium nucleus can fuse with a tritium nucleus forming one helium 4 nucleus, one free neutron and releasing 17.8 MeV of energy. There are various other reactions, but the last one is the one most sought after since the threshold conditions for this reaction are more favourable.

Deuterium is abundant in the waters of the oceans. One deuterium atom is present for every 6700 hydrogen atoms. The fusion energy released by the deuterium contained in one cubic metre of sea water is roughly around 8000 billion joules. The energy one can obtain by the fusion of all the

deuterium atoms in the sea, is equivalent to the burning of 450 billion billion tons of coal, which is about one hundred million times the known reserves of coal. Thus fusion can solve energy problems for all time to come, provided, there is sufficient, technology development to harness it.

Fusion can take place only when the element is subjected to great pressures and temperatures simultaneously. The pressure required is a few hundred megabars, and the temperature to which the element is heated should be in excess of 100 million degrees Kelvin. To obtain net positive power from a fusion reaction, a condition known as 'Lawson Criterion' has to be satisfied. This condition states that the product of fusion fuel particle density and its confinement time must exceed  $10^{14}$  sec/cm<sup>3</sup>. In other words, if one can maintain a high particle density in the fusion reactor, the confinement times are low, and vice versa.

It requires no explanation that at fusion temperatures, the element is in the form of a plasma. To satisfy the Lawson Criterion, the plasma, which is formed by heating the element, would be confined for a minimum period depending on particle density, so that, net positive power condition is obtained. There are essentially two approaches which are being investigated today to satisfy the Lawson Criterion. The first concept, which will perhaps result in a practical reactor, employs magnetic confinement of a low density plasma. A machine to perform this function was first developed in the USSR, and is known by the name 'Tokamak'. The second concept employs compression or implosion of fuel pellets by either laser or particle beams to produce simultaneously, the high pressure and temperature requirements. Since the particle densities are high in this concept, the confinement times are small enabling exploitation of inertial forces. We may now examine these two concepts in some detail.

The Tokamak is a toroidal chamber in which the plasma is confined by the application of magnetic fields. The chamber walls are thus thermally isolated from the hot plasma. One set of field coils are wound around the hollow torus, as in a variac, and this produces a toroidal magnetic field. A magnetic field in the poloidal direction of the toroid is created by the induction of a very large current in the plasma from an external coil. An iron core or an air core can be used for this coil. The net magnetic field lines are in the form of helixes inside the toroid and this field confines the plasma within itself. Increasing the plasma current has a pinching effect on the plasma. Such schemes, where the current is distributed in the plasma, and the pinch effect increases with increase in plasma current are called toroidal diffuse pinch schemes. In most Tokamaks, the plasma is heated by the induced current in the plasma. We may note that the plasma conductivity corresponding to 1000 eV, or in terms of temperature 11.6 million degrees Kelvin, would be the same as that of copper at room temperature.

The Tokamak can be operated by pulsing the current in the plasma by induction. The particle densities achieved are of the order of  $3 \times 10^{13}$  particles per cubic centimeter which corresponds to a very low vacuum. Thus, to satisfy the Lawson Criterion which ensures that the fusion energy at least equals the radiation losses and the energy required to raise the plasma to ignition temperatures, the confinement time should be of the order of a third of a second. Confinement times of several milliseconds have been obtained and it is expected that the Lawson Criterion will be met in the near future.

The reason for the non-attainment of the requisite confinement times is due to the various Macroscopic and Microscopic instabilities in the plasma. One of these important instabilities is the Kink Instability which manifests itself when the poloidal field is increased beyond a certain value. Kink instability distorts the plasma, which may quench itself by coming into contact with the walls of the chamber.

We shall now discuss Laser and Particle Beam fusion wherein the densities of fuel are very high which results in a requirement of only very small confinement times. Thus use of inertial forces will adequately meet the demand of confinement times to satisfy the Lawson Criterion.

The basic principle of this process is to bombard the fuel material either with intense laser beams, or particle beams to create the necessary compression and temperature. An implosion is created in the fuel simultaneously with the rise of temperature to fusion level. The fusion energy output is extracted in the form of heat, and employed to drive heat engines to convert the heat into electricity.

The Los Alamos Scientific Laboratory in the USA is pioneering the use of lasers for fusion applications. The fuel, which is a mixture of deuterium and tritium gases, is filled at high pressure into hollow glass or metal microspheres which are submillimetre in diameter. The surface of the spheres is covered with concentric shells of metal or plastic to optimise the interaction with lasers. These spheres are known as microballoons, and some of the advanced filling processes involve cryogenics by which the material is allowed to deposit inside the glass sphere uniformly, either as a solid, or as a liquid. These spheres are inspected critically for defects. To achieve the fusion reaction, the microsphere is placed in a chamber whose walls are cooled by liquid lithium. Simultaneous bombardment by high energy carbon-dioxide lasers from all sides, implodes the fuel to a density of about 200 to 2000 grams per cubic centimetre. This is 1000 to 10,000 times the density of liquid hydrogen. Along with this compression, a temperature of 50 million degrees is obtained, and the fusion reaction takes place. In addition to removing the heat of fusion, the lithium coolant absorbs the neutrons released and converts itself to tritium which is used as fuel.

The largest laser fusion facility at Los Alamos is named Helios. It consists of 8 numbers of 1250 kilojoules carbon-dioxide lasers which can be triggered simultaneously to bombard the target with a total energy of 10 kilojoules lasting over a period of 0.5 to 1 nano-second. The power level for this short period is thus in excess of 20 terawatts. This laboratory is now working on a still bigger facility called Antares, which has a total energy content per pulse of 100 kilojoules delivered at 100 terawatts. This facility when completed in 1984 will most probably enable demonstration of the scientific breakeven, which means that the fusion energy output will equal the laser input. The lasers will occupy a total area of 8464 square metres. It is clear that more work will have to be done even after this experiment to scale up the use of lasers for a practical fusion reactor.

The Particle Beam Fusion concept is being developed by the Sandia Laboratories in the USA. The advantage of particle beams is that they can deliver much more of their energy content to the target. The efficiencies are typically 25% as compared to 1.8% for large laser system like the Antares. This does not mean that Particle Beam Fusion is much superior to laser fusion. There are problems in guiding the beam of particles and focussing them on the target with the required concentration. Also since the particles have a tendency to penetrate the fuel, the inside gets heated rapidly, and explosive forces which work against the densification effect are generated. This is being overcome by use of ions instead of electrons as the particles, since the range of an ion which is much less, allows the deposition of energy on the outer surface of the fuel.

The Particle Beam Fusion Accelerator being built by Sandia will have a total beam power of 1 megajoule delivered at a level of 8 terawatts. The facility is expected to be in operation in 1983. One may note that though the energy is large, the pulse width of about 40 nanoseconds is also large as compared to 1 nanosecond for laser systems. This brings down the peak power developed during the pulse.

One more fusion concept known as the mirror machine is also important. In the mirror machine, fusion reaction at a low level is allowed to take place in a magnetically contained plasma inside a long pipe. The two ends of the pipe contain fertile materials like  $U^{238}$  or  $Th^{233}$ . The neutrons produced in the fusion reaction convert these materials into fissionable fuels which can be burnt in fission reactors.

I have tried to cover briefly the different energy sources available for use for future generations. Solar energy, and geothermal energy are very abundant, but their tapping is made difficult and expensive due to the dilute form in which these are available. One cannot, however, rule out the possibilities of breakthrough which may make these

sources commercially exploitable. Nuclear energy sources are highly concentrated sources of energy and fission reactor systems have been very well developed for commercial power production. It is also expected that the work being done on fusion will result in practical reactor systems in the early part of the next century. This may be the permanent solution to all energy problems of the future.

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## The Challenges of Electronics in Defence

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I thank the IETE for inviting me to deliver this year's Memorial Lecture. I shall share with you my thoughts which I hope will form a tribute to the great Indian Scientist.

Dr Bhabha talked about India producing Rs. 3,000 crores worth of electronics goods. I leave it to you to decide where we have come in this technology today. In electronics, he found another option—an option to take country's technology to the highest level of competence. He also saw in electronics an escape clause for nations which have missed the first industrial revolution. Like all the ages—stone age, bronze age, the thought that perhaps silicon age was going to stay. He wanted our nation to be there as part of it.

I had an occasion to re-read his report again and I was awestruck by the care, by the audacity of intellectual planning this man had. For him, there was no linear growth—it was all geometric growth that he demanded of our electronic industry. He talked about—if I had extrapolated the curve and accounted for some kind of price escalation—he talked about India producing about 3,000 crores of electronics goods today. Today, the output is there before all of us. And this was when Dr Bhabha did not fully realize the implications for what he said in the beginning that he had abandoned the integrated circuits, the meticulous planner he was—he decided his dreams should take a second place because he did not realize by then the full potential of integrated circuits e.g. LSI the mind-boggling achievements that the silicon technology will thrust on the mankind.

Dr Bhabha argued that if you invest in iron and steel industry, the products value vs investment is mere 0.5, whereas in electronics, the product value is 2 times the investment value. Also, the employment potential was high e.g. with investment of Rs. 170 crores, 300-400 thousand direct or indirect, skilled/unskilled technicians and scientists receive employment. Therefore, he was always pleading for this technology with the government.

Dr Bhabha emphasized, that, in no circumstance, we should follow up the development of electronics industry as in the more advanced countries as it would entail production of obsolete components and equipment, obsolete production processes, and obsolescent thinking.

He recommended that the country should pay greatest heed to the defence electronics. It was he who said that electronics in civil and defence sectors cannot be separated: Electronics in public and private sector cannot be separate: Nation building activities in electronics should flow together. Therefore, when one reads this report, one feels pride—because there was this genius who thought about such things. He felt that one of the most powerful ways of exploiting the potential of electronics was through defence. It has reached a level—that when we want, seek, obtain, information, we have electronic systems that can sense, communicate, store, process, assimilate, compare, display and process it further. Having secured the necessary information, it would be very simple to initiate, control, guide and trigger a weapon so that enemy would think twice before attacking us.

Electronics has force multiplier effect in defence. Even if you do not have superiority in conventional armaments but if you do possess clever and more advanced electronics, your forces are automatically multiplied.

It is not an easy thing selling electronics in defence: defence itself is a very conservative element—very correctly so—for when you will pull the trigger, it must fire before the other guy fires at you first. When you fire a missile, it shouldn't come back at you again. In this context, one hesitated in going for very complex electronic systems—so complex that mind boggles at the amount of things put on a single chip. But that is the simplistic thinking. Running away from complex systems is like running away from modern life. Has it not been said in the *Bhagvadgita* that if you want peace, you don't have to go to forest—if you want noise, you don't have to go to the bazaar. You are what you are but be in equilibrium with your surroundings and it is the surroundings that electronics have challenged today.

When we try to do this, we notice that we still want to go back at the umbilical cord, wanting us to build small equipment because small is beautiful. But today's systems are very sophisticated—which do things at incredibly fast speed. One wants to put as much payload as possible in a missile and here again electronics helps smallest of the chips handle large amount of information so that in the limited volumes available, you can accommodate greater amount of payload—giving an almost extra degree of

freedom to the designer of weapons and weapon systems.

The electromagnetic spectrum has become crowded. Take for instance radars: the radars came into existence in II World War when Britain wanted to protect London against German war planes. Today, how sophisticated the radars have become! We have an early warning radar—the missile-tracking radar—the surveillance radar—the fire-control radar—the sea-borne radar—the millimetric radar—etc. But today every one of these radars has become ineffective! In this war of today, the radar stations before they are switched on will be inviting anti-radiation missile homing onto the radars. Before you switch on the radars today—the signals don't come but the nonsense or the jamming comes. The aircrafts today have stealth characteristics that make them extremely difficult for detection. Similarly, on the radar, you may be getting signals meaning that the enemy is far away but the enemy is really quite near and homing onto your station. The electronics warfare and the electronic counter measures—have changed the whole concept of war.

Let us assume we know our enemy and the frequency used by him—it is no secret—in fact we ought to be knowing. When we know the frequency of their operation—we switch on the frequency of our jammers. But the enemy will be agile enough to switch onto another frequency, or jump frequency, or spread spectrum or assume that in the midst of noise, he has the most sophisticated signal processing to make sense. This is no science fiction—look at the Falklands War—on May 4th 1982 morning—the Captain of *Sheffield* wanted to communicate routinely with London via satellite—but there was the nuisance of e.m.i. and so he asked the radar operator to switch off the radar. But just then there were aircrafts flying from Argentina—carrying excocet missiles. Again—a radar attached to the UK helicopter reported friendly emissions—the radio emissions were interpreted to be from a western country! Ten seconds later, these missions did not cease. Two seconds before the excocet hit them, they actually saw the missile straight coming onto them. At that time, there was no way to prevent or mislead them—no way to deceive them: it was too late! Thus by operating a superstar electronics technology on a superstar missile, a militarily second-rate country won a battle over a technologically first-rate country! In the end, the war was won by UK by using nuclear submarines, signal processing techniques, sophisticated communication & control techniques and ability to deploy night-vision systems. *Therefore, the war was won because of high technology, but the battle was lost due to low technology.*

In an other recent war in the desert, the missile system was alerted because some aircrafts were coming—the radar started operating: both the surveillance & fire control. Later, they realized there was no aircraft—it was a remote controlled pilotless vehicle. It turned back—carrying all the frequencies of radar as well as the fire control operations.

Thus persons manning radars are put to hard test—if they switch on the radars, they divulge their frequencies of operation and if they don't, they run the risk of aircrafts destroying the station. In the above desert war, most of the missiles and aircrafts were wiped out because there was no protection against frequencies. Why did it take place? Because, each one of the system was imported, installed and put in operation by foreign experts! So if you have to win today's electronics war, you not only have to possess sophisticated systems but these systems should be designed and developed within the nation: there is no security if all these things do not emanate from our laboratories and production agencies, public or private. When such a thing happens—a technology of quite confidence takes over—a technology which can totally revolutionize our thinking and our way of life.

Napoleon said that army marches on its stomach. Today the army marches on its communications—informing when the food is coming. If you look at the communications, we find that it is based on command—communication—and control—out of the CQ emanates the intelligence and we decide what action to take. This communication should be totally fool proof. There should be no deception, no jamming—the message must go across. The reliability should be near 100%. The nodal points have to be created in a hurry in the enemy territory. A nodal point might be incapacitated or destroyed by the enemy—but the system should be self-healing i.e. adjusts itself so that communications are not affected. The commander must have control over the man fighting at the front. Thus it is the communication technology that will determine how far can we go into extension of our army. Previously, one used to think that if we have that tank, gun, or, that missile, we will be superior to the enemy. Today, these things will be useless unless accompanied by reliable communication facilities. However, the same hardware will be extremely useful if we have excellent communication that will command and control the total operation. These communication systems should also be able to bear the extreme stresses and stains of the environment. We should also have capabilities of jamming enemy's communications. Our facilities of cryptography, artificial intelligence and pattern recognition should have reached a level that by the time the enemy commander receives a message, our interpreter should be able to debug the same.

In fact, we are working on a logic system: Is it advisable to jam an enemy communication, or, is it advisable to deceive him into thinking that we are not able to jam but quietly understanding his communication, deciphering it and taking the counter-measure? These are the mind-boggling challenges of the software combined with the hardware that will determine our place in the sun in a future war.

Take the instance of a tank. A tank must have three

things—it must be mobile—it should move with confidence and reliability—the tank should have the fire power—it should be able to fire most lethal shot that the enemy will be afraid of. The tank should also have immunity from fire by the enemy. But, today, these three traits are totally inadequate. We need a fire-control system, a system that can see an enemy even in the dark—the thermal-imaging system. We also need accurate control by the computer telling us what ought to be the trajectory of the weapon we must fire. We need automatic loading system—that electronically pushes the weapon. I would like to have the system equivalent to that in the aircraft, called, the hudavox system: In the thermal-imaging system, an enemy tank is pinpointed, the computer calculates the ballistics details, the automatic loading takes place, the gun fires, the enemy tank gets destroyed and our commander gets the kudos. This kind of a situation again is not science fiction! Such things are in actual operation in aircrafts. This did happen in a recent war, to a level, that one country's 50 aircrafts were totally destroyed.

It is not only true for army and air force that they march on electronics—it is true for navy also. Naval responsibility is enormous. The Indian Ocean is only Indian in name. We just do not have enough means to monitor what goes on there: the economic zone has made our country bigger by at least 50%. What means do we have to ensure that the marine wealth is available to our country alone? Again the ships and submarines must be equipped with the latest means of communication.

Have we achieved enough as dreamt by Bhabha? We have major production agencies—BEL, ITI, ECIL to name a few which are totally committed to production of sophisticated electronic equipment. Just a few days ago, I

had the proud privileged to watch an automatic electronic switch, designed and developed by an electronics research lab from defence at Bangalore and TIFR, Bombay. Both have been successfully productionized by ITI and BEL. An automatic electronic switch with the most sophisticated controls and options that you can ask for today is available in the country because of our capability to design, develop and manufacture. This is not the only instance. Consider the solar system recently designed in the country. This is no ordinary solar system: the signal processing, the image matching and the information-handling capability have few equals in the world—not to mention our neighbours. Also, the system which we have developed at LRDE has few equals as far as the low-flying radars are concerned. Now our laboratories are very confident and there is tremendous change in the culture which precisely Dr. Bhabha was pleading for—when he objected to the import of obsolete technology and associated obsolescent thinking. However, I must admit, we have a long way to go. We must assert ourselves as a nation to build up both hardware and software for our defence forces. We should not say that expenditure on defence is an unproductive expenditure. This argument can be forceful only if the country depends totally on foreign equipment. However, if the country has established, nurtured and sustained the nation's capability to design and develop the defence hardware, the overall development of the country gets boosted. We all know of example of a country which after the II World War was known for its perfumes and wines. Today, that country is known for its aircrafts, nuclear submarines, missiles, and also, perfumes and wines. Thus we must exercise this option of developing the systems ourselves and gaining confidence in their production. This will go a long way in realizing Dr Bhabha's dream.



# Role of Electronics in Fundamental Research

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IT is indeed a great honour and privilege for me to have been invited to deliver this prestigious lecture under the auspices of this distinguished institution. I have chosen the topic of my lecture as "Role of electronics in fundamental research". There are many reasons for choosing this topic. First of all, since this lecture is to commemorate Dr. Bhabha, I thought it would be appropriate to talk about fundamental research, since Dr. Bhabha was an outstanding scientist who had distinguished himself for his pioneering contributions in several aspects of fundamental research in the late 30's, 40's and the early 50's of this century. Secondly since the lecture is organized under the auspices of the Institution of Electronics and Telecommunication Engineers, I thought it should have some bearing on electronics and communication. The third reason is rather a personal one. My own career started in electronics in the late 40's. I did my MSc in Wireless from the Central College, Bangalore, which was then part of the University of Mysore and then spent a year at the Communication Engineering Department of the Indian Institute of Science, Bangalore, working on the generation and absorption characteristics of ultra high frequency radio waves. It has so transpired that I have spent the last thirty-five years at TIFR using electronics for fundamental research. A final reason for choosing this topic is that it gives me an opportunity to share with you some of the current excitement in the frontier areas of science which, as I will endeavour to show, has been the result of tremendous advances in the field of electronics.

Fundamental research can be broadly classified as under:

- (i) Life Sciences—biology, medicine, agriculture etc.
- (ii) Chemical Sciences—bio, organic, inorganic, physical.
- (iii) Physical Sciences—material sciences, nuclear, high energy.
- (iv) Astronomy and Astrophysics—planetary and geophysics.
- (v) Mathematics.

There is no area of science in which electronics does not play a role. In the life and chemical sciences area, the use of spectrometers, electron microscopes, lasers, X-ray machines is too well known. There is no experimental set-up now-a-days without a microprocessor control. All data has necessarily to be processed on computers. Even in the

area of pure mathematics, as illustrated in the solution of the famous "four-colored problem", computers have become an important tool. I will however demonstrate the use of electronics in research by confining myself to some areas of physics and astrophysics with which I am more familiar.

Investigations in high-energy physics, to take a specific example, require—

- (i) High-Energy Accelerators of charged particles
- (ii) Particle Detectors or Sensors
- (iii) Electronic Instruments
- (iv) Data Recording and Analysis Systems.

I am sure you are familiar how simple voltage doubler circuits and a set of condenser banks led to the construction of the Cockroft-Walton accelerator. Then followed the Van de Graaff generator, the Cyclotron, the Synchrotron, the Intersecting Storage Rings etc. In all these, the basic requirements are a high vacuum system, an ion source and the judicious use of electric, magnetic and electromagnetic fields to steer the particles into the proper orbits and accelerate them. To study the interaction of these particles and analyse the secondaries produced in the interactions and determine the parameters like the charge, momentum, energy, angular distribution etc. of these particles, we require various types of particle detectors. Finally, to analyse the data and come to specific interpretations and conclusions, we require the computers. I must emphasise that *one of the most important developments that has taken place with the availability of the sophisticated computers is the extensive use of the Monte Carlo Simulation Technique* which helps in the interpretation of diffuse multi-parameter dependent physical situations.

The particle detectors themselves are electronic devices or require electronic control. Most of the detectors depend on ionisation and discharge of electricity through gases. Among the gaseous detectors, we may list-

- (i) Ionisation chambers and proportional counters
- (ii) Geiger counters
- (iii) Spark counters and spark chambers
- (iv) Drift chambers
- (v) Neon flash tubes

- (vi) Cloud chambers (electronic control)
- (vii) Scintillation counters
- (viii) Cerenkov counters
- (ix) Bubble chambers (electronic control).

In addition, we also have solid-state proportional counters, and liquid and solid-state scintillation and Cerenkov counters which require the use of photomultipliers or image intensifying devices for recording.

In all these experimental set-ups, the common type of electronic circuits and systems that find use are:

- (i) Amplifiers—linear, logarithmic
- (ii) Oscillators
- (iii) Pulse-height analysers
- (iv) Analogue-to-digital converters
- (v) Logic circuits—coincidence, anticoincidence etc.
- (vi) Discriminators
- (vii) Time-to-digital converters
- (viii) Master pulse generators
- (ix) Sequencing and multiplexing units.



Fig 1 Victor Hess's historic voyage in space

In addition, one requires various types of test instruments like oscilloscopes, multimeters etc and recording systems—paper tape, magnetic tape etc. Data transmission and control by telemetry and telecommand systems and radars are very essential for certain areas of research especially in space research as we shall see later on.

*Sometimes, a very simple observation with a simple detector system becomes the starting point of a major discovery.* This is best illustrated with the discovery of cosmic radiation which has played such an important role in high-energy physics and astrophysics. It all started with the observation that a gold-leaf electroscope on which some charge was deposited, for some mysterious reason lost its charge even if kept in perfect isolation. The puzzle remained for almost 150 years. With the discovery of radioactivity at the turn of the century, it was thought that the leakage was due to ionization produced by the radioactive emanations from the earth. However, the real and most astounding solution came in 1912 when Victor Hess went up in a balloon carrying the recording instruments with him to an altitude of 4267m and showed that the intensity of the penetrating ionizing radiation first decreased with altitude and then started increasing thus disproving the radioactive theory. It soon became clear that the radiation was extraterrestrial in origin and was not due to the Sun also—it was coming from depths of space at all places, in all directions and at all times. Figure 1 shows Victor Hess getting ready for his historic voyage in space.

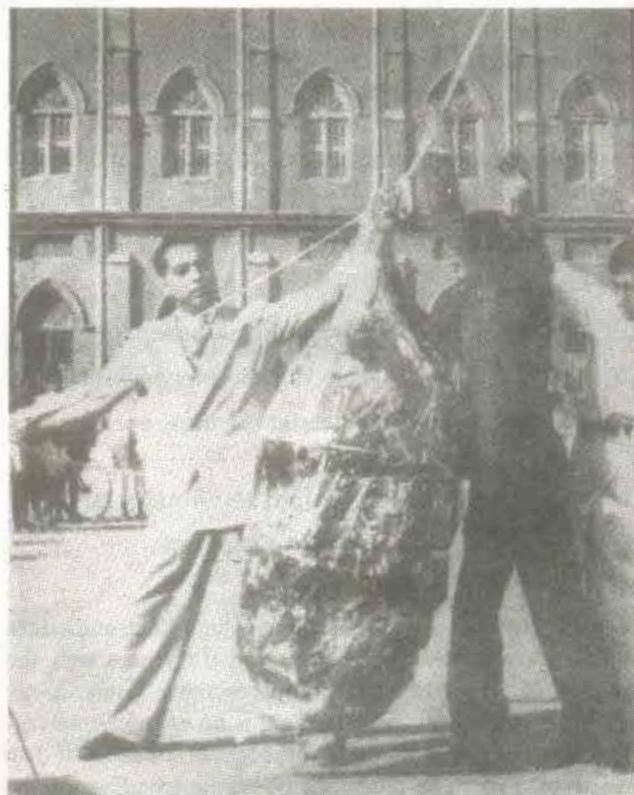


Fig 2 Dr Bhabha's experimental research

I would like to talk a little more on cosmic rays mainly because it is in this field that Dr. Bhabha made some very important contributions, and also initiated experimental research in this country (Fig.2). It was noticed early in cosmic ray research that occasionally Geiger counters separated by a few tens of centimeters in a horizontal plane gave rise to coincident discharges indicating the simultaneous passage of several particles. This phenomenon was beautifully explained by the famous Bhabha-Heitler Cascade theory according to which a high-energy electron in passing through matter would multiply into several particles due to the sequential processes of bremsstrahlung radiation and pair production or materialization of quanta into electron-positron pairs. A second feature that had been noticed in cosmic radiation was the presence of particles that could penetrate tens of centimeters of lead without multiplication or appreciable energy loss thus violating the well-established laws of Quantum Electro Dynamics which explained so well the cascade showers of electrons. Dr. Bhabha in a classic paper in the proceedings of Royal Society showed that the presence of the penetrating component in the cosmic radiation meant the existence of a new particle with mass value in between that of the electron and the proton. This particle, the mu-meson was later discovered in a cloud chamber experiment by Carl Anderson.

About the same time, the Japanese physicist Yukawa had postulated a heavy-mass particle to explain the nuclear forces between the nucleons inside the nucleus. This particle, the pi-meson, was discovered by Powell in 1947 and it was also recognized that the mu-meson was the decay product of the pi-meson. Cosmic ray research also led to the recognition of the act of meson production in high energy collisions through the use of cloud chambers and nuclear emulsions. Another remarkable feature of cosmic radiation was that it contained particles of extremely high energy. While the intensity of high-energy particles decreased as the energy increased, nevertheless there were particles of such high energy ( $\sim 10^{20}$  eV) that could never be produced in terrestrial accelerators.

Something very dramatic takes place in the atmosphere when one of these very high-energy particles enters from the depths of space. At an altitude of say about 20km, the primary cosmic ray particle which could be a proton, an  $\alpha$ -particle or a heavy nucleus interacts with the air nucleus and produces something like a hundred secondary particles—the dominant secondaries being charged and neutral pi-mesons. Some of the charged mesons as they travel down in the atmosphere interact again and produce more mesons. The neutral pions on the other decay into gamma rays and the gamma rays give rise to electron-positron pairs through the phenomenon of pair production and thus initiate chains of electromagnetic cascades. Each nuclear interaction further down feeds more high energy gamma rays which again multiply. Thus, by the time, these particles reach mountain altitude or sea level, their numbers would have

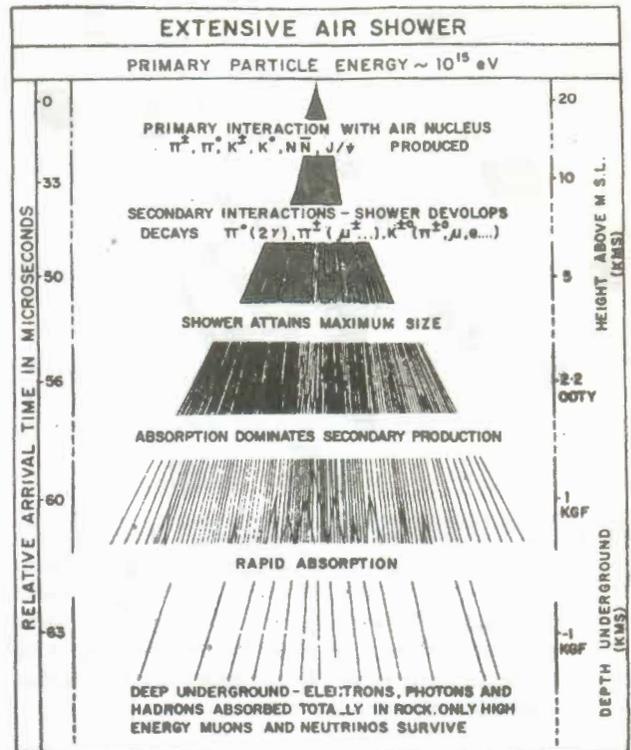


Fig 3 Extensive air shower

swelled to millions, even billions of particles and they would be spread over hundreds of square metres (see Fig 3). While the entire phenomenon takes about sixty microseconds to develop and propagate in the atmosphere, at any level of observation the particles will all pass through in a time interval less than a few tens of nonoseconds. This is where the power of modern electronics comes in. The details of the phenomenon known as "extensive air shower" can be recorded by arrays of counters—scintillation counters, spectrometers, cloud chambers etc., and the various special features of the radiation analysed. The shower contains electrons, positrons, photons, pi-mesons, nucleons, mu-mesons, *k*-mesons, neutrinos etc. These different components can all be sorted out and analysed by a variety of techniques. Figure 4 shows the array at Ooty for such a purpose that is operating day and night for more than two decades now.

Cosmic ray research and in parallel research at higher and higher energy accelerators revealed the existence of a large number—running to several hundred—of elementary particles, most of them highly transient in nature, living for less than a hundredth of a microsecond, nevertheless having distinct properties and identities. These particles ultimately decayed into the relatively stable particles like the proton, the electron, the neutrino etc. Some of them are highly interacting type and are called hadrons. The others are weakly interacting and generally of lower mass and are called leptons. It is really the number of hadrons that has multiplied into hundreds. However, very recent developments seem to show that the hadrons are composite

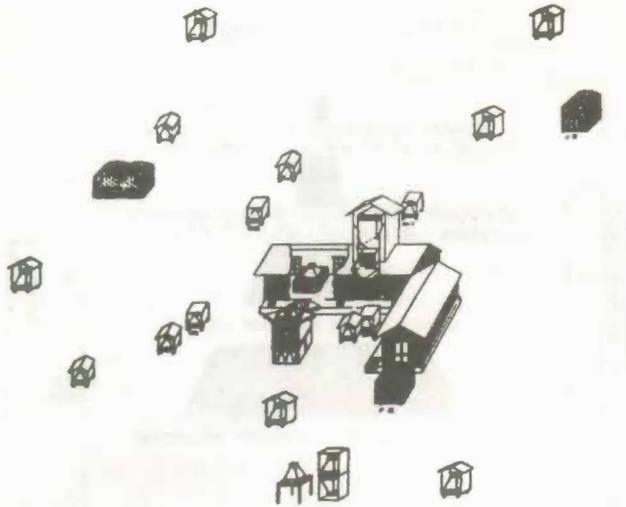


Fig 4 The layout of the Ooty extensive air shower array—which has scintillators, clouds chambers, spectrometers etc to measure the different components of the shower at an altitude of 2.2 km. Each small hut contains a plastic scintillator of one sq m. area. The main building at the centre has all the control instrumentation and the on-line computer and recording systems

particles—composites of more elementary entities known as “quarks”. So ultimately, the world is supposed to be made up of quarks, and leptons and radiation of photons. It is however necessary to have some additional particles called intermediate vector bosons, the gluons and the lepto-quarks to understand the interactions between the quarks, between the quarks and the leptons.

Now let me move on to another field where too, the application of electronics has led to important

developments.

Astronomy as you all know is one of the oldest sciences. Much of our knowledge concerning the universe has come through the observation in the optical window through the use of larger and larger aperture telescopes. With the advent of electronics apart from making observations at the telescopes more sensitive and more quantitative, entirely new windows of the electromagnetic spectrum have been opened up for observation.

Curiously, the vibrant field of radio astronomy was an accidental fall-out of a study of the noise level of a sensitive short wave radio receiver that had been coupled to a directional antenna. This discovery was made by Karl Jansky of Bell Laboratories and reported in the Proceeding of the Institution of Radio Engineers in the December issue of 1932. Jansky was actually listening to crackling noises in his receiver generally attributed to thunder storms. He noticed however a steady hiss whenever the antenna pointed to a particular direction in the sky—towards the centre of the galaxy. It soon became clear that the centre of the galaxy was a very strong radio source. Subsequently, many other radio sources were discovered in the sky and radio astronomy was ushered in as yet another astronomical vehicle for observations on the happenings in the distant environments of the universe. The picture (Fig 5) shows how a modern radio telescopes looks like—it is the one at Ooty that is operating for more than a decade now.

Radio Astronomy over the past fifty years has supplemented the knowledge concerning the universe in many ways. The discovery of the 21 cm line, the discovery

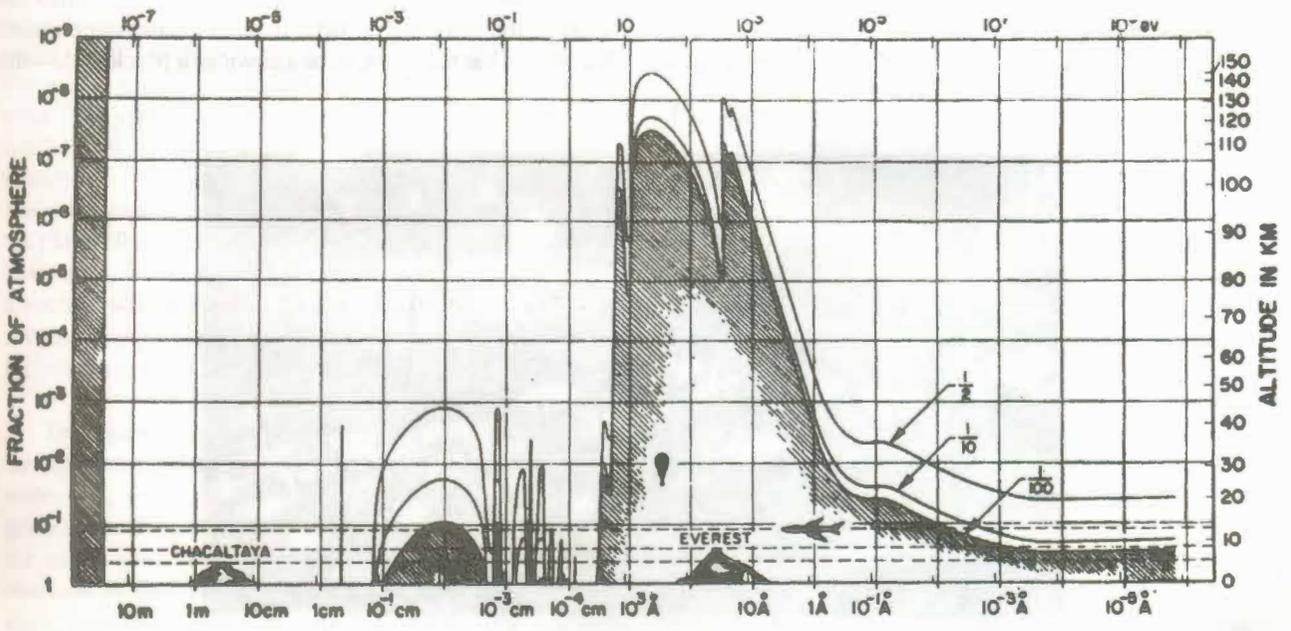


Fig 5 A picture of the Cylindrical Radio Telescope at Ooty—530 metres long and 30 metres wide along an N-S slope of  $11^\circ$ —the latitude of Ooty. It is steerable for 10 hrs a day in the 'E-W' direction. It operates at a wavelength of 92 cm

of organic molecule in interstellar space, radio stars, radio galaxies, the quasi-stellar objects known as quasars which are very powerful radio and optical sources almost at the edge of the universe, the discovery of pulsars which give out pulses of electromagnetic radiation at extremely accurate repetitive frequency are some of the major highlights of this area. A discovery of tremendous consequences particularly to the theories of the origin of the universe is the discovery of the existence of a universal microwave radiation—which has come to be known as the 3° K radiation. This radiation was again a chance discovery. The discoverers Penzias and Wilson used a 6.1m horn shaped antenna that had been built by Bell Lab engineers to detect radio waves bounced off the Echo Balloon Satellite. In the historic experiment, Penzias and Wilson eliminated all receiver noise by cooling it to a very low temperature of 4° K and their intention was to record the radio waves from the Milky Way. To their surprise, they found a residual hiss even at this temperature that was a hundred times more intense than expected. Moreover, it turned out that the intensity was the same in whatever direction the antenna looked. This extreme isotropy was crucial to the findings that this radiation was universal in character. It turns out that there are regions in the universe where the matter density is extremely low, less than a single atom of hydrogen in several litres of space, but the intensity of the universal radiation that has the characteristic black body of temperature 2.7° K persists at the same level everywhere. The existence of a universal microwave radiation of this nature can be beautifully explained in terms of the Big Bang origin of the universe and has thus become one of the strongest evidences in support of this theory.

Developments in Electronics and Space Technology have led to the advent of yet another new field that has come to be known as "Space Astronomy". In order to understand the importance of this field, let us look at Fig. 6, which depicts the attenuation of the different bands of electromagnetic spectrum which extend from the long wavelength radio to infrared, optical, ultraviolet, X-ray to high energy gamma rays, as they pass through the earth's atmosphere which is a mixture of several gases—nitrogen, oxygen, hydrogen, water vapour, ozone etc. It is seen that we are extremely lucky that the visible band—the part of the spectrum that the eye can see, is almost transparent and not absorbed by the air—(well, imagine if this was not so, we would not see the moon, the stars and other exciting phenomena in the sky—even the sun would have appeared as a dull faint object). What is clear from the figure is that an enormous wealth of information that is contained in the other bands of the spectrum is not accessible from ground stations. With balloons, rockets and satellites and with the light-weight telecommand and telemetry electronic units that have become feasible with the developments in solid-state devices, this atmospheric barrier has been overcome and in the past two-and-a-half decades observations in the infrared, ultra violet, soft and hard X-ray and gamma ray regions of the spectrum have revealed a variety of new types of celestial objects and processes; so much so there is a complete transformation in our understanding of the constituents of the universe and its evolution.

While certainly, I do not have the time to talk about some of these developments in detail, I would like to just illustrate the high points with a few typical examples.



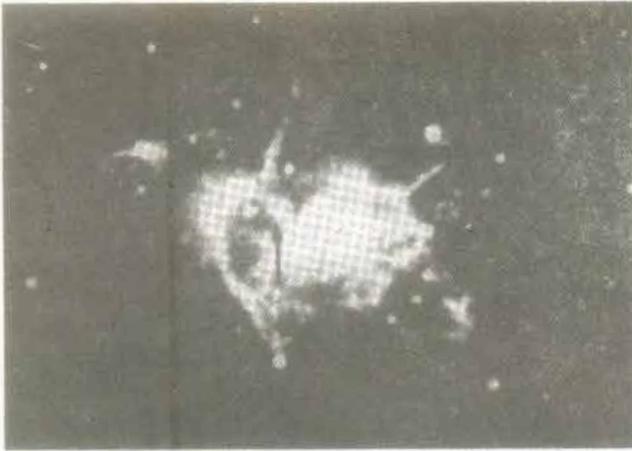


Fig 7 Picture of the Crab Nebula as seen to-day with a large telescope. At the centre is the remnant star which is the Pulsar and a neutron star

Let me first talk about the Crab Nebula. A picture of this Nebula as obtained with a large optical telescope is shown in the Fig 7. In 1054 AD, a star in the constellation Taurus suddenly started becoming brighter and brighter and exploded on the 4th of July. Accurate records of the happenings around this period had been maintained by the Chinese royal astronomer of the time, Yang-Wie-Tie. The object was visible even during the day for 23 days as bright as Venus and was visible during the night for 650 days following the explosion. Measurements have shown that the radio and optical radiations from the Nebula are highly polarized which suggests that the emission is by the synchrotron mechanism—spiralling of high-energy electrons in strong magnetic fields. This aspect of the nebular radiation had indicated the possibility even in the early 50's that it could be a source of high-energy gamma

rays and cosmic rays.

However, what has made the Crab Nebula an extremely interesting object is the discovery that the central star—the remnant of the supernova explosion of 1054, is one of the fastest pulsars. It pulsates at the rates of 30 times a second. It has been found that the pulsation is observed not only in the radio and optical bands, but also in soft X-rays, hard X-rays, gamma rays and even in ultra-high-energy gamma rays. Evidence for pulsation in ultra-high-energy gamma rays has been obtained from the Ooty Gamma Ray Telescope shown in Fig. 8. The pulsation is now understood in terms of the remnant star being a neutron star—a highly collapsed object with a diameter of about 10km and having roughly solar mass, thus the average density is higher than  $10^{14}$  g/cc—higher than the nuclear density. Also surrounding the neutron star which is spinning at the rate of 30 times per second, is a dipole magnetic field whose strength is  $10^{12}$  gauss or higher. What is important to note here is that, while the highest density material available to us on the earth is not more than  $\sim 20$  g/cc, the neutron star density is  $10^{14}$  g/cc. The highest magnetic field that can be produced in the terrestrial laboratories is of the order of  $10^6$  gauss or so, even that for a short duration, while the magnetic field around the neutron star is a million times more than this. Thus these celestial environments provide us with opportunities to learn about physical phenomena and processes that can never be simulated in the laboratory.

While on the subject of the Crab Nebula and the Supernova explosion, I should also mention about a slightly different scenario that can arise if the mass of the remnant star after supernova explosion is several times the mass of the sun—say  $> 4M_{\odot}$ . In such a case, the remnant becomes what has come to be known as a Black Hole—the



Fig 8 The Ultra high energy ( $> 10^{11}$  eV) Gamma ray telescope at Ooty. It has twenty search light mirrors mounted on independent electronically-controlled orientation platforms to enable tracking of individual sources. It operates through the detection of Cerenkov radiation produced in the atmosphere by the high-energy electrons in the cascade showers initiated by ultra high energy gamma rays.

gravitational field around this object is so high that even light cannot escape from its surface—the escape velocity from a black hole is higher than the velocity of light. The formation of such objects in stellar explosions had been envisaged even in the 1930's by theorists like S Chandrasekhar. It is only with the advent of space astronomy and with the discovery of X-ray sources which exhibit time variations even down to milliseconds that the possible existence of such objects has been taken seriously. In particular, one X-ray source in the Cygnus constellation known as Cyg X-1 is regarded as a strong candidate for a black hole. X-rays have to be produced at sufficient distance from the black hole to be able to escape from it. The mechanism envisaged is that as matter falls from a companion on the black hole, the gravitational field of the black hole accelerates the matter particles which attain high temperature due to friction and produce X-rays. It is the combination of the X-ray and optical observations on the orbital parameters of this Cygnus X-1 binary system that makes us recognize the possibility of one of the companions being a black hole.

To give you a flavour of some of the other exciting discoveries connected especially with the binary systems involving collapsed dense objects, I would like to mention about another phenomenon that has been recorded with X-ray telescopes—repetitive bursts of X-rays from certain X-ray sources. One such source the Rapid X-ray Burster MXB 1730-335 exhibits certain unique and spectacular features. Normally, this object is a quiescent X-ray source. Occasionally, it flares up and every few minutes emits bursts of X-rays and this intermittent bursting activity continues for several weeks and then the activity dies down for almost a year, to erupt again. What is the intriguing about this phenomenon is that the energy that is put out by the source in each burst corresponds to that of a million suns. The question that arises is—what is the physical mechanism by which a million suns are turned on in a matter of seconds, switched off and turned on again after a few minutes and this sequence repeats for weeks? Among the plausible theories the one that is most popular is the one envisaging the accretion of matter on to a dense object like a neutron star or black hole, the frequency and chance of accretion and stoppage of material flow being controlled by the movement of a companion object.

The quest for an understanding of the ultimate constituents of matter and radiation led us in the direction of molecules, atoms, nuclei and fundamental particles and generally in the direction of smaller spatial dimensions. On the other hand, the quest for an understanding of the denizens of the sky led us to the macro world of planet, stars, galaxies, clusters of galaxies and nay the universe itself, ever expanding and generally in the direction of vast dimensions of space. One remarkable thing however is that all the physical phenomena near and far can be explained on the basis of just four fundamental forces—gravitation,

## FORCES OF NATURE

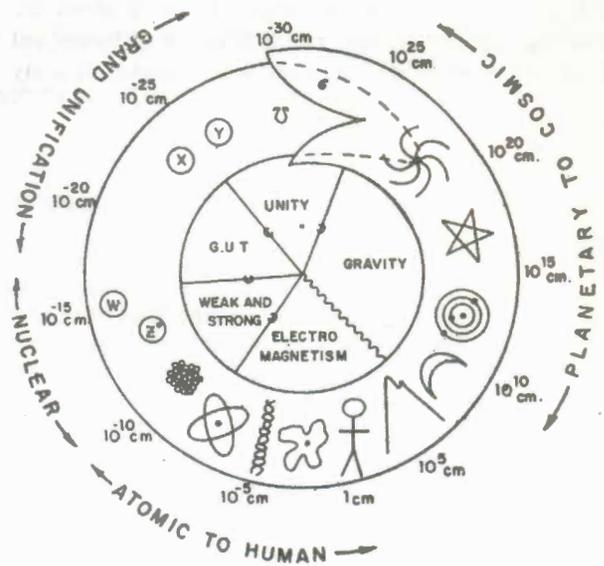


Fig 9 Glashow's snake

electromagnetic force, weak force and strong force. The realms in which the different forces dominate is beautifully depicted in the picture (Fig. 9) known as the Glashow Snake first sketched by Sheldon Glashow who shared the Nobel Prize in Physics for the year 1979 with Abdus Salam and Steven Weinberg. It is seen that gravitation dominates the macroworld of planets, stars and galaxies; the electromagnetic force the domain of and biology—man to amoeba to DNA, and all the atomic phenomena; the weak and the strong forces in the nuclear and elementary particle domains. What is most tantalizing and very significant in the picture is that the snake's tail representative of phenomena at minute spatial dimensions of  $10^{-25}$  cm enters the mouth which from the opposite direction is representative of dimensions larger than  $10^{25}$  cm, and the corresponding force region has been marked "unity". In fact this is one of the most important outcomes of the exciting investigations at the accelerators and at the telescopes. It has now been recognized that at least the electromagnetic, weak and strong forces are manifestations of a single force and the distinction between them disappears as one is able to probe extremely small regions of space. The universal expansion and the existence of the universal microwave radiation which point to the Big Bang origin of the universe, when extrapolated backwards in time lead us to scenarios in which immediately after the explosion, the universe was extremely hot and had just the physical conditions of energy, temperature etc for the manifestation of the unification of the different forces discerned from particle physics experiments. Strangely enough, applications of findings in particle physics help us in solving some of the outstanding problems of astrophysics and cosmology—the dominance of radiation

over matter in the universe and dominance of antimatter over matter.

It is electronics that has helped to bring about the knowledge concerning the great unification of forces and the relation between the micro and macro worlds. It is my

sincere hope that applications of electronics particularly through communication and mass education will bring about a revolution in the economic, social and political spheres too and bring about a unity of hearts and make this country and the world at large a happy place for the future generations.

## Investing for the Future : Some Technological Considerations

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Technological issues underpin the methodologies we need to tackle the problems of our country. Although the industrial base of India is claimed to be the tenth largest in the world, ours is more a trading culture than a technological culture. We are more concerned with buying and selling than with designing and fabricating. One consequence of this that we find ourselves being bypassed repeatedly by new technologies. One way to try to transform ourselves into a technological culture is to learn from the action scenarios of others – both historically and contemporaneously. The problems we face in our country are unique in the sense that we are called upon to tackle simultaneously issues that relate to the high-technology end (space, atomic energy) and issues that relate to the low-technology end (rural poverty). It would be a fallacy to think that what we need are high-technology solutions to deal with the former, and low-technology solutions to cope with the latter. For solving both categories of problems high-technology thinking and high-technology culture are essential. Action plans to come to grips with both these categories of problems need to be simultaneously formulated and implemented. While at the high-technology and scientific and industrial issues may predominate, at the low-technology end the real issues are of a managerial and engineering nature. A radical shift in thinking is needed to see our age-old problems in a fresh light and seek solutions for them through investing in new skills, new technologies and new management techniques. It is not only our civil servants who must transform themselves, but our industrialists, and, in many cases, also our scientists.

I am deeply grateful to the Institution of Electronics and Telecommunication Engineers, and to Dr P B Parikh in particular, for inviting me to deliver the Bhabha Memorial Lecture at this convention. I have been very fortunate to have had the opportunity to know Dr Bhabha personally and work with him. I think it would not be an exaggeration to claim that he was the chief architect of the science and technology profile of post-independence India. Dr Vikram Sarabhai was a close colleague of his and was much influenced by him. And all those who are currently heading the science and technology agencies or giving shape to science and technology policies in the country have been nurtured by these two. Both of them were great innovators and organization builders deeply concerned with the methodological issues relating to organization building. Dr Bhabha has discussed at great length in a speech he gave a few weeks before his death his views on the right method for building up science and technology in a developing country like India. Most of what Dr Bhabha had to say in this speech continues to remain relevant in dealing with the problems that still face us today. It is this concern with methodology that I would like to take as my main theme today.

It is of some interest and much relevance to note that Dr Bhabha's ideas on the management of research institutions already incorporate many of the components of the so-called Japanese style of management. For the

essence of this style is to value commitment to results and loyalty to institutions above routine observance of rules and procedures, and to value excellence in performance above everything else. Excellence in performance is difficult to achieve unless there is a conscious concern with methodologies that match means with end. Technological issues underpin the methodologies that we need to tackle the problems of our country.

### Growing a Technological Culture : Lessons to Learn

The Bhabha Committee report on "Electronics in India" was completed in 1965 and submitted to the Government in early 1966. That report envisaged the building up of a production base in the following 10 years to achieve an annual turnover of Rs 300 crores in the electronics sector. Today the Department of Electronics is talking in terms of a target of Rs 10,000 crores in the electronics sector by 1990. Of this contribution of computers and control instrumentation alone is projected to be Rs 2000-2500 crores.

If we do achieve this target would we be in a position to say that electronics has come of age or taken root in India? While there should be no reason to minimize this achievement if we do get there, I think a little reflection would convince one that if one asks the question : "Has

electronics technology brought about a major socio-economic change in the country?" the answer would have to be "no". Again, if one asks the questions: "Has electronics technology taken root in the country? Has it become self-generative?" the answer would have to be "no". If you accept the validity of the negative responses, then it becomes necessary to analyse the situation to understand why Rs 10,000 crores turnover is not in itself a satisfactory index. We have to look much more critically at the way electronics technology is generated and put to use in the country at large. This is what I would like to do in the rest of this lecture and provide the outlines of a critique, and make some suggestions on the kinds of actions we, perhaps, should be seriously considering.

Let us take the first question first. Electronics technology, like electric power technology, is a pervasive one. It has the potential to underpin every activity in every sector and transform it. In fact, electric power technology and electronics technology truly complement each other. The first is concerned with motive power, and the second with control and communication. The two together, therefore, underpin the whole of socio-economics. The major socio-economics changes taking place in the industrially advanced countries are the effects of exploiting systematically and in a coordinated manner the pervasive potential of both these technologies.

• In the case of India, electric power technology has become reasonably pervasive. But electronics technology has not. We can see this readily by considering what would happen to a community – say, a city – if electric power were to be turned off. And what would happen if electronics technology were to stop functioning suddenly. In the first case there would be a major disruptions of activities in all sectors industrial, commercial, household, and social. In the second case there would be no disruption at all, or only marginal disruptions. We must contrast this with what would be the case if these technologies were to be turned off in a country like Japan or USA. I must correct myself and say that there is one area where the disappearance of electronics technology would have an impact on the public at large. And what is in the disappearance of radio and TV. There is an important lesson to learn from this.

Coming to the second question, what about the generation of electronics technology? I would argue that, except for a very few instances, our preoccupation in this country has always been with products and not with processes, or technology *per se*. The foundation of any technology is a set of techniques and materials that enable new products to be made or new services to be offered. I include in "techniques" both design and fabrication. Although there has always been some awareness in India at the planning and decision-making level of the need for access to materials in the context of electronics technology, there has not been the same awareness of the

importance of growing a base for design and fabrication. The design and fabrication aspects of a technology are underpinned by tools. Thus, growing a base for design and fabrication know-how in the country is equivalent to growing a base for conceptualizing and making appropriate tools. This is equally true whether the tools relate to hardware or software. We always tend to think of tools (i.e., design and fabrication) in the context of producing particular product. In buying know-how for producing a product or a set of products, we buy the related tools. But we do not bother to abstract the tools (i.e., the design and fabrication know-how) away from the set of products to understand how they relates to the underlying technology *per se*.

This excessive preoccupation with products has tended to distort seriously both our perceptions and our priorities for investment. Our perceptions are distorted in the sense that we do not pay attention to what technological innovations are on the horizon worldwide. We became aware of new technologies only when we see them embedded in specific products. At that stages, if we find that these products are of value to us, we find ourselves confronted by a dilemma. Should we invest in the underlying technology or in a production unit for the product? Since many of the new technologies (the "high-techs") are sophisticated and require large investments and have a long lead-time before they can be successfully made to yield useful products, the decision to invest in product-manufacture wins out. So, we import the know-how for this. Unfortunately, this decision almost always turns out to be an infructuous one. Because, by the time a technology has come to the stage of yielding useful products, it is already starting to become obsolete. This is specially true of electronics technology. And a newer technology is already on the horizon and being worked on. So by the time the transferred know-how enables us to produce the original products, we find that the newer technology has started to yield newer products, and the ones we are producing are becoming obsolete. We are now back in square one with respect to this new set of products. And the whole cycle tends to repeat itself viciously.

Some may think I am painting an exaggerated picture and the actual situation is not so bleak. I do not want to deny this. Nevertheless, I think it is a fair assessment to claim that we have not created a tooling culture in this country that understands and values design and fabrication know-how delinked from the context of the manufacture of specific products. This is the reason why our efforts to learn by copying, reverse-engineering, or otherwise adapting what we import, have been so unsatisfactory. Again, because we have not developed a methodology to scan the world horizon and became aware of new technologies in the making, we constantly find ourselves being bypassed by new technologies. All our deliberations to arrive at investment decisions are repeatedly rendered irrelevant. This can be clearly appreciated by noting that

when we were seriously arguing about the need for investing in transistor technology in the late 60s, IC technology was already on the horizon and confronted us with new products in the '70s. When we were arguing about small-scale IC technology in the '70s, LSI technology was already on the horizon.

When we were arguing about the need for making wide-spread computer access available through regional computer centers based on large mainframes, minis and super-minis were already on the horizon. And now we are talking about supercomputers. It is not at all evident that 10 years from now supercomputers as they now exist would continue to be relevant. We have been experiencing the same kinds of frustrations in other technological fields also. Because of our massive investments in production bases for specific products, we have allowed new technologies to bypass us in automobiles, telecommunications, textiles, and even in such basic industries as steel.

There are at least two lessons that must learn from all these experiences. The first is this. We pride ourselves on the fact that we are the tenth largest industrial country in the world. But notice that this does not enable us through our existing industrial base either to meet our own internal modernization needs, or to compete effectively in the world market. The reason for this anomaly, as I have tried to explain, is that our industrial base is specific-product-oriented and not technology-oriented. We are, therefore, unable to react fast and keep in pace with a fast-changing technological scene. We are unable to buy, borrow, or even steal technologies and turn them to use fast enough. I think it would be wrong to see this as a problem of insufficient availability of investment capital. It is wholly a problem relating to our industrial culture. Bluntly put, ours is still not a true industrial culture but a trading culture masquerading as an industrial culture. Most of our industrialists are more concerned with the short-term financial returns of their ventures than with long-term technological issues. I see this as an essential difference between ourselves and a country like the United States: this is all the more true in high-tech areas.

So, our first problem is to decide how we can transform our trading culture in disguise into a truly technological culture—into a culture that is knowledgeable and skilled in tooling, design and fabrication; that takes pride in making rather than buying; that invests in creating rather than trading.

The second lesson relates to our need to become aware of new technologies even when they are still in their very nascent changes. We must devise methodologies not only to spot their birth but, more importantly, to understand their implications and uses. We must be able to evaluate their importance to us. And once they have been judged to be of value to us, we must be able to move rapidly to

promote the necessary activities to create effective bases for these technologies in our country. Note that this cannot be achieved unless we have a framework within which scientists, technologists, industrialists, and civil servants can come together, discuss technological issues coherently, formulate policies, and initiate actions. The only country which is at present able to do this in an exemplary manner is Japan. We should undoubtedly be able to learn a lot by studying their methodologies and techniques systematically and analytically.

### Learning for Models

How can we make a start in tackling both these problems? I think profiting from models should be a useful first approximation. We can study what has happened historically, and what is happening contemporaneously, in other countries. Such studies should indicate not only what aspects of their action scenarios are applicable to us and, hence, could be adopted, but also which ones are not applicable and, hence, should be avoided.

In many ways the problems that confront us in this country are quite unique. Ignoring for the moment issues relating to politics and sociology, even at the purely technological level, the issues are methodologically quite complex. This is so because we have to find technological solutions to cope with a dauntingly wide spectrum of problems. At one extreme we need the most modern, hightech technologies to support our programs concerned with space, atomic energy, defence, and basic research. At the other extreme, we need technologies to underpin our integrated rural development programs which are concerned with moving the poorest of the poor above the poverty line. Our bureaucratic, industrial and educational cultures must be able to span this entire spectrum of demands. At present, we are unable to manage this. The natural tendency is to look upon the extremities of this wide spectrum of demands as defining two polarized worlds which cannot meet. We try to deal with the low-tech end through low-tech thinking and low-tech technology, and deal with the high-tech end through high-tech thinking and high-tech technology. Thus we end up by perpetuating an already existing cleavage: the technologically poor remain poor while the technologically rich become richer. What is needed is a change in perspective which would enable us to look at low-tech problems from a high-tech viewpoint. A visionary breed of bureaucrats and technologists are needed for this.

Historically, in all the industrially advanced countries the trend has been for labour to move first away from agriculture to industry, and subsequently from industry to the services. A typical contemporary occupation profile in such countries is for 5%, 25%, and 70% of labour to be engaged, respectively, in agriculture, industry, and the services. In India this distribution according to recent data

is 70%, 10%, 20%. And this distribution has remained more or less constant during the last 50 years.

It would be a fallacy for us to think that in India the occupation profile could ever approach the asymptotic situation that we find in other industrialized countries. We have to accept these boundary conditions and operate on the basic assumption that the bulk of our population would continue to live away from the major cities and metropolitan centers. They would continue to be involved in agriculture and other food-growing (e.g., dairying, etc) and craft-related occupations. But what is needed is a movement or a program to underpin these non-urban occupations and non-urban life-styles with modern technology. This is essential for many reasons: to improve productivity, to modernize the life-style, and to improve the quality of life. Such an underpinning would eventually make non-urban living more attractive in terms of its intellectual and aesthetic content and physical comforts.

What this implies is that we need to select and deploy relevant technologies not only to modernize agricultural and other rural occupations, but such services as primary and secondary health-care, primary and secondary schooling, communication, transportation, etc. It is clear that universal access to a modern telecommunication infrastructure is an essential prerequisite to any viable attempt to modernize the non-urban life-styles. Information technologies imaginatively deployed has a vital role to play in bringing about the kind of transformation I have been describing. Traditional crafts can be modernized and made more productive, and their outputs made more widely marketable, by equipping the craftsmen with modern tools and design capabilities. Craft industries are, in fact, being revived in the West through the introduction of computer-assisted design techniques and through the use of production equipment such as computer-controlled looms, etc. Hospitals and schools can be modernized through the incorporation of microcomputer-based techniques. Modern management techniques can be deployed through computerized task-monitoring and task-scheduling practices. Transportation systems can be improved and made more productive through the use of computerized schemes for scheduling, reservation, etc. Similarly banking and postal systems can be modernized through the deployment of appropriate information technology. Some of these innovations are already being tried out in India. But so far as I know, the little that is being attempted is restricted to the urban regions. Modern information technology is still out of the reach of rural India. Yet, this need not remain so. We have access to the relevant technology; we have people with the necessary technological and engineering competence. The problem seems to be entirely one of structuring appropriate programs and implementing them. The gap is essentially an organizational and managerial gap; not a technological one.

It may be of some interest and relevance in this context

to note that in the USA, as recently as the early 1900s, rural life-style was hardly different from what it is many parts of India today. A US Public Health study in 1918 of 51544 farm homes in 15 countries throughout the US revealed that only 1.22% were equipped for the sanitary disposal of human excreta : 68% of the drinking water sources were exposed to dangerous contamination from privy contents. In 1910 an estimated 6.69 million students, or 37.6% of the students of the nation's public schools, attended 21230 one-room schools. Nearly every one-room school was rural and almost no rural school had more than one room or one teacher.

Very few of us know about organizations like the Country Life Movement and the American Country Life Association which, during the first decade of this century, spearheaded initiatives and reforms to modernize the rural life-style in America. The driving force behind these movements was made up of urban professionals, intellectuals, journalists, and others, who were convinced that technologizing of rural America was a prerequisite to modernizing the life-style there. The automobile revolution was a major factor in breaking down the isolation of rural life. It seems to me that we should be able to bring about a comparable revolution in rural India through the use of communication technology and information technology.

At the other end of the spectrum, however, the gaps are truly technological ones. When we try to deal with the high-tech problems from a high-tech perspective, we cannot afford not to keep pace with the rest of the industrially advanced world. Here, a good model to base our thinking on should be Japan.

Two key innovations that are determining the character of Japanese post-industrial society are: 1. Factory Automation, and 2. Knowledge-based Computing. Automated factories are based on industrial robots, NC machine tools, computer aided design, and flexible manufacturing techniques. With flexible manufacturing schemes, it is now possible to produce economically many varieties of machined parts in small quantities. 64% of the machine tools produced in Japan in 1983 were NC machine tools and this trend is expected to grow. Through appropriate deployment of machine tools, it is claimed that a 100-fold increase in efficiency in manufacture is attainable. NC machine tool culture is quite consistent with a significant part of manufacturing being carried out by small and medium-scale enterprises. A case study of a small town called Sakaki in Japan has been reported. This town with a population of 17000 achieved an industrial output of US \$ 560 millions in 1983. NC machine tools are widely used and the town absorbs 1% of all the machine tools made in Japan. Despite its inconvenient and remote geographical location and inadequate transportation system, Sakaki exports to more than 100 foreign countries. An electronic device company

in the town holds market shares of 70% and 90% in the world and domestic markets.

Factory automation is having a major impact not only in the manufacturing industry but also in basic materials industry such as steel. More than 90% of steel production in Japan at present depends on continuous casting technology. Wide-ranging benefits are claimed such as: conservation of energy, higher quality, higher yield rates, shortening of process time, smaller plant sites and labour saving.

Knowledge-based computing has, of course, been extensively publicized as the foundation of the 5th generation computer project which Japan was the first country to launch. Japan has made, and is continuing to make, major investments in this area. The technologies that underpin these efforts are: LSI/VLSI, high-resolution intelligent graphics terminals, computerized vision systems, speech input-output systems and, in the software area, AI language processors and expert systems.

In the remaining years of this decade and in the next decade we, in India, should be making major investments in technologies such as LSI/VLSI, robotics, and intelligent computer terminals, and in systems incorporating high-resolution graphics and other input-output facilities, if we are to keep abreast of the rest of the industrialized world in the high-tech areas. It is important to note that all these technologies have already been classified as "sensitive" by the Western countries, and transfer of know-how for manufacture even at the product-level would be difficult to negotiate. It would be pretty nearly hopeless to expect assistance from outside to grow a base for these technologies in India. We have to organize ourselves, pool our resources, and grow these technologies mostly through indigenous efforts. This is not a technologically impossible task considering our achievements in space, nuclear technology and other areas. But major mission-oriented efforts are needed if we are to succeed in a reasonable time-scale. Unfortunately, as of now, we have not demonstrated our willingness to commit the manpower and money needed for this task, and evolve an organizational structure that is likely to deliver results.

## PLANNING FOR ACTION

We have seen so far that modernizing our country poses complex methodological problems because the issues that confront us span a very wide spectrum from the low-tech end to the high-tech end. But I have been emphasizing that high-tech thinking is needed to tackle this whole spectrum of problems. We need both a management and technological culture which would be sensitive to the issues involved, understand their implications, and initiate appropriate actions to tackle them. I shall refer to the management aspect a little later on. But continuing our discussion of the technological

aspect, our analyses so far suggest some methods to evolve action plans and assign priorities.

Firstly, it is absolutely clear that unless our communication infrastructure is modernized and improved there is no hope of being able to deal with either our low-tech or our high-tech problems. Therefore, we must assign the highest priority to achieving this. There has recently been an awareness of the need for highest priority action in this sector and some changes in the style of operation have been initiated. Nevertheless, the problem is so critical to the success of all our efforts, and it is so complex in its dimensions and ramifications, that it would be a mistake to deal with this in a routinely departmental way. It is likely to yield results in a reasonable time-scale only if it is seen in a national perspective and tackled in a mission-oriented way.

Assuming we are able to succeed in tackling our communication infrastructure problem, in my view the next set of priorities must address the low-tech problems and high-tech problems simultaneously. We can see that it is possible to do so if we recall that the low-tech problems require essentially managerial and engineering initiatives, while the high-tech ones need scientific, technological and industrial efforts. The groups of persons involved in these two efforts should be by and large non-overlapping, although judicious overlaps at appropriate levels should be very valuable.

Let me outline here very briefly what kinds of action schemes, I think, are possible to deal with the problems at the low-tech end. Recall that these problems relate to modernizing the non-urban life-style and under-pinning them with the requisite technology. Confining my considerations here only to the deployment of information technology (IT), I would list the following problem issues as capable of being handled using technology either already developed and which, therefore, can be immediately deployed, or almost developed and can be put to use with some additional effort.

1. Use of IT at the district level in implementing integrated rural development programmes: task scheduling and monitoring; use of appropriate databases in planning, administration; etc. The scheme should be completely decentralized so that IT access is available at all levels, from the panchayat, through the taluk, district, and up to the state level.
2. Similar schemes in health-care delivery.
3. Use of IT in schooling.
4. Use of IT in banking.
5. Use of IT in transportation.
6. Use of IT in the publication of reading/discussion/publicity material in regional languages at the community level.

7. Use of IT in modernizing design input to arts and crafts.
8. Use of IT in introducing telex and telegram services in Indian languages.

Some of these applications are actually being tried out at present by isolated groups as isolated efforts wherever the concerned state government departments have shown an awareness of the potentials of IT for district-level development. But what are needed are national-level awareness campaigns to build up public opinion and urge state governments to establish appropriate framework to formulate and implement such schemes. In my personal experience I have found that in the present governments set up, secretaries of state government departments turn out to be critical influences in promoting such high-tech thinking in dealing with non-urban issues. Where secretaries are well-informed and motivated to try out technology-based solutions, action programs are easy to formulate and implement; otherwise, it is very difficult to get the government machinery to think along new lines. The most unfortunate feature of governmental functioning is the rapid turnover of secretaries. Because of this either projects do not take off, or after taking off they are allowed to drift and then eventually die for want of continuing enthusiasm and support.

Analogous analyses and action planning must, of course, be carried out to deal with the problems at the high-tech end. I said earlier that at this end of the spectrum we cannot afford not to move with the rest of the industrialized world. Factory automation, in this sense, is bound to be forced on us if we want to stay competitive in the world market. Shutting our eyes to inevitabilities will not make problems disappear. Labour reduction in the production process is one such inevitability. We must find rational ways of coming to grips with this problem.

In the Western countries, including Japan, the implications of high levels of automation in the production process are being seriously debated. It is envisaged that reduced work requirements would lead to earlier retirement, shorter work weeks, increasing use of time for leisure, and educational throughout the working life. The educational framework is being restructured so that working life and educational activities can overlap to the maximum extent.

Some of these alternative modes of organizing the work life may be applicable here, in India, also. But we have one great advantage in that there is still so much work to be done outside the factory framework that it should keep many persons employed for a long time to come. As I pointed out earlier, the bulk of our immediate problems are at the low-tech end. These, as we saw, are engineering and managerial problems. Also skills in these areas are needed at a variety of levels. By imaginatively and systematically analyzing the need we should be able to train and divert a

large percentage of the work-force (students and others) to deal with problems at his end.

One might ask "Would these occupations create real wealth to the nation?" My answer would be "yes". For these are investments in enriching and increasing the productivity of the non-urban occupations and in improving the non-urban life-style and making it more creative. Ultimately most of the non-urban occupations are concerned with food generation in one way or another. In that sense they create real wealth. Of course, we may find ourselves at some stage confronted with unsaleable milk-lakes and butter-mountains as is happening in the European countries now. But I think the size of our population and the size of our country would act as countervailing forces for the foreseeable future.

I would like to emphasize once again that a radical shift in our style of thinking is needed if we are to tackle our problems effectively. To take just one example, consider our rich cultural heritage. It is clear that all aspects of it are marketable. At present we tend to view this potentiality through a very narrow window, namely, tourism development. But a much more diversified attack on the problem is possible. Culture can be packaged and marketed in many ways. We send our performing artists out to publicise our heritage. But we can package the output of our creative artists in other ways also : as records, audio cassettes, video cassettes, films, slides, posters, books, and so on. By doing all this within the country-rather than letting outside entrepreneurs to exploit these potentials, which is what is happening now—we will be creating employment and wealth at the same time. Our radio and TV could, in fact, use this potential to commission the generation of wealth of products. All this would not only earn them revenue but, more importantly, also improve the quality of their services. If a model is needed we can learn from what other Radio and TV establishments in the West (for instance BBC TV) are already doing along these lines.

## CONCLUSION

To sum up, then, the problems that we face in this country are vast and complex. Qualitatively new methodologies for understanding them and dealing with them are needed. Modern technologies—for example, information technology, communication technology—can assist us in coming to grips effectively with many of these problems. But to take advantage of this possibility we must move away from stereotyped thinking and learn to look at our problems from the perspective of the latest technologies. It is not only for civil servants who must transform themselves, but our industrialists and, in many cases, also our scientists. But, ultimately, social and economic changes cannot be brought about through widespread use of modern technologies unless one is able to convince the major part of our population of the real benefits of technology. To stimulate public discussion of the long-term implications of

technology-based social change, the Australian government has established a "Commission of the Future". The Commission hopes to go about its task by publishing popular discussion papers on a range of issues. It will use the media—newspapers, magazines, radio and TV—to promote widespread discussions of these issues. It would also work through local organizations, schools, unions, and other community groups. Massive informational, educational and promotional campaigns along these lines are needed in our country also. Our will to undertake such efforts and our ability to carry them out would ultimately determine whether we succeed in solving our problems or we succumb to them.

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## Microelectronics Technology for India : A Case for Hybrid ICs

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Having decided to progress as an industrialised nation since independence, India has made remarkable advance in several sectors of industrial development in these four decades. In this endeavour, the Country has rightly laid considerable emphasis on the development and application of electronics in all spheres of human activity. It is now known that the key to success in electronics is the development of a self-reliant microelectronics technology in the Country, which is not only contemporary, but also cost competitive with the advanced countries. While commendable progress has been achieved in microelectronics in the country by following the traditional route of monolithic ICs, further progress appears to be limited now on account of the constraints of cost, technology and rapid obsolescence. Can there be an additional route more suited to a developing Country like India to advance its microelectronics technology further? The realization of hybrid ICs using monolithic ICs in a judicious manner appears to hold promise for the future of microelectronics technology in India. This is examined and discussed in the Lecture with specific examples.

IT is indeed a great pleasure and honour for me to have been invited by the President of the Institution to deliver the 20th Bhabha Memorial Lecture at this Annual Meeting of the Institution. I am most grateful to the Council of the Institution for this very unique opportunity. Dr Homi Bhabha was a Scientist-Administrator par excellence and his contribution to the development of Science and Technology in our Country, particularly in the post-independence period, are indeed immeasurable. We in the field of electronics have immensely benefited by the advice, guidance and direction he has given for the orderly development of electronics of India, through the well known Bhabha Committee Report on Electronics of 1966. It is therefore, appropriate that we pay our respects and express our gratitude to him, through this Memorial Lecture.

Through the policies framed in the early years of independence, India has been steadily progressing towards an industrialized society. In these four decades since independence, the Country has made remarkable advance in several sectors of industrial development. In this endeavour, the Country has rightly laid considerable emphasis on the development and application of electronics in all spheres of human activity. Manpower training, R & D, industry and applications in electronics are not only emphasized in the Country, but also the electronics activity now covers various sectors, such as, Consumer Electronics, Communications, Broadcasting, Aerospace & Defence, Control Instrumentation & Industrial Electronics, as well as Computers, Data processing & Office Automation. From humble beginning in 1947, the electronic industry in the

Country has now grown to an annual output of about Rs 4000 crores and is poised for an annual production of Rs 10,800 crores by the end of this decade.

It is well recognized that the electronics equipment industry in the Country can progress only with the support of a strong electronic materials and components base, in particular the base of microelectronics. It is not only necessary for the Country to have a self-reliant microelectronics technology, but also the products and functions developed have to be contemporary and cost-competitive with those from the advanced Countries, and if possible to be superior to them. While major investments have been made in this Sector and Commendable progress achieved so far, further progress in microelectronics technology in the Country appears to be limited. This is because :

- The Country has chosen the traditional route of monolithic ICs, including LSI/VLSI, which requires a high capital outlay;
- This is indeed a high technology greatly influenced by technological developments and market forces all over the World;
- This technology is suitable only when the production volume of each IC type is large, e.g., several million, which is a primary factor to bring down the IC price.
- Not only is a large internal market required for these ICs in the Country to sustain a large production volume, but also a good export strategy necessary; while the former is possible to some extent in selected areas, the latter is

more difficult as India is a late entrant in this field, unless the products have an edge over those made elsewhere;

- New developments and obsolescence of old processes are very frequent in LSI/VLSI technology, thereby demanding frequent capital investment of a high order.

In view of these factors, it is now necessary to explore additional routes which may be more suited to a developing Country like India to advance its microelectronics technology further. Hybrid IC technology is a good candidate in this connection. The realization of hybrid ICs monolithic ICs in a judicious manner appears to hold promise for the future of microelectronics technology in India. I would like to discuss this topic with specific examples in this lecture while paying my homage to Dr Bhabha.

### MICROELECTRONICS

Miniaturization of electronics or microelectronics has been an area of great technological interest for many decades. In the early years, electronic functions were miniaturized by mounting the discrete transistors and associated components on PCBs, which also provided the interconnections. As transistor technology developed leading to silicon transistors, it became evident that it would be advantageous to integrate them together with components and interconnections, in a chip of silicon using the various fabrication processes, such as, Oxidation Photolithographic, Selective diffusion, Metallization etc, so as to perform well defined electronic functions. Thus was born the era of monolithic ICs, also known as silicon microchips. Initially, the objective was the development of a complete circuit such as logic gate, linear amplifier, etc as a monolithic IC. But, it soon became clear that several similar circuits could be fabricated on a silicon chip of a larger area at very little extra cost. Therefore, the next step was to fabricate many such circuits at a time and interconnect them on the chip to meet a required function. This has resulted in more complex electronic functions at the chip level itself. Advance in fabrication technology in recent years have made it possible to reduce the dimensions of devices and thereby increase the component density in the chip. This has greatly helped in improving the operating speed and frequency of the ICs and also made it possible to realize highly dense electronic functions at the chip level in an economical way. Other characteristics of these ICs include standardization-functional as well as in package style, ease of mass production and consequent low cost chip, and high reliability. Such microchips are now of great application value in electronic equipment and systems. Typical examples are Digital logic circuits, Linear amplifiers, Radio and TV ICs Codecs, Microprocessor, Memories, CCDs and more recently ASICs.

As the packing density at the chip level has increased steadily year after year ever since the first monolithic ICs

were fabricated in the early sixties, it is now common practice to categorize this development on the basis of complexity levels on the chip. While it was Small Scale Integration (SSI) in the early years with packing density of less than 100 components/chip, the technology has steadily advanced to Medium Scale Integration (MSI) having 100-1000 components/chip, to Large Scale Integration (LSI) with 1000-100,000 components/chip and more recently to Very Large Scale Integration (VLSI) with over a million components/chip. Thus, the component density at the silicon chip level has already increased by over a million times in these decades and now doubling almost every year. And the microchips now form the basic building blocks of subsystem (very similar to components of the past) used in every sector of present-day electronic equipment industry.

At the present state-of-the-art MOS technology is the most dominant one for LSI/VLSI functions. While the scaling down of dimensions of MOS FETs improves the LSI/VLSI performance, it has physical, material, technological and economic limitations. The physical limitations include the minimum energy required to perform the switching functions, whereas the material limitations include how fast the generated heat can be removed. Both the limits are absolute and they decide the ultimate limit of the shrinking of device/circuit dimensions in the chip. However, at the present time, both these limits seem to be far off. On the other hand, the technological limitations are basically a result of the resolution limits brought about by lithography used in IC fabrication. While line width of  $5\ \mu\text{m}$  were common in the advanced countries about a decade ago, they came down to  $3\ \mu\text{m}$  over five years back; and the current line widths in semiconductor processing are less than  $2\ \mu\text{m}$ . The present trend in such that line widths are expected to go down to  $1\ \mu\text{m}$  and sub  $\mu\text{m}$  range progressively. But, this requires the use of electron-beam and x-ray lithography techniques as an alternative to photolithography, which has been the main strength of IC technology ever since its inception. This calls for major investment in new equipment when line widths much below  $3\ \mu\text{m}$  are required. Moreover, the demand for ICs using such line width being limited, they are likely to be more expensive. Hence, economic limits are likely to dominate more than the technological limits in the minimum feature size of IC devices in the future. However, it is likely that the minimum feature size of  $0.25\ \mu\text{m}$  will be common by the year 2000 in the advanced countries.

Of the wide variety and complexity of ICs now available, memories and microprocessor constitute the main stay of microelectronics, on account of their large number of applications. The evolution of semiconductor memories has indeed brought about revolutionary changes in electronics. Three major memory families are now important, viz, Read/Write or RAM, serial memory and ROM, the first two beings either static or dynamic. While bipolar, MOS and CMOS configurations are common for

static RAM and serial memory realizations, dynamic RAMs are based on MOS and dynamic serial memories are either MOS or CCD type. And, the ROMs are either MOS or bipolar. Spectacular advances have been witnessed in the specifications of memory devices, in particular their storage density. While 1 Mbit RAMs, serial memories and ROMs are now available, the most common memory devices are still of 16 Kbit and 64 Kbit types only. In a short span of about fifteen years since their development, microprocessor have become a key factor in the computer and information technology fields all over the World. At the present state-of-the-art, NMOS and CMOS technologies are widely used for microprocessors. While 32-bit microprocessors are now available, 8-bit and 16-bit types continue to be the most popular ones. In addition to these, some of the standard LSI/VLSI products now in use cover calculator ICs, Wrist Watch ICs, Codecs, etc. Custom and Semi-Custom LSI/VLSI devices are also becoming important now a days as high density functions are more suited to specific applications. ASICs fall in this category. It is expected that ASICs will dominate the microelectronics scene in the coming years.

### HYBRIDS VERSUS MONOLITHICS

Simultaneously with the spectacular progress of monolithic IC technology as seen above, there have also been major developments in the field of hybrid IC technology. This technology is useful not only as a circuit technology, but also as an interconnection technology, and is truly intermediate between monolithic IC and PCB technologies. Basically, hybrid ICs are of two types; viz, thick-film hybrid ICs and thin-film hybrid ICs. Of these, the former is more popular and has a larger share of the market because of the various benefits of hybrid ICs, in performance, flexibility, reliability and economy as summarized in Table 1. However, it is not uncommon to have some hybrid ICs taking advantage of both thick- and thin-film technologies on the same substrate. The thick-film hybrids generally use passive components (R, C) and interconnections fabricated in thick-film form on the substrate, typically ceramic, and active devices/monolithic ICs (available as bare chips or miniature packages) bonded on wherever required. At the same time, it is also common in hybrid ICs to employ only thick-film interconnections on the substrate and have the passive/active devices and monolithic ICs (all in miniature form) bonded onto the substrate to perform the required function.

Thus, hybrid ICs facilitate the assembly of monolithic ICs on ceramic substrate in a very elegant manner, so as to realize highly complex electronic functions. This is indeed second level of integration leading to hybrid ICs becoming available as packaged devices in standardized form, which can be further assembled on PCBs to realize subsystems. As seen from Table 1, the electrical performance of hybrid ICs is comparable to monolithic ICs in several respects, and their reliability is also equally high. Besides, there is

TABLE 1: Major benefits from hybrid IC technology

Performance	<ul style="list-style-type: none"> <li>- Ease of trimming of components (R &amp; C) for close tolerance;</li> <li>- High performance because of precise component values;</li> <li>- Higher component and interconnection density than in PCBs;</li> <li>- Excellent thermal tracking of components and absence of hot spots;</li> <li>- High frequency and speed capability;</li> <li>- High voltage and power capability;</li> </ul>
Flexibility	<ul style="list-style-type: none"> <li>- Wide variety of active/passive components usable : Film type (thick/thin-film), Bare chips, packaged (conventional/SMD) types;</li> <li>- Ease of design and testing on breadboard before transfer to substrate;</li> <li>- Ease of design changes;</li> <li>- Short turn-around time;</li> </ul>
Reliability	<ul style="list-style-type: none"> <li>- Excellent: Because of rigid bonding of components/interconnections on substrate and absence of local heating;</li> </ul>
Economy	<ul style="list-style-type: none"> <li>- Moderate capital investment;</li> <li>- Wide variety of circuits possible with little variation in process technology;</li> <li>- Low circuit development time, effort and cost;</li> <li>- Useful for small production runs;</li> <li>- Useful for custom circuits, circuits requiring frequent design changes and special functions</li> </ul>

considerable design flexibility associated with hybrid ICs which facilitates easy design changes and short turn-around time. Also, lower capital investment for hybrid IC technology and possibility of small production runs, e.g., a few thousand packages at a time, make hybrid ICs economically highly attractive as compared to monolithic ICs performing similar functions.

Hybrid ICs available at present cover a wide range of electronic functions required in several application areas; viz, Telecommunications, Instrumentation, Automobile, Biomedical, Defence, Aerospace, Consumer Electronics, Computes, etc. Moreover, the range of functions, circuit complexities as well as application areas are continually expanding. Most of the functions being of great interest to the physical design of electronic equipment, hybrid ICs have largely developed as proprietary products for captive use. This is unlike monolithic ICs which have developed mostly for general-purpose applications. While the World-wide production of monolithic ICs in 1986 was about Rs 30,000 crores, the hybrid IC production in the same year

was about Rs 5,500 crores with about 60% of this being for captive use. A growth rate of 15-20% is now estimated for both these technologies on the World scene. These figures clearly indicate the importance of hybrid ICs, in electronic applications.

The technology of hybrid ICs, like other microelectronics technologies, is continuously under development and evolution. Not only the conductor line widths of present-day hybrid ICs have shrunk to as low as 100  $\mu\text{m}$ , but also multi-layer hybrid ICs making use of 10-15 wiring layers have become common on the World scene. Newer materials are now being developed with a view to bring down the cost of hybrid ICs while at the same time maintaining their performance and reliability. In this connection, the developments in copper-based conductor pastes, copper compatible resistor pastes, polymer thick-film (PTF) conductor resistor/dielectric formulations, porcelain-steel as well as polymer-based substrates are important. Also, printing and firing techniques are now evolving to facilitate high density integration. Besides, a recent development in the field of packaging of components, i.e., surface-mounted device (SMD) technology is now playing a crucial role in realizing high-quality hybrid ICs. Passive/Active components as well as mono-lithic ICs of various complexity levels being now available in SMD form, their assembly on hybrid ICs leads to superior performance. Moreover, this development is also greatly influencing PCB assembly. Computers are also being increasingly employed in the design, manufacture and testing of hybrid ICs. In view of all these developments, it is expected that hybrid ICs will penetrate deep into several additional application areas in the coming years.

### THE INDIAN SCENE

The Indian microelectronics industry has a standing of about 25 years, and it is supported by R & D laboratories and academic institutions with specific programmes for R & D, design, applications and man power training in this area. Several public and private industries have made major investments in microelectronics and are now engaged in the development, production and application of micro-electronics products—both monolithic ICs and hybrid ICs. In addition, some CSIR/Defence R&D laboratories, leading academic institutions such as, IISc/IIT/Universities have set up technological, design and application engineering facilities in microelectronics. Research programmes in the area of raw materials, particularly semiconductors, dopants, thick-film materials, substrates, etc, are also being emphasized in the Country.

Beginning with discrete germanium/silicon devices in the early years, the semiconductor device technology has steadily advanced to monolithic IC production in the mid-seventies. Today, monolithic ICs of SSI, MSI, LSI complexity following bipolar, NMOS and CMOS

technologies are produced in the Country, at three major public sector industries. While two of these industries cater to the general electronics market in the Country, the third one has facilities geared for its captive use only. The product range of monolithic ICs in the Country covers the ICs required in consumer applications, such as, Audio/Radio/TV (mostly bipolar), Calculators and Wrist Watches (NMOS/CMOS), as well as those required in professional applications, such as linear/digital ICs (bipolar/CMOS), voltage/switching regulators (bipolar), memories, micro-processors, codecs, PLAs, etc (NMOS/CMOS). Most of these ICs are under license production from well known overseas manufactures. However, products based on local design are coming up only recently. The minimum feature size used in these ICs is currently in the range 3-10  $\mu\text{m}$ .

Even though the performance of these ICs is comparable with those imported from abroad in many respects, Indian-made monolithic ICs have several limitations. They are:

- They have a limited functional variety; moreover, package styles available are also limited;
- Functionally, the IC packages now produced in the Country are at least a few years behind the current state-of-the-art; This is particularly in respect of the packing density;
- ICs produced in the Country do not yet meet the high reliability standards stipulated for professional equipment applications;
- Design innovation or new IC development is still not very successful;
- Local ICs are priced much higher than those in the international market.

A study of this problem has brought out that the following factors are mainly responsible for these limitations:

- The total demand of monolithic ICs in the Country is still very small, as even on a conservative estimate, the annual electronics production in India is less than 1% of GNP (in contrast to 5-7% in the advanced Countries);
- As Indian electronics equipment technology is based on imported designs to a large extent, a very wide variety of ICs is required. But, the quantity required in each case is very limited, except in few applications;
- The monolithic IC production being highly automated is not able to exploit the skilled labour force available in the Country, in spite of its low cost;
- Capital investments required are of a very high order particularly when the monolithic IC technology has to be upgraded from 3-10  $\mu\text{m}$  feature size to sub-micron

feature size;

- The base of materials development and CAD to support monolithic IC technology in the Country is still weak.

Therefore, it is necessary that these factors are carefully considered before further expansion of technological facilities for monolithic ICs in the Country.

At present, a wide variety of hybrid ICs is produced in the Country through four public-sector and three private-sector industries. While the hybrid IC production in the public-sector industries is largely for captive use, the private-sector industries cater to the general requirements of the electronics industry. Of the many R&D laboratories engaged in this area, two have set up pilot production facilities to qualify their hybrid IC products for defence/space applications. The product range of hybrid ICs in the Country covers the requirements in Telecommunications, Defence, Aerospace, Computers, Instrumentation-in-particular biomedical, and the applications are mostly in the professional equipment area. However, indications are that hybrid ICs will penetrate other areas, particularly consumer/industrial/automobile electronics areas in the coming years, as the production costs come down. Most of the hybrid ICs are based on local design. The minimum conductor line width used in these ICs is currently in the range 150-250  $\mu\text{m}$ , and multi-layer hybrid ICs making use of 3-5 writing layers are also being produced in the Country.

While the technical capabilities in the development of hybrid ICs and their production in the Country have greatly advanced, the hybrid IC industry has yet to take off like in other advanced countries. The major problem areas are:

- The variety of hybrid ICs produced in the Country is too large; but quantity in each case is still small;
- Hybrid ICs are yet to be standardized in the Country, functionally as well as in packaging;
- Hybrid ICs activity is mostly dependent on imported capital equipment and raw materials;
- Capabilities in Academic institutions and R & D laboratories are not effectively linked with those in industry;
- Application engineering of hybrid ICs is not given due attention, so far;
- Exploitation of economical materials for hybrid ICs has yet to receive the attention it merits;
- Indian made hybrid ICs are more expensive as compared to imported ones;
- Hybrid ICs have yet to penetrate application areas requiring large production volume, e.g., consumer, automobile, industrial, biomedical, etc.

In spite of these problem areas, the several attractive features of hybrid ICs covered in previous section and summarized in Table 1 clearly suggest that hybrid ICs have a bright future in India.

#### A CASE FOR HYBRIDS

The realization of hybrid ICs using standard monolithic ICs as the basis is an attractive approach to take care of the several problems of each of these technologies individually. Besides all the attributes of hybrid ICs, this is helpful for:

- stimulating innovation and development of new products in an economical manner;
- obtaining VLSI functions by using LSI devices;
- improving the power dissipation of high density circuits;
- low cost through standardized products.

Some aspects of this are now covered with specific examples. It is well known that the package size of LSI/VLSI function increases with the complexity of the function. As an example, packages with 64 pins in DIP form are common with present-day VLSI devices. Such a package has a surface area of about 26  $\text{cm}^2$ ; but, the VLSI device, if available in single chip form, has an area of less than 0.5  $\text{cm}^2$ . Therefore, there is no space saving by going over to single-chip devices for such high density functions. A multi-chip solution would also be useful for many applications. In this context hybrid IC approach is helpful, as it facilitates a multi-chip solution in an elegant manner.

Memories, Microprocessors and PLAs are the most common LSI/VLSI functions, now a days. It is well known that their quality requirements go down as the circuit complexity is increased. For example, fewer 1 Mbit DRAMs are required as compared to 64 Kbit DRAMs; and fewer 32 bit microprocessors are required as compared to 8-bit microprocessors. Therefore, it would be attractive to standardize and mass produce lower density DRAMs microprocessor, etc and assemble them using innovative approaches to obtain the required VLSI functions. The hybrid IC is a useful solution in this connection, as it enables final packaging in standardized form as well, besides bringing down the unit price through mass production. This also enables the strengthening of the base of 3-10  $\mu\text{m}$  monolithic IC technology already established in the Country.

Looking at monolithic ICs, it is seen that only one technology, viz, Bipolar, NMOS or CMOS has to be used to obtain a single chip function. But, for superior performance, it is often advantageous to make use of a judicious combination of all these technologies to realize the required function. Here again, a multi-chip solution is attractive, for which the hybrid IC is highly useful. For example, a per-channel codec of greatly superior

performance can be realized by using Bipolar, NMOS and CMOS monolithic ICs for different blocks in a hybrid IC.

Single-chip LSI/VLSI devices generally have high power dissipation. This calls for forceful techniques for heat dissipation to be associated with the chip. However, this problem can be considerably simplified by using a multi-chip solution to obtain the complex function IC. Here, each chip having lower complexity and consequent lower power dissipation is chosen, and their assembly as a hybrid IC not only reduces overall power dissipation, but also improves the IC reliability.

### CONCLUDING REMARKS

It is clear from the above discussion that hybrid IC technology has an important role in strengthening the microelectronics base in India. This is not only from the

technical, but also from economic considerations. As indicated, a judicious combination of monolithic IC and hybrid IC technologies is helpful for realizing complex electronic functions, which can fill the gaps in certain application areas. This is particularly important in the Indian context.

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# Computers and Intelligence

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We are living in an age which is often called the computer age. Recently a chess grandmaster made history by losing to a chess-playing computer. In science fiction, computers are not only intelligent, but are also capable of having emotions, are such things possible? In this talk, the focus is on one aspect of computers, namely whether they can ever be intelligent in the sense that they can learn, think and create new knowledge without human intervention. To answer this question, an attempt is made to define intelligence through several examples. An example of a computer displaying an ability to learn, namely a perceptron, is given and the question is raised as to whether this means the perceptron is actually intelligent? A distinction is made between rational and irrational behaviour, and it is claimed that even that human behaviour which can be said to be rational is often not reproducible in a computer. In spite of all these reservations, a case is made for the discipline of artificial intelligence, and recent advances in artificial intelligence are briefly discussed.

WE are living in an age which is often called the computer age. The widespread use of computers is all walks of society is transforming our lives almost beyond recognition. Many of the effects of computerization are of course beneficial. For example, a great many boring and uninteresting jobs have been turned over to computers, such as bookkeeping and record maintenance; fraud in STD billings, and air and train reservations is greatly reduced though not eliminated entirely. But there are also some negative effects. Many people lack the skills to coexist with computers in the workplace. There is talk of "techno-stress" which refers roughly to anxiety caused by the fear that one might suddenly find oneself replaced by a computer. These days one reads in newspapers about computers that can understand speech and translate from one language to another. A chess-playing computer has recently made history of defeating a Grandmaster, and people think it is just a matter of time before a computer becomes the world chess champion. It has been claimed that, when presented with the facts of the world as they were known in 1560, a computer discovered Kepler's three laws of planetary motion in just twenty minutes; compare this with the nearly two thousand years that we poor human beings took, from the time of Ptolemy to the time of Kepler, to achieve the same thing. In science fiction, the situation is even more drastic: computers are not only intelligent, but they also have emotions, and can even recreate themselves. In the movie "2001: A Space Odyssey," the computer HAL not only has feelings, but it can also read lips. When the astronauts aboard the space ship plan to shut down HAL, it reads their lip movements and maroons them in space.

All the effects of computerization are far too numerous to be covered in a single talk. So far the present talk I have chosen to focus on one specific aspect of computerization, namely whether they can ever replace humans in those

tasks which might be said to require *intelligence*. So I am specifically excluding science fiction type topics such as whether computers can ever have emotions, whether they can appreciate fine music or good paintings, or in the final analysis, whether they can have "life" in the sense that they can recreate themselves. My scope is much more limited, namely: To what extent can computers replicate those aspects of human behaviour which can be said to be "intelligent," and if so what form will this intelligence take? The point is this: Most of us don't feel threatened by computers just because they can calculate much faster than we can; that is just an extension of the industrial revolution which created machines which can lift heavier loads than we can, or run faster than we can, or fly while we humans can't fly, and so on. But we would all feel very threatened indeed if we felt that, say, research scientist could be effectively replaced by computers, because it is our fervent belief that the one thing that we humans can do better than anyone or anything else is to *think*.

So the point of the talk is to examine whether computers can ever be intelligent in the sense that they can learn, think, and create new knowledge *without human aid or intervention*. Is such an eventually even conceivable, if not in our lifetimes then in our children's or in our grandchildren's? There are strong views on both sides in this question. The proponents of what is often called "strong AI" claim that the human being is just another computer, even if we don't quite understand at present just how it works. These people believe that it is just a matter of time (though it could be a *very long time* before human beings themselves become obsolete. On the opposing side is an impressive array of scientists and philosophers, and I would refer interested people to read the books *Mind Over Matter* by Hubert Dreyfus or *The Emperor's New Mind* by Roger Penrose. These people, and others like them, claim

that there are fundamental reasons why a computer can *never* replace human minds and intelligence.

Ultimately a discussion of computers and intelligence must address some pretty fundamental issues as to what we mean by intelligence, thinking and creativity. I don't of course claim to have any answers, only lots of questions. But I hope that the talk will at least stimulate you to reflect further on the issues I will raise.

### WHAT IS INTELLIGENCE

We can do no better than to start by asking, "What is intelligence?" Rather than attempt an all-encompassing answer, I prefer to make a few points via examples.

The first point to be made is that intelligence is not just the ability to solve difficult problems. As we know, several people have been building chess-playing computers. One of the most advanced among them is called "Deep Thought," and is from Carnegie-Mellon University. Recently Deep Thought created a sensation by defeating a Grandmaster, Bent Larson (of Denmark?). So Bent Larson goes down in history as the first Grandmaster to lose to a machine? Now the question is: Does one consider Deep Thought to be more "intelligent" than Larsen (at least on one occasion)?

To answer that question, let us see how exactly Deep Thought plays chess. It is a massively parallel computer, and it decides its moves essentially by an exhaustive search. Deep Thought can examine *one million* board positions at a time, and does this examination one thousand times before deciding its next move. In other words, it examines *one billion* board positions before choosing its next move. In contrast, interviews with Grandmasters show that they rarely contemplate more than ten or so moves at a given time. Now, it seems to me that *optimization by exhaustive search* is not particularly intelligent. Suppose I asked you to minimize the function  $f(x) = x^2 - 4x + 4$ . If one imitates Deep Thought's mode of operation, one can first decide that the minimum is not likely to occur outside the interval  $[-1000, 1000]$ . Then one can divide this interval into a billion parts, calculate  $f(x)$  at each of these grid points, a million at a time, and pick the lowest value. But is this an "intelligent" way to do minimization? Isn't it much more intelligent to differentiate  $f(x)$ , i.e., to solve the equation  $2x - 4 = 0$ , and find the answer  $x = 2$ ?

Again the point I am trying to make is that mere problem-solving ability, or even the ability to solve problems *rapidly*, does not constitute intelligence. I don't feel inferior to a computer just because it can invert a  $10 \times 10$  matrix faster than I can, so should I feel inferior to a computer because it can evaluate a billion chess board positions faster than I can?

Let me give another example, again based on chess. This is to solve a problem which can be stated informally as "How many matches are there?" Let us begin with the

world chess championship, as conducted by FIDE. They way in which the world champion is determined is well-known: There is a current champion, and several challengers, each ranked according to his current merit. Let us say, to be specific, that there are ten challengers. Then No.10 plays No.9, and the winner of that match plays No. 8, and so on. Finally, the winner of the match between the No.1 challenger and another person plays the current champion, and the winner of *this* match is the new champion. Now let us ask the question: "How many matches are needed to decide the winner?"

Of course, we can write a computer program which can compute the total number of games given the total number of players (eleven in the above example, including the current champion). The program can be just a counter. It reasons as follows: "No. 10 plays No. 9, so that is one match; then the winner plays No. 8, so that is another match....." No doubt, such a program is capable of answering the question "How many matches are there?" given the number of participants. But is it a form of intelligence? Alternately, we can observe from the diagram of pairings (Fig 1) that the total number of matches is *always* one less than the number of players, or ten in the above examples. I leave the proof of that statement to you, but isn't it more intelligent to give a *general solution* than a computer program which can solve *any given problem*?

Now let us change the problem a bit. Suppose the tournament is conducted not according to the FIDE format but according to the Wimbledon format; that is, the players are divided into  $n$  groups where  $2^n$  is larger than the number of players. Then the players are paired, and byes are given in case of an odd number of players. Then the winner of each match advances to the next round while the loser is eliminated. Eventually there will be quarterfinals, semifinals, finals, and then the winner is decided (Fig 2). Now how many matches are there in this case? For, example if the tournaments starts off with 113 people, then in the first round one player gets a bye, while 56 pairs of players play against each other. In the next round, there is another bye, and 28 matches. In the next round, another bye and 14 matches, etc. The final answer turns out to be: 112. Again, one can write a computer program to calculate the answer in any *given* instance of the problem. Or, one

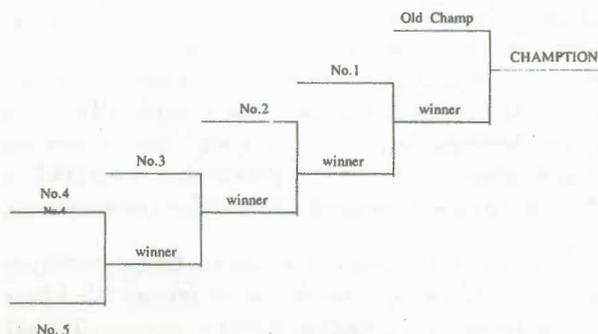


Fig 1 Pairings diagram for a Chess championship



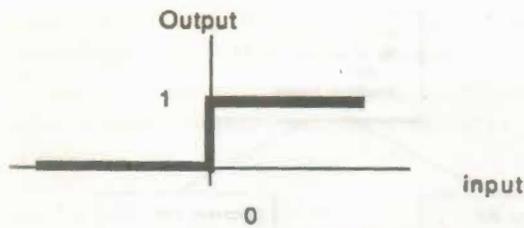


Fig 4 Perceptron characteristic

classifies a pattern, the supervisor tells it whether the classification is correct or not, but nothing more. The objective is to endow the perceptron with the ability to "learn" from its mistakes, and eventually reach a state where it can distinguish between those vectors in the set  $I_+$  and those in the set  $I_-$ .

Suppose there is a weight vector  $w_0$  with the property that

$$w_0^T y_i > 0, \forall y_i \in I_+, w_0^T y_i < 0, \forall y_i \in I_-$$

In this case the two sets of vectors  $I_+$  and  $I_-$  are said to be *linearly separable*. Figure 5 shows a graphical interpretation of this situation. The equation  $w^T y = 0$  defines an  $n - 1$ -dimensional hyperplane in  $n$ -space, and the assumption is that all vectors in  $I_+$  lie on one side of this hyperplane, while all vectors in  $I_-$  lie on the other side.

Now the "perceptron classification problem" can be stated as follows: Suppose the perceptron is given two set of vectors which are indeed linearly separable, though it doesn't know ahead of time the weight vector  $w_0$  which achieves the separation. Thus the rules of the game are: (i) The perceptron is given the two sets of vectors  $I_+$  and  $I_-$ , (ii) It can perform some experiments and adjust the weight vector  $w$  based on the outcome of the experiment, (iii) Any time the perceptron attempts to classify an input vector, it is informed whether the classification is correct or not, but nothing more. Can we train a perceptrons so that it eventually adjusts its own weight vector to a suitable classifying weight?

An answer is given by the so-called "perceptron-learning algorithm". Simply stated, it is this: Start with an arbitrary weight vector, and apply each of the input vectors  $y_i$  in turn, cycling through *all* of the given vectors  $y_i$ , including those in both sets  $I_+$  and  $I_-$ . So the "training sequence" of inputs looks like

$$y_1, y_2, \dots, y_k, y_1, y_2, \dots, y_k, y_1, y_2, \dots$$

At each stage of the "learning," the inner product  $w^T y$  is computed, where  $w$  is the current guess for the weight and  $y$  is the current training input. If the inner product is positive then  $y$  is classified as belonging to  $I_+$ , and if the inner product is negative, classify  $y$  as belonging to  $I_-$ . Now comes the "learning" part. At each step of the training, the perceptron either classifies the training input  $y$  correctly or incorrectly, and it is told which is the case. If it classifies  $y$

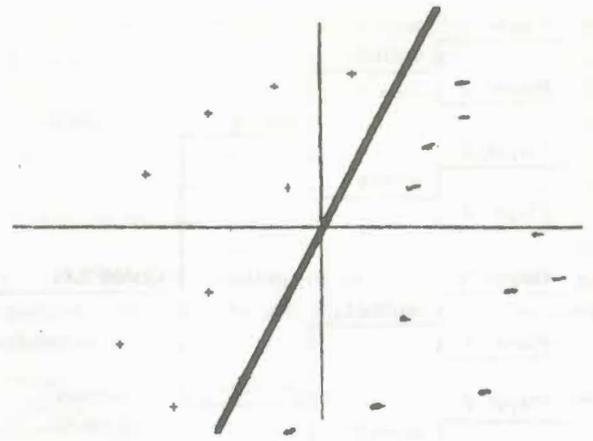


Fig 5 Linearly separable sets

correctly, then the weight  $y$  is left unchanged. If it misclassifies  $y$ , then the training input vector  $y$  is *added* to  $w$  if  $y \in I_+$ , and *subtracted* from  $w$  if  $y \in I_-$ . Now it can be shown that, in a finite number of steps, this algorithm does lead to a weight vector which will classify all input vectors correctly. This is known as the "perceptron convergence theorem."

Let us not worry about the proof of the above statement and accept it as is. Let us ask instead: Is a perceptron which incorporates the above learning algorithm "intelligent?" There is no doubt that, in a very limited and well-structured problem, the perceptron does exhibit some aspects of learning, and thus could be termed "intelligent." But I have a great deal of difficulty with that notion. Just what is the source of intelligence in this case? It is the perceptron itself, or the learning algorithm with which it has been equipped? I lean towards the latter answer. But if so, the *real* source of the intelligence is not the perceptron itself, but rather *the person or persons who thought of the learning algorithm*. Put another way, my point is that a perceptron which is able to classify patterns is not really intelligent, but the person who programmed it to classify patterns is certainly intelligent! If this view is adopted, namely all machine intelligence really derives from the people who programmed them, then one can state that: A computer is not more intelligent than the person or persons who programmed it, though it can be more intelligent than the person or persons using it at any one time!

## RATIONAL VS IRRATIONAL BEHAVIOUR

As mentioned earlier, in this talk I want deliberately to limit the scope of the discussion to whether computers can perform tasks which require intelligence, learn, and create new knowledge. So the issue of whether computers can have feelings or emotions is not included in the discussion. To make the distinction more precise, I would like to spend a few minutes giving a very simplified definition of rational vs irrational behaviour.

Performing arithmetic is an example of rational

behaviour. If I ask each one of you to add 535 to 1023, or to multiply 618 by 82, each and everyone of you will get the same answer, though you might take different amounts of time and might use different methods. So the point is that arithmetic is *repeatable*, in the sense that there is a consensus on what the "right" answer is. Now there are other aspects of human behaviour that are also rational. For example, if I show you a photograph of a person, and then take you to a lineup of people which includes the person in the photograph, almost all of you will be able to pick out that person. Similarly, if you hear a tape recording of a voice and then talk to several persons including the owner of that voice, you will again be able to pick out that person. If I give you a sentence in English and give you a set of five Hindi sentences including the translation of the given English sentence, you will be able to pick out that translation. Almost anyone who is well-versed in Carnatic music can distinguish between Balachander playing the Veena and Emani Sankara Sastry playing it. So these activities are also repeatable across a wide cross-section of the public, which is my definition of a rational activity. In contrast, evaluating whether a piece of poetry is good or bad, or whether a particular song is nice or not, these are what I would call *irrational* activities, because there cannot be widespread agreement on what these adjectives mean.

Of course, the line between rationality and irrationality is not clear-cut, so perhaps rationality should be measured on some sort of a grey scale instead of a binary scale. Also, rational activities are not always *exact*. For example, we can often get fooled by voice impersonators, or by actors portraying another individual. Even art critics get fooled by fakes of masterpieces. But this does not really invalidate my thesis that voice or face identification is a rational process. All that means is that each of us has a quantization limit, which is something like a machine zero in a computer, beyond which we cannot distinguish.

### CAN COMPUTERS "CREATE" KNOWLEDGE?

I have already talked about the fact that mere ability to "learn" in a specified sense does not comprise intelligence. But what about the ability to "create" new knowledge? As I mentioned at the outset, it has been claimed that, when given the data on planetary motion available to Kepler, a computer "discovered" his three laws of planetary motion in about twenty minutes. Does this not demonstrate that computers can create knowledge?

Again, in order to make a point, let me focus on a very specific situation. Rather than talk about scientific discovery in its broadest form, let me restrict attention to one particular aspect of it, which is commonly referred to as *automatic theorem proving*. This is a good testing ground for the hypothesis that computers can create knowledge, because after all mathematics is widely perceived to be the most dispassionate and rational of all intellectual activity, since it is based on axioms and strict rules of logical

inference.

In mathematical logic, there is a branch known as *propositional logic*. The statement

$$((a \Rightarrow b). a) \Rightarrow b$$

is an example of a formula from propositional logic. In words, it states: "If  $a$  implies  $b$ , and  $a$  is true, then  $b$  is true." The statement itself is true, and is referred to as *modus ponens*. Now every formula in propositional logic is either *well-formed* or it is not. Without getting into technicalities, a well-formed formula is one which makes sense; thus the formula can be studied to see whether it is true or not. In contrast, an ill-formed formula does not make sense. For example,

$$((a \Rightarrow b). b) \Rightarrow a$$

is a well-formed, formula, but it is not true. But,

$$((a \Rightarrow b).)$$

is not well-formed, so we can't even ask whether the formula is true or false.

Now let us ask the question: Can a computer decide whether or not a given (well-formed) formula is true? This is one version of automatic theorem proving. It so happens that there is a systematic procedure which can be employed to ascertain whether or not a given (well-formed) formula is true or false, known as the *method of derivations*. As with the perceptron learning algorithm, it is possible to equip a computer with this procedure, and in this way come up with an oracle which can (within its limited universe) discern between true and false statements. Presumably, a computer which is capable of deciding the truth or falsity of statements can be said to "intelligent." What more can one ask of an "intelligent" machine? But I don't agree with this statement. First, the method of derivations is essentially based on the enumeration of *all* possibilities and an exhaustive search, so it doesn't meet my criterion of an elegant solution. Moreover, I say that the intelligence if any derives not from the computer but from the person or persons who developed the algorithm which resides within the computer.

But now let us change the question somewhat. Since the rules of logical inference are quite well laid out, isn't it possible for a computer to mix and match various known facts to come up with new and unsuspected facts, and in this way, isn't a computer able to "create" knowledge? In a sense, this is what is meant by a computer "discovery" Kepler's laws of planetary motion.

Such ideas have been around for at least three decades, and serious efforts have been made to use computers in this way. I will quote one example, from a subject known as *Lyapunov stability theory*, which is a branch of the theory of ordinary differential equations. The subject itself is far

too technical for a talk like this, but it suffices to say that the theorems of Lyapunov theory have a very specific structure. There is a superset of hypotheses, and superset of conclusions; by choosing various possible combinations of hypotheses, it is possible to obtain various possible conclusions, and the process is well-understood. Now some scientists generated *all possible* theorems of Lyapunov stability theory using a computer, which numbered in the thousands. But interestingly, a group of mathematicians appointed to wade through these theorems came to the conclusion that three was not a single new theorem that was worthwhile. The point is that a good theorem is not merely a statement which is true; rather, a good theorem is a statement which is both true and interesting. Stated in this way, it is clear that proving *good* theorems is, by definition, an irrational act, since the quality of being "interesting" is clearly a subjective one.

It might be mentioned that several famous mathematicians have already given a lot of thought to this matter of creation, most notably Jacques Hadamard, Henri Poincaré, and Georgi Polya. Their essays on the topic are worth reading, but in the final analysis, they seem to conclude that mathematical creation is itself an irrational process, and thus perhaps not suitable for automation. Many of us have heard the statements "If you know how to find the answer, then it isn't research." I couldn't agree more.

- This viewpoint should not be misinterpreted to mean that computers are of no use in the discovery process. Clearly, the ability of computers to enumerate all possible combinations, which is far beyond human ability, is obviously very useful. But the point being made here is that this ability in itself does not comprise intelligence, in the same way that the fact that a statistical regression analysis can turn up unexpected correlations between parameters doesn't imply that the regression package is intelligent.

Another point to note is that ultimately all such computer programs perform within the bounds of a pre-specified universe, which is determined by someone else and not the computer. In the case of Kepler's laws, for example, it is not very surprising that, once the computer is given the information that planetary positions are some how related to each other *and to nothing else*, it is able to discover Kepler's laws. But this is doing a grave disservice to Kepler's genius, which lay among other things in being able to come to precisely this conclusion, namely that nothing else influences the positions of planets other than the positions of other planets, and to disregard all the misinformation and misbeliefs caused by ignorance and superstition.

### WHY ARTIFICIAL INTELLIGENCE?

So far I have argued that computers as they are and as they will be in future, can never be intelligent or creative in the sense defined here. So what justification can there be

for a subject called "artificial intelligence?" I think the two issues are not related. As mentioned earlier, there are several aspects of human behaviour which are more or less rational but are so far inexplicable. Hence it is quite worthwhile to try to replicate such rational behaviour in a computer, even if this doesn't make the computer "intelligent." For example, it is highly desirable to have a computer which is capable of recognizing hurricanes in a satellite photograph, even if that doesn't make the computer "intelligent." This is because a computer's "eyes" don't get tired with time as human's eyes do. Similarly, it is clearly worthwhile to have a computer which is capable of translating between languages, if the passages to be translated are dry business contracts and not poetry, say. Viewed in this way, a computer which executes some artificial intelligence program becomes just another machine which is an extension of the human brain, in the same way that a robot becomes an extension of the human arm (a means to life and transport things), and a car or an airplane becomes an extension of the human legs (a means to get somewhere).

Here I would like to make a distinction between *functional* AI and *operational* AI. Some people also use the terms *theoretical* AI and *applied* AI. To illustrate the difference, suppose we want to build a pattern classifier, which can detect the sharp edges in a photograph. This can be done in one of two ways. We can study very deeply just how the *human eye* detects edges and then replicate the procedure in a computer. This would be called operational AI. Or, we can just think about the problem abstractly and come up with a solution which is suitable for implementation on a computer, and not worry whether that is the way in which a human eye solves the problem. This is an example of functional AI. In the first case, we might build an artificial retina which resembles a natural retina as closely as possible; in the second case, we might take the Hough transform of the intensity function because the procedure *works*, even though there is no evidence that this is the way in which a human eye detects edges.

It is fair to say that, at present, functional AI is far ahead of operational AI. The reason seems to be that the human brain is far too complex to be understood with currently available tools. Indeed, it appears that we don't have a clear understanding of how the human brain works, but its functional counterpart, namely theoretical computer science, is in a very satisfactory state. The difficulty in understanding the human brain become apparent when we realize that the human brain doesn't have particularly good *hardware*. The basic units in the brain are the neurons, of which there are about  $10^9$  or one billion in an average human being. That is roughly equal to the number of transistors or switching elements in a large computer. On the other hand, the switching time of a transistor in a modern computer is of the order of *nanoseconds*, while the neuron in the brain switches in only *milliseconds*. Thus, when it comes to changing its state, a computer is a *million*

times faster than the human brain. In spite of this speed advantage, computers are unable to perform tasks which humans can perform with ease, such as real-time speech processing, which I hope all of you are doing right now. So the advantage of the human brain over a computer is in terms of its *software*. The details of this are obviously harder to unearth than the details of the hardware, which is one reason why functional AI is likely to stay ahead of operational AI in the foreseeable future.

### GOOD OLD-FASHIONED AI

Now let me change directions briefly and talk about the origins of AI and of rule-based expert systems, and what is often referred to as GOFAI (Good Old-Fashioned AI).

What is "artificial intelligence?" Elaine Rich defines it as any activity performed by a computer, which, when performed by a human being, can be said to require intelligence. That is far too vague a definition in the present context, so let me list some activities which are clearly a part of AI, without attempting an all-encompassing definition. At present, some of the major subtopics in AI consist of: pattern recognition, also known as computer vision; natural language processing, including both spoken and written; and heuristic, automated and approximate reasoning.

• Though some sections in the "scientific" community have tried to picture AI as a new and hot topic, the fact is that the subject dates back at least to the early 60's, with pioneering work being carried at Stanford University. One of the contributions of the work of that time was to introduce the concept of a "rule-based expert system." In essence, the idea is that within each domain of knowledge, be it medical diagnosis, legal practice, or income tax assessment, the acknowledged experts can distill their knowledge to a set of rules. These rules can either be very simple formulas in propositional logic (as described above), or can be much more complicated, involving probabilities, factors of uncertainty, and the like. The set of rules can be conflicting, redundant, and/or incomplete. But in any case, by interviewing the various acknowledged experts, it should be possible to arrive at an "expert system" which can do just as well as or better than a human beings is well-structured situations.

The idea had intuitive appeal, especially in some domains. For instance, field of medical diagnosis appears to be well-suited to this type of "treatment," since often it is possible to deduce the nature of the ailment from the list of symptoms, and even to decide on the required medication. Indeed, an early expert system called MYCIN is an oft-quoted success story in the expert systems field.

During the early 1980's, there was a great deal of hype about AI, with lots of exaggeration and hyperbole, if not outright lying, about what AI had already accomplished. Several notables were found to state that scientists had

already constructed a computer that could "think." As I hope I have persuaded you by now, such a computer not only doesn't exist even now, but will probably *never* exist. But these proponents of AI had a very smooth sales pitch, and unfortunately several people were taken in by it. New computer languages that were specially tailored for AI applications, such as LISP, became the rage, along with new computers that were specially tailored to run such languages. Fortunately, the AI bubble did not take long to burst. One of the nice things about the scientific community that it is pretty difficult to fool even some of the people some of the time!

Quite predictably, the original euphoria about AI gave way to an equally strong backlash against AI. My own view is both the euphoria and the current pessimism are quite unwarranted. One of the myths perpetuated by the boosters of AI in the 80's was that AI began and ended with expert systems. Personally I think that GOFAI (i.e., Good Old-Fashioned AI) is declining, and deservedly so. If anyone of you has glanced through a book on expert systems or AI written during the glamour period of AI, you would surely have been noticed that there wasn't a single equation in the entire book, not a single theorem or proposition, not a single principle - in fact, none of the features that one would associate with a scientific discipline. Unfortunately, in the backlash against AI (which means expert systems), we have lost sight of the fact that the *questions raised by AI* continue to be valid, even if the *expert systems methodology* has pretty well been discredited. For instance, it is *still* important to ask: How can knowledge be represented in a machine? How do we acquire new knowledge? How can a machine be made to learn? and so on.

One of the welcome trends in AI is the increasing use of mathematics. This is specially the case in a subject such as artificial neural networks. Previously AI used to be a very horizontal subject, in the sense that no apprenticeship was needed before one could label himself an AI "researcher." I am a firm believer in "the unreasonable effectiveness of mathematics," as Wigner put it, and I believe that the salvation of AI as an intellectual discipline lies in putting it on a firm foundation of principles, instead of treating it as a collection of tricks, as in GOFAI. During the early days of quantum mechanics, David Hilbert is supposed to have said "Physics is too complicated for physicists." In the same vein, perhaps it is true that AI is too complicated for the practitioners of GOFAI.

### RECENT ADVANCES IN AI

I will conclude the talk by giving a brief summary of the current status of AI and some recent advances. Again, a talk such as this one is far too brief to survey *all* the recent advances in AI, so I will settle for a representative sample.

By far one of the most exciting areas in AI these days is neural networks. Again, neural networks are not new, and one of the basic papers in the subject (by McCullough and

Pitts) was written in 1943, i.e., before I was born? But of late there has been a resurgence in activity in this area, mainly because of the advances in *hardware*. Now it is not only possible to conceive of interesting learning algorithms for neural networks, but it is also possible to implement them. Many tall claims have been made on behalf of neural networks, and I see a parallel between the type surrounding expert systems in the 80's and the current hype about neural networks. But an important difference is that, as I have emphasized earlier, the subject of neural networks does have a sound analytical foundation, and is therefore unlikely to fade as fast as GOFAI. At present, neural networks are claimed to solve very complex optimization problems such as scheduling and traveling salesman problems, which have a property known as "NP-completeness." But it is not yet clear whether a neural network solution of such problems is superior to alternate forms of solution. There is a pressing need for *performance norms* for evaluating whether the claims made on behalf of neural networks are really valid. But as with any rapidly evolving discipline, there is a sense of excitement in this area which is often lacking in more established fields.

Now let us look at speech processing. Many of the foundations of speech processing have been known for some time, but the practical realization of such processors had been limited by the speed of the available computers. As a result, most speech processing systems could only recognize a very limited vocabulary, of the order of a 1000 words or less. (This might seem like a lot of words, until one realizes that see, sees, and seeing count as different words!) Moreover, the systems were able to recognize only one speaker. But now, with advances in computational speed, it is possible to have *speaker-independent* speech recognition systems.

Along the same lines, the area of machine translation has also made rapid strides. Right now, if one sticks to pretty simple syntax and uses a limited vocabulary, computers are able to translate from one language to another. Most such experiments have been from one

European language to another, but there have been several successful experiments in translating between Indian languages. There is even a school of thought which holds that Sanskrit is best-suited for communicating with a computer, since it has a well-structured and *unambiguous* grammar. Let us see!

The area of computer vision is by now so well established that one almost call it a "classical" area. Again, many of the fundamental principles in this area were discovered years ago, but with the increase in the speed of computers, it is now *almost* possible to have real-time vision comparable to human vision, especially in well-structured situations. This opens up several exciting possibilities. For example, how about a so-called "eye in the hand" robot? We humans, viewed as robot manipulators, have a handicap in that our eyes are quite far off from our hands. This is why, when we have to do fine manipulation tasks like turning a screw, we have to use other senses like touch. But in building an assembly robot from scratch, we can put the robot's eyes wherever we like! So perhaps a robot which has its eyes and its hands in the same place can do a better job of assembly than it could otherwise. Or how about a robot which can work in dangerous environments like the inside of a nuclear reactor? Right now most such robots communicate with the operator via a fibre-optic link, but perhaps with the advances in vision such robots can be made fully autonomous (i.e., independent).

## CONCLUSIONS

In this talk I have attempted to make two points: The first is that, in a specific sense, computers can *never* be expected to display any form of intelligence, learning, or creativity. The second is that artificial intelligence, and especially functional AI, is a perfectly valid intellectual discipline. It has led to a great many new subjects of study and several scientific advances, and should remain an active field of research for several years to come.

# New and Emerging Technologies Influence Future Radar Designs

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**A brief account of the salient developments in the new and emerging areas of technology as they affect future radar designs has been presented. It is evident that the new challenges and excitement in this area lie in absorbing the new technologies and bringing about a reduction in the cost without compromising on quality and performance.**

**R**ADAR systems even after five decades offer an exceptionally large range of challenges for designers in the application of a variety of new and emerging technologies such as monolithic microwave integrated circuits (MMIC), fibre optics and integrated opto-electronic components, high- $T_c$  superconductor components and subsystems and quasi optics. The motivation for this gamut of activities is the ever pressing need for a sensor with increased performance characteristics, higher reliability and greater versatility in operation, at an affordable cost. Already, there has been a perceptible shift in the last five years in the design philosophy towards active aperture with distributed transmitter and receiving subsystems. In this concept, each individual radiating element is easily combined with a module that transmits RF power of adequate level in phase and frequency synchronism with other modules in the array and receives RF energy in the receive mode for combining either at the RF, IF or at video level as the case may be. Since there are likely to be a thousand or more such modules in any given system, these can be manufactured economically by adapting techniques perfected over the years for high volume manufacture of IC's.

Active aperture technology in being tried out in technology demonstration projects possibly for introduction in radar systems of the 1990's. Currently in the United States of America development programmes are under way for demonstrating key performance factors, cost and RAM (reliability-availability-maintainability) features of active aperture radars. In addition, a major programme aimed at ensuring not only the MMIC's but also the processes by which such circuits can be designed rapidly, repeatedly and productionised at lower costs, has been taken up.

## BASIC CONFIGURATION

A basic configuration of the active aperture system is shown in Fig 1. A T-R module is placed in the immediate vicinity of each radiating element, preferably behind the

array antenna. Each module needs microwave, bias, IF and digital lines to provide and process the data. Because of the space combining aspect of the RF power in these systems, the microwave feed network deals with relatively low level signal distribution to and from the aperture. For the sake of clarity three separate networks for feed, reception and control are shown away from the array in the figure. The RF distribution generates and transmits the necessary microwave signals to the power amplifiers in the transmit path of the T-R module so that phase and frequency synchronization among the modules is realized to provide effective radiated power (ERP) at the target in free space. It also provides the local oscillator outputs necessary for converting the signals received through the receive channel of the T-R module into IF for combining, mixing and signal processing. Further, it is possible to perform the combining of the received signals at the video level because the active aperture system lends itself easily for digital beam forming due to the distributed nature.

In the transmit mode of operation, the use of MMIC power amplifiers with each T-R module eliminates all high potentials and the necessary safety mechanisms that need to be incorporated. Further, the distributed nature of the RF sources across the array provides for graceful degradation and thus removes additional constraints of dual or standby transmitters for reliable operation. Since low level RF signals are transmitted to each of the T-R modules, digital modulation of transmitter waveforms can be implemented with greater ease and computer control can be effected without the attendant problems faced in high power transmitters. The advantage of the distributed nature of the RF sources is also available for controlling the excitation of the array so that wide pencil, pencil, and shaped beams can be generated by altering on command, the amplitude of the output signal either by gain control or by attenuator, and the phase through the microwave phase shifter. In the receive mode it would be possible to have a different radiation pattern and even to have multiple beams without loss of gain in the system.

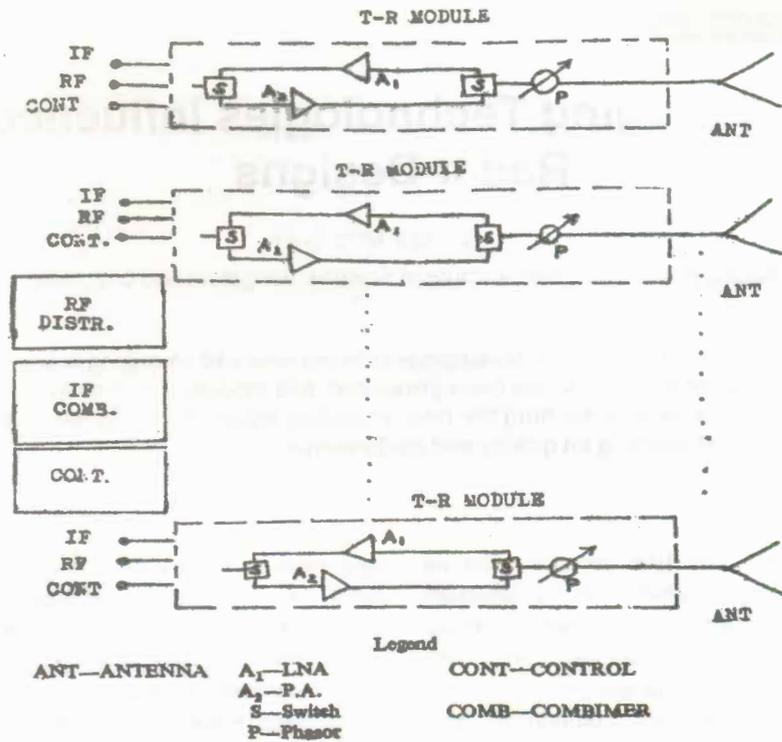


Fig 1 Block diagram of active aperture array

The distributed nature of power generation as well as the receiver chain enables us to recast the classical radar equation in terms of T-R module and antenna characteristics as follows.

$$R^4 MAX = \frac{P_t L_t L_r G_e^2 N^3 \eta^2 \lambda^2 \sigma}{(4\pi)^3 F_n KTB} \left[ \frac{S}{N} \right]_{out} \quad (1)$$

Here,  $G_e$  is the gain of the radiating element,  $P_t$  is the average output of the T-R module,  $L_t$  is the loss in transmission including propagation loss,  $L_r$  is the loss in the receiving path,  $N$  is the number of T-R modules,  $\eta$  is the efficiency of illumination of the antenna,  $\lambda$  is the operating wavelength,  $\sigma$  is the radar cross section of the target,  $F_n$  is the noise figure of the receiver,  $K$  is the Boltzmann's constant,  $T$  is the temperature in degrees Kelvin,  $B$  is the bandwidth and  $\left[ \frac{S}{N} \right]_{out}$  is the signal to noise ratio at the output of the receiver. The dependence of the maximum detection range for a given radar cross section of the target on,

- (i)  $N$ , the number of T-R modules
- (ii)  $P_t$ , the average power of the T-R module, and
- (iii)  $F_n$ , the noise of the receive channel, is clearly brought out in equation (1)

Prima facie it would appear that the most effective way of improving the detection range would be to increase  $N$ ,

the number of T-R modules in the system. Constraints of physical aperture and beam width considerations can restrict the increase. If however, the average power  $P_t$  of the T-R module is also taken into consideration, then by a judicious mix of increase in  $N$  and  $P_t$ , the power aperture product ( $N^3 P_t$ ) can be increased for improving the detection range. Therefore the power amplifier in the T-R module becomes a crucial element for enhancing the radar performance.

### MMIC TECHNOLOGY — T-R MODULES

Right from the beginning it was clearly seen that the only way to bring down the cost as well as to reduce the size and volume of the T-R modules for fitment within the inter-element spacing was to realize them in the MMIC configuration. In MMIC all components, both passive and active, are incorporated into a single semiconductor die permitting complete operation by the application of microwave signals and DC voltages. There has been considerable progress in the last fifteen years in MMIC realization from a single function module to multifunction modules containing power amplifier, low noise amplifier, phase shifting network, limiter, switches, etc. After considerable R & D effort and usage in discrete RF devices, GaAs has emerged as a material for the MMICs and is now available in four inch diameter wafers. As far as functional integration is concerned, a comparison of typical GaAs MMIC multifunction modules of 1986 and of today brings out that the present module has a lower component count (59 versus 348), lesser number of sub assemblies

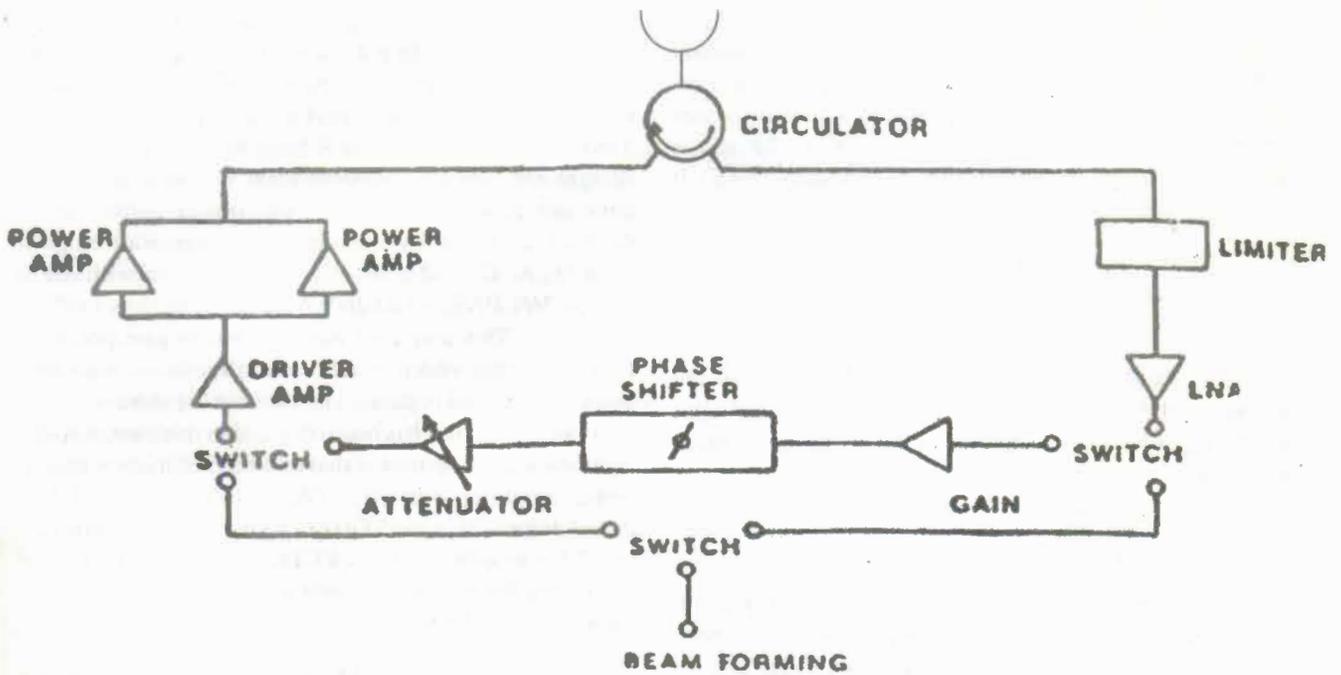


Fig 2 T-R module block diagram

(2 versus 5) and fewer interconnections (200 versus 561). In most cases, a T-R module contains power amplifiers for transmit and low noise amplifiers for receive states, and electronic multi-bit phase shifting network, switches and control electronics. Thus it carries out four RF functions, namely power amplification, phase shift/control, low noise amplification and switching between transmit and receive channels. A generic form of the T-R module is shown at Fig 2. Throughout the years, the emphasis has been for reduction of size and volume, higher rating for the power devices and better efficiency for the power amplifiers with gradual decrease in the cost of production [1-3].

The placement of the T-R module in the vicinity of the radiating element imposes design constraints on the circuit configuration used in the module. Some of the more important of these are,

- (i) The input microwave signal to the transmit channel being of the order of a few milliwatts, multistage power amplification is necessary for power output in tens of watts.
- (ii) To keep the power dissipation a low figure, high efficiency modes of amplifier operation such as class B would have to be used at the final stages of the power amplifier. Due to non-linearity of class B amplifiers, their behaviour over a large number of such units over the design bandwidth and over the temperature range as well as for variations in primary power supply noise will not be identical. Hence tight manufacturing tolerances for the processes will have to be enforced.
- (iii) The variations of the output of the power amplifier

will have to be achieved through variable gain or variable power amplification with minimum loss of efficiency.

- (iv) The receive channel should have enough gain to offset the effect of the post-LNA losses on the noise figure. In addition, since very little spatial filtering takes place of the signal received through individual radiating element, the LNA stages must have a high third order intercept.
- (v) The distributed constant phase shifting networks need higher surface area of the GaAs substrate which will raise the cost of fabrication by automatic processes. Hence lumped constant phase shifting networks may be switched in.
- (vi) The procedures evolved for testing and calibration of the module will have to be accurate, simple and economical.

The active device most commonly used in the GaAs MMIC is the MESFET, i.e., the field effect transistor using Schottky barrier gates. The device has high power gain per stage, excellent thermal stability, a better noise performance and it is insensitive to amplifier class operation. Higher output powers from the MESFETs means high channel currents, and large gate widths and the present trend in power density (output power per unit gate width) over the frequency band 1GHz to 30 GHz indicates that it lies between 0.3 watt to 0.5 watt per millimeter of gate width. It has therefore been necessary to connect several gate fingers in parallel to achieve higher output power per chip. The accepted design technique for power amplifiers is

to combine several chips of large gate widths combining circuitry so that higher output powers with low input/output VSWR are achieved. An equally important consideration is the thermal management of the device. This is linked to the heat that is produced within the device during the process of conversion from DC to RF and is measured in terms of the power added efficiency (PAE). It is expressed as,

$$P_{dis} = P_{out} \frac{[(1 - PAE) - (1 - PAE) / G]}{(PAE)} \quad (2)$$

where,  $P_{dis}$  is the power dissipated in the device,  $P_{out}$  is the RF output of the amplifier,  $G$  is the gain,  $P_{in}$  is the RF input power,  $P_{dc}$  is the power supplied to the device and  $PAE$  is defined as,

$$PAE = \frac{(P_{out} - P_{in})}{P_{dc}} \quad (3)$$

Figure 3 brings out the data on PAE for MESFET amplifiers up to 1989[4]. While a minimum PAE of 20% can be obtained at frequencies upto 40 GHz, recent reports indicate that power amplifiers with PAE's 60% to 70% have been successfully developed.

In view of the device limitations, initially the power amplifier designs were mostly class A with power added efficiencies less than 40%. However, with improvements in chip design tuned B, (class F) operation has led to PAE's of 60% and higher. In this approach high efficiency is achieved by controlling the harmonic loads presented to the FET. In essence it results in shaping of the voltage and current waveforms at the FET to reduce the overall

dissipated power at the device which is operated close to the B mode of operation. The increase in efficiency comes about as a result of the reduction of the time average of the voltage current product. Figure 4 provides the status of GaAs MMIC amplifier development in the world upto 1989. The developments at S-band indicate that amplifier designs are currently available for 6 W output with 12 dB gain and 22% efficiency [5]. The power output can be doubled to 12 W by combining two six watt chips in parallel. At C-band a double chip amplifier with 10 W output, 36% PAE and 0.626 W/mm power density has been fabricated. This amplifier has two 8 mm gate periphery FETs in single ended amplifier configuration with their outputs combined in parallel on the chip [6]. An average IC yield well over 70% has been obtained in this case. Another significant development is that of a high efficiency class B power amplifier with 70% PAE, 8 dB gain and 1.7 W power output [7] in the 5 GHz to 6 GHz region. In this case two 2.5 mm gate periphery FETs with a power density of 0.7 W/mm have been combined with the combining circuit external to the chips.

An alternate device to MESFETs is the hetero-junction bipolar transistor (HBT) for power amplifiers. The HBT has none of the disadvantages of lower power density, higher  $1/f$  noise and lower breakdown voltages under non-linearity in operation. The vertical structure of the device leads to greater compactness for monolithic circuit applications. Since it is a GaAs device it is compatible with

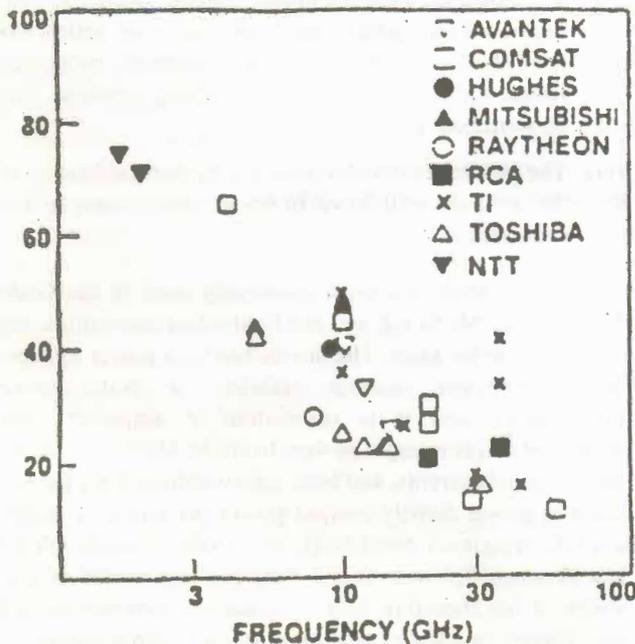


Fig 3 State-of-art (1989) PAE—MESFET amplifiers [4]

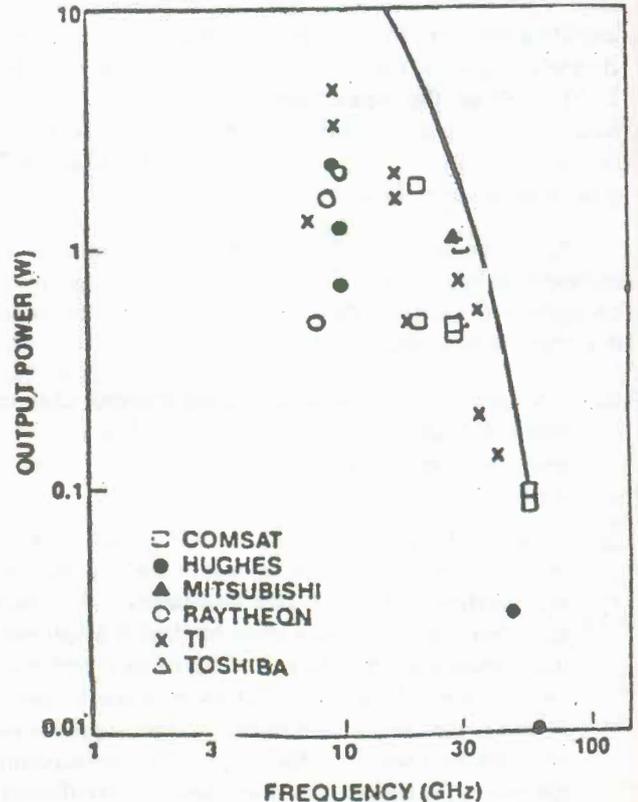


Fig 4 State-of-art (1989)—GaAs MMIC amplifier [4]

the present processes of fabrication. Already single stage class B power amplifiers in the 3 GHz region with 1 W output, 61% PAE and 12.3 dB gain have been developed [8].

The phase shifting network which is second only to the power amplifier in cost has been under development with MESFET as the switching device for more than a decade. The shift from the PIN diode has taken place primarily because of total integrability with other subsystems of the T-R module, fast switching speeds, wide bandwidths, low power consumption, high power handling and bi-directional switching. Phase shifting has been realised from one or more combinations of any of the four phasor configurations, namely, loaded line, reflection type, switched line and switched low pass/high pass network. For small phase bits up to 22.5 degrees the loaded line has been preferred. The first three types however use distributed line lengths needing relatively large substrate area which leads to enhanced costs. Because the switched high pass/low pass network phase shifter configuration uses combinations of lumped constant  $T$ - and  $\pi$ - networks, it requires less chip area. Several multibit phase shifters using one or more of the phasor techniques have been developed. A typical specification is that of a C-band six bit phase shifter. It spans the frequency range 5 GHz and 6 GHz with reflection type for large phase bits and loaded line for the three smaller phase bits, namely, 45, 22.5 and 11.25 degrees. It also has an analog phase bit between 0-11 degrees. Folded transmission line lengths with sufficient spacing are used to reduce the chip area. It contains 12 FETs, has an insertion loss of 6 dB, return loss higher than 12 dB and an rms phase error of  $\pm 2^\circ$  at the centre of the band. It provides excellent phase accuracy with good chip-to-chip phase tracking over the temperature range 25°C to 80°C. The entire phase shifter has been contained within an area, 9.43 mm  $\times$  4.2 mm. There is a need for further reduction in the surface area of the GaAs substrate for the phasor, and the two most promising technologies are the optical fibre and the high- $T_c$  super-conducting meander line in the microstrip configuration.

Simultaneously with the development of the individual circuit functions, single chip and multiple chip T-R module development is also being progressed. The thrust is towards low cost units through higher levels of functional integration so that the chip count is reduced and the chip test and module assembly cost is brought down. The developments relating to S-band and the X-band T-R modules will be of relevance in the context of radar. The S-band module has a power output of 2 W with 20% bandwidth, a noise figure of about 4 dB for the receive channel with 20 dB gain and a four bit phase shifter [9]. The module has eight GaAs devices of which 5 are MMICs and has the physical dimensions of 40 mm  $\times$  117.5 mm  $\times$  10 mm and 100 gms weight without the heat sink. In the X-band, a low cost transceiver consisting of a voltage

controlled oscillator, two stage gain/buffer amplifier, a 3 dB coupler and a double balanced mixer has been fabricated as a single chip with the dimensions 120 mil  $\times$  150 mil [10]. Each of the two stages of LNA has noise figure less than 3 dB and 20 dB gain. The power amplifier stages provide about 14 dB gain and 23 dBm out put power. The entire transceiver has been designed to be compatible with printed circuit antenna. The other effort in this band has resulted in a single chip T-R module for an airborne radar with an output power of 0.5 watt, and 12.3% efficiency, a 5.3 dB noise figure receiver with 13.8 dB gain [11]. The phase shifter has four bits and the fully integrated module contains 25 FETs, 24 resistors, 43 capacitors, 48 through-the-substrate vias and has the dimensions of 13.0 mm  $\times$  4.5 mm  $\times$  0.15 mm.

It is very clear from the present trends that the T-R module will be multichip with a maximum RF output of around 10 to 20 W and having dimensions that will facilitate it being fitted well within the 0.5 wavelength spacing normally used for antenna array lattice. From the point of view of complexity, the T-R module represents the highest level of functional integration. One of the major factors standing in the way of fulfilling the objective of low cost module is the inadequacy of the present CAD tools to meet the requirements in MMIC fabrication since peaking of the circuit after manufacture is difficult in this medium. The need to provide more circuit functions on small chip areas complicates the design further as it has brought the inter component distance to 100 microns for a chip of say 200 micron thickness. Under these circumstances, intercomponent electromagnetic coupling significantly affects the performance. In the layout of the MMIC chip for reducing the area on the substrate, component placement, aspect ratio, and orientation will result in changes in strip width, transmission line bends and other discontinuities that can cause significant performance changes. Apart from layout aspects, fabrication of multi-layer multi dielectric structures with non-negligible metal thickness can further deviate their performance. Incorporation of the coupling effects is thus one of the essential requirements for efficient and successful design. In addition, as the frequency of operation moves into the mm-wave region, the phenomenon of radiation, surface waves, package modes also come into existence. These are some of the challenging tasks at the MMIC design stages which are being attempted for low cost realization of active aperture systems.

## FEED & CONTROL NETWORK—OPTICAL FIBRE TECHNOLOGY

In an active aperture system the distribution of a large number of RF power sources and the receiver channels throughout the array calls for a feed and control network that has to allow the passage of a variety of signals as follows.

- (i) RF signals of high stability in phase, frequency and

amplitude for phase and frequency synchronization of the power amplifiers in the T-R module in the transmit mode and for coherent processing in the receive mode.

- (ii) IF return signals with a dynamic range of about 70 dB, only if digital beam forming at IF or video is carried out.
- (iii) Digital signals at base band to control accurately the phase shifter setting (amplitude and phase) at each T-R module for purposes of beam forming steering. Timing signals to provide an accurate timing reference at each active element. Transmission of communication and data and diagnostic signals to and from the T-R modules.

Thus each T-R module would need microwave, IF, bias and digital lines to provide and process the data. This presents an extremely complex signal distribution network with topology and interference being quite severe as thousands of T-R modules are involved. Because of such advantages as light weight, small size, high speed compatibility with the GaAs technology of the modules, good electrical isolation, elimination of grounding and immunity to electromagnetic pulse (EMP) an optical fibre feed and control network is the most promising solution. Of the tasks enumerated above the distribution of microwave signals for phase and frequency synchronization will require more attention and care in design.

The basic building blocks of an optical link are, the optical source with facility for modulation (microwave-to-optical converter), optical fibre and optical detector/receiver (optical-to-microwave converter). The optical source will be the semiconductor laser, and is a current sensitive device, with its output varying rapidly with the driving (bias) current after the threshold value is crossed. The lasers function with low powers, the driving current in most cases ranges from 20 mA to 300 mA. A Majority of these lasers have relatively broad gain and multi mode emission. The spectra is in the form of a series of peaks separated from each other by a few angstrom units ( $10^{-8}$  cm). The output intensity of the peaks has been observed to change abruptly in a random fashion even though the total output intensity appears to be stabilized. The fluctuations give rise to Relative Intensity Noise (RIN) spectrum in the power output from the laser. For this application RIN will be the dominant source of noise. This is AM noise and the noise output of all the modes is typically 40 dB lower than that of an individual mode. While the RIN of the earlier lasers had a floor of about 110dB/Hz below the carrier, improved optical sources such as the InGaAsP/InP distributed feedback laser operating at 1300 nanometers has a lower noise floor of 145 dB/Hz below the carrier. There are two methods of modulating the output of semiconductor lasers, namely the direct and the indirect. Direct current modulation is the preferred mode for active aperture systems because it is simple and requires fewer components/parts, has less light attenuation and

requires reduced modulator drive power ( $< 1\text{mW}$ ). Present indications are that the upper frequency limit for direct modulation in the near future will not be higher than 20 GHz [12].

The receiver side of the optical fibre network would need a high speed detector followed by a low noise amplifier to effect the optical-to-microwave conversion. The recommended optical detector is the PIN photo diode because it is faster, has a better temperature stability, lower operating voltages and is compatible for monolithic integration. The detector being basically a square law device, the output photo current of the detector is a linear function of the incident optical power. The PIN photo detector produces relatively a small swing from 1 mV to 10 mV which would mean that a gain factor ranging from 100 to 1000 is required of the amplifier. Since the GaAs FET amplifiers have relatively low gain per stage multi-stage amplification would be needed. Therefore the detector and the amplifier have to be designed as a unit so that their monolithic integration can provide a significant improvement in performance.

The transmission of the optical signals to end from the T-R module is affected by an optical fibre which can be multi mode, step or multi mode graded index or single mode. Since the total length of the link in an active aperture system will not exceed a kilometer, neither the attenuation nor the dispersion which are distance dependent, is of significance and, for all practical purposes they are taken to be zero. Thus for purposes of design, the feed and control network for the active aperture system can be termed as a short haul direct modulated multi port optical link. The noise figure of such a link can be expressed as,

$$F_2 = F_1 - \frac{8P_i}{m(I_{PK} - I_t)^2 R_L} + \frac{2P_i(RIN)}{m^2 KT} + \frac{8e \frac{\sqrt{R_D}}{\sqrt{R_L}} P_i}{m^2 \xi^2 KT(I_{PK} - I_t)} + \frac{8P_i(F_2 - 1)}{m^2 \xi^2 (I_{PK} - I_t)^2 R_L} \quad (4)$$

Here  $F_1$  is the noise figure of the amplifier before the link.  $P_i$  is the input power,  $m$  is the modulation index,  $R_L$  is the incremental drain resistance of the laser about the driving point,  $\xi$  is the square root of the electrical power transfer function,  $I_{PK}$  is the peak current of the laser,  $I_t$  is the threshold current,  $F_2$  is the noise figure of the amplifier after the link and  $e$  is the electronic charge. Figure 5 shows in graphic form, the performance according to equation (4) for a typical link [11]. For large input signal levels the link noise figure is degraded from the noise figure of the amplifier. On the other hand, for low input signal levels the link noise figure is given by the noise figure of the amplifier before the link. By using such lasers as buried hetero-structure direct feed back type, the RIN of which is

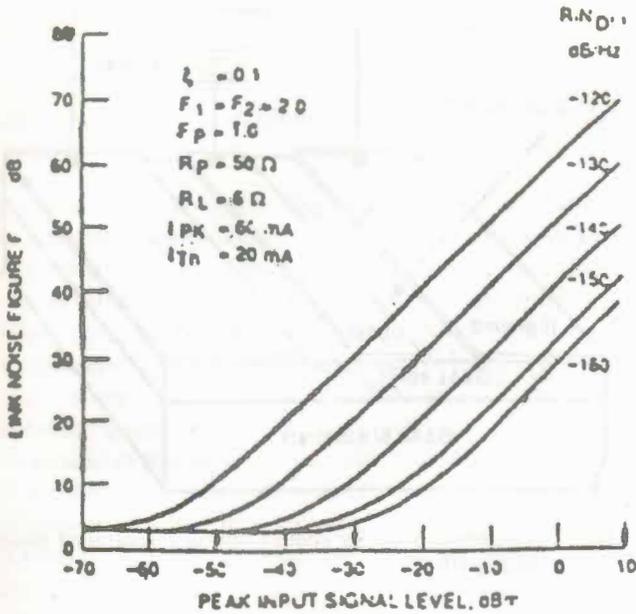


Fig 5 Overall link noise figure of directly modulated of link [11]

lower, the link noise figure is brought down. For High performance Doppler radars, the near carrier noise of the microwave source is around 130 dB/Hz below the carrier level which means that the signal to noise ratio for the RF signal out of the fibre optic link has to be at least 130 dB if not better. From Fig 4 it is evident that if GaAlAs/GaAs buried hetero-structure laser is used then, the link will not meet the (S/N) requirements of the microwave signal for the Doppler radar because the RIN of the laser at 840

nanometer wavelength is about  $-120 \text{ dB/Hz}$ . On the other hand InGaAs-InP distributed feedback laser operating at 1300 nanometer has a lower RIN, of the order of 145 dB/Hz below carrier so that a noise figure of 15 dB is available for the link to meet the microwave source quietness requirements. Figure 5 also indicates that the peak input RF signal power required is about  $-22 \text{ dBm}$  which after amplification, transmission through the optical fibre and demodulation after the link, delivers about 12 microwatts of signal to the T-R module. In the case of active aperture systems, the link is multi-port and assuming that there are 10 branches at the receiving end, that is, the microwave signal is distributed to ten T-R modules is about 120 nanowatts. More than one stage of gain would be necessary to amplify the microwave signal to the desired level and at these frequencies the realization of such high phase-stable gain from direct amplification of microwave signals is not possible. However, the use of injection locked microwave oscillators instead of amplifiers has been found to provide high AM noise compression and low AM-PM conversion, so that the phase noise that would have been added by the fibre optic link is suppressed. The recent advances in single modes lasers with RIN of around 158 dB/Hz which is practically the shot noise limit, will also go a long way in easing the problem of phase and frequency synchronization [13] for high performance Doppler radar systems.

Injection locking is the forced oscillation of an oscillator to follow the characteristics of a master oscillator. In this application, the microwave oscillator which is a highly stable signal directly modulates the laser diode output light which is then transmitted over the optical fibre

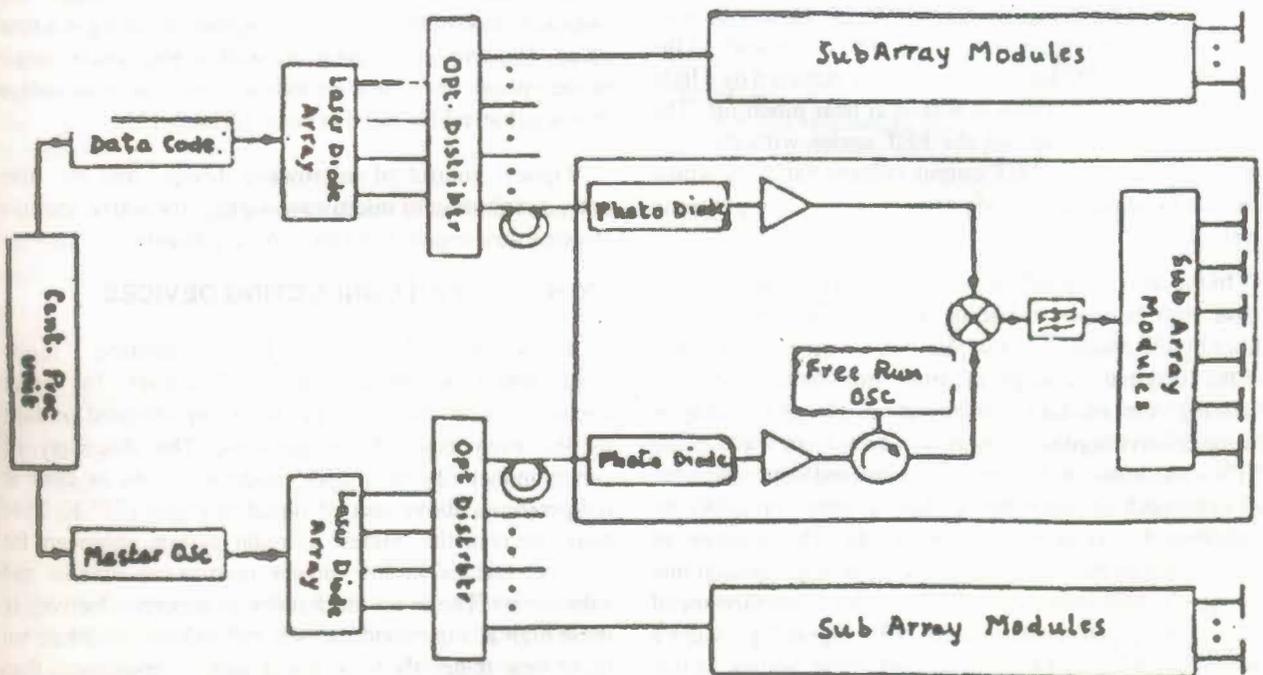


Fig 6 Conceptual representation of injection lock [14]

link and then distributed to the T-R modules. At the module, modulated light is first detected by a high speed photodiode and, after amplification is electrically injected into the local oscillator. By this means, higher master oscillator signal power and greater coupling can be achieved, which in turn results in a higher locking range and a better close-in carrier phase noise. Figure 6 presents a conceptual representation for injection locking in the distributed structure of an active aperture array [14]. In recent experiments where an efficient double stage microwave injection locking system has been explored [15], it has been conclusively shown that significant AM compression of 30 dB or more takes place because of enhanced gain and because of high compression the increase in AM to PM conversion does not result in noticeable noise conversion. However, since the phase of the injection locked oscillators in the T-R modules vary, the unwanted phase shifts will introduce pointing inaccuracy of the radiated beam. A technique of phase correction which is a combination of injection locking and phase locked loop and currently termed injection locked PLL (ILPLL) has been successful in phase and frequency coherence of remotely located microwave oscillators [16].

The use of optical signals for amplitude and phase control in beam forming and steering is another promising application which is being vigorously explored. In the indirect method a fibre optic link is used to transmit the beam control signals to the T-R module to activate the conventional phase shifting and gain control circuits. The feasibility of this technique has been experimentally demonstrated by controlling an eight element array antenna by means of a fibre optic link and a high speed hybrid GaAs optoelectronic integrated circuit for serial to parallel conversion of the control data [17]. An alternate technique is to transmit the appropriate phase shift commands to the T-R modules by FO links where they are detected by a light sensitive MESFET which is biased at near pinch-off. The drain to source voltage of the FET varies with the light intensity resulting in FET output voltage variation which can then be scaled to provide control signals at appropriate levels [18].

In the direct control method the concept of progressive phase shift between radiating elements can be achieved either by the controlling the phase delay or by going back to the original concept of true time delays between radiating elements for beam formation. The phase delay of the microwave signal is obtained in a coplanar wave-guide (CPW) transmission line in a multi-layered semiconductor substrate such as aluminium gallium arsenide on GaAs, by exploiting the slow wave (SW) mode. The velocity of propagation of the SW mode in the CPW transmission line is controlled through the use of Schottky controlled metal lines on the doped semiconductor [19]. Figure 7 provides a cross-sectional view of an experimental phase shifter. In this case an MBE-grown, 7 micron thick epitaxial GaAs layer is used on an SiGaAs substrate. CPW devices were then

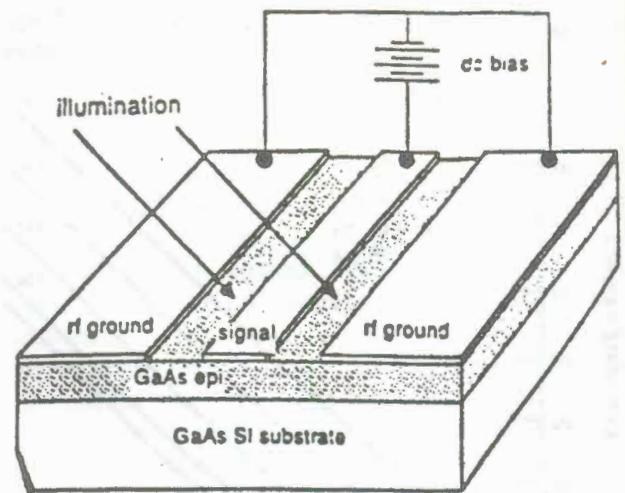


Fig 7 Combined Schottky contact optically controlled phase shifter [19]

fabricated on the substrate and the central conductor is reverse biased at 35 V dc. The device is now illuminated with spectral radiance below 750 nm with illuminating densities less than 4 mW/cm<sup>2</sup>. Since the light can be absorbed through the gaps between the central conductor and the ground planes, the maximum power absorbed was about 6 microwatts and at 20 GHz. This device showed a phase shift of 90°/cm with 12 dB/cm insertion loss. Clearly, it is a promising alternative. In the case of true time delay, the microwave signals directly modulate the laser output and the optical fibre transmitting these signals to the T-R module is wrapped around a piezo-electric crystal, the circumference of which is controlled by an external dc voltage [20]. Upon application of the voltage, the circumference of the crystal is elongated resulting in a time delay. Experiments conducted with a step index single mode optical fibre have established that true time delays can be achieved for antenna beam forming [21].

Optical control of microwave devices and the fibre optic distribution of microwave signals for active aperture systems now appear to be increasingly feasible.

### HIGH $T_c$ SUPER CONDUCTING DEVICES

Conventional metallic low-temperature superconductors had been considered earlier for radar applications but they have not been implemented because of the high cost of refrigeration. The discovery of superconductivity in copper oxide materials in 1987 at temperatures above that of liquid nitrogen (77° K) have again revived the interest of radar system engineers for passive devices in low power microwave circuits and subsystems. The exact mechanism of superconductivity in these high  $T_c$  superconductors is still a matter of debate but these new materials have lower surface resistances than such high purity normal metals as copper at the same temperature ( $<T_c$ ). Therefore there is motivation to

consider their use either in liquid nitrogen environment or with a closed cycle refrigerator. Superconductivity in these materials can be destroyed by operating temperatures above the critical value  $T_c$ , sufficiently high current densities, high magnetic fields and very high operating frequencies.

The new super-conducting materials can be used in two basic forms, namely, bulk and thin film. In bulk form they have relatively poor characteristics unless they are single crystal bulk material, leading to small size and small lots. The progress in the fabrication of thin films is far more satisfactory from the microwave engineer's point of view. Various deposition techniques such as off axis sputtering, E-beam evaporation and laser ablation have been successful in producing high quality thin films on a variety of substrate materials such as magnesium oxide, lanthanum aluminate, lanthanum, galleate, neodymium galleate. Except for magnesium oxide ( $\epsilon_r=9.6$ ) all the other substrate materials have a dielectric constant in the range 20 to 25. They have a loss tangent that is lower than  $10^{-4}$  in the microwave frequency band. When thin super-conducting films are used in microstrip transmission lines, the phase velocity of the electromagnetic wave has a dependency on the super-conducting properties of the strip and the ground plane so long as the thickness of the strip is small compared to the penetration depth. The penetration depth is defined as the characteristic decay length of the magnetic field into the superconductor. In contrast to the skin depth of normal conductor, the penetration depth has a strong temperature dependence and is independent of frequency in the region of interest to radar designers. For high  $T_c$  superconductors the penetration depth at absolute zero is about 0.1 micrometer and its value at any other temperature  $T$  is given by,  $0.1 \sqrt{\{1-(T/T_c)^v\}}$  micrometer. The parameter  $v$  varies from 1 to 4 in the extreme case. The reduction in the phase velocity of the em-wave propagating on the microstrip line is the result of the kinetic inductance contributions from the energy stored as kinetic motion of the charge carriers in the superconductor.

The most promising applications of superconductivity to passive microwave devices and subsystems can be ascribed to one or more of the following attributes.

- (i) Miniaturisation: super-conducting components can be configured to have much smaller size and weight as compared to the state-of-art normal conductor circuits.
- (ii) Superior performance: the very low losses associated with the super-conducting components makes the fabrication of ultra high- $Q$  resonators or nearly lossless transmission lines.
- (iii) 3-D Coupling: in guided wave propagation, significant percentages of the em-fields are contained in the superconductor rather than in the dielectric region. This permits new microwave circuits in a layered super-conductor dielectric structure.

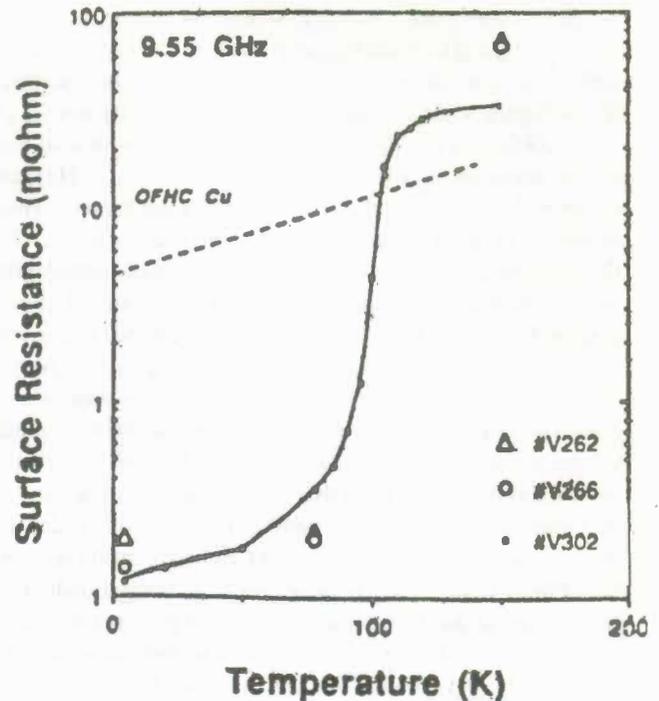


Fig 8 Surface resistance of superconducting thin films [24]

The meander line as a high  $T_c$  superconductor microwave components has been the subject of considerable attention because it is a convenient test vehicle to explore the RF losses of patterned thin films and also because it finds uses in the form of miniature delay lines, high- $Q$  resonators and discriminators [22-25]. Experiments with thin films of such super-conducting materials as Tl-Ca-Ba-Cu-O, Y-Ba-Cu-O reveal that at 77° K the films are at least twenty times less lossy as compared to OFHC copper at the same temperature even up to 10 gauss fields. Figure 8 shows the variation of surface resistivity versus temperature [24]. The loaded  $Q$ s of these microstrip meander line resonators are ten to twenty times higher in the 1 GHz to 10 GHz band (7300 at 2.6 GHz and 6000 at 7.3 GHz) than the values found for an identical thin film silver device at the same temperature. Though the  $Q$ s of the HTSC resonators decreased monotonically with increasing input power, at the highest input power of 1 W the loaded  $Q$ s were three times or more higher than the low power loaded  $Q$ s of silver resonator. At 7.3 GHz, the effective power in the resonator for an input power of 1 W is greater than 100 W and the peak magnetic field is greater than 100 gauss. Even under such conditions, the meander line was super-conducting. Even though the experimental results have established the superiority of the high  $T_c$  materials for microwave circuitry, there is a vast scope for bettering these results. With improvements in fabricating super-conducting thin films the gap of more than two orders of magnitude between the measured and predicted values for surface resistivity can be closed and with the use of dielectric substrates with loss tangents less than  $10^{-4}$  will lead to more than one order higher  $Q$  values.

Resonators made of high  $T_c$  super-conducting materials and with high  $Q$  ( $> 10,000$ ) can provide microwave sources with very low phase noise as compared to the existing technologies. Calculations show that for a cavity with a  $Q$  of 150,000, it is possible to have a 25 dB reduction in the phase noise at 1 kHz from the carrier (10 GHz) as compared to the crystal oscillator multiplier chain. This would be of great advantage in airborne radar systems. In the stripline configuration the meander line resonator will be truly miniature having a volume of less than 0.4 cubic centimeters at 1 GHz. This is made possible because with super-conducting strips very narrow ground plane spacings, of the order of 60 micrometres, can be used while maintaining low loss. The ratio of stripline width to ground plane spacing can be ignored. Even then the line width will be of the order of 1 mm so that the interline spacing can be very close without fear of coupling. Delays of the order of one nanosecond for a volume of 0.01 cubic centimeter can be obtained with the present high  $T_c$  superconductor technology so that non dispersive delay is possible with the meander line. Using hybrid integration techniques and with PIN diodes or HEMT devices as switching elements compact low loss phase shifters can be built.

In super-conducting microstrip lines where the ground plane, the dielectric substrate and the strip have thicknesses much lower than the penetration depth, the electromagnetic energy on one side of the super-conducting film can be transferred to the other side of the film. In addition, the phase velocity will be as low as  $0.1c$  ( $c$  being the velocity of light) so that the size of the microwave circuits is significantly reduced. These two characteristics make it possible to consider compact and elegant multi-layered MMICs which eliminate lines and cross-overs. The present difficulties faced by MMIC designers in compressing more circuit functions without increasing the surface area in one plane can be resolved by going 3D and still have a compact T-R module which can be easily fitted in the half wavelength spacing between the radiating elements of the array in the case of higher microwave frequency range.

It is visualized that as the available size and quality of the substrates and thin films continue to improve, high- $T_c$  super-conducting devices will find place in MMICs for forward locations in array antennas.

### QUASI OPTICS TECHNOLOGY

Quasi optics technology is based on the exploitation of the properties of quasi optical transmission which can be defined as the propagation in free space of beam of radiation that is a relatively small number of wavelengths in the transverse direction. The necessity for this has arisen because millimetre wave radar using components built in conventional propagation media are found to be lossy as well as expensive. The starting point is a Gaussian beam which can be produced by a scalar feed horn with 98% efficiency. The beam radius is smallest at the location and

the beam radius grows as it propagates away from the location according to the spreading factor.

$$\omega(z) = \omega_0 \left[ 1 + \left[ \frac{\lambda z}{\pi \omega_0^2} \right]^2 \right]^{0.5} \quad (5)$$

where  $z$  is the distance of the observation point from the location in the direction of propagation,  $\omega_0$  is the minimum beam radius called the waist ( $\geq \lambda$ ), and  $\lambda$  is the wavelength. Due to beam spreading the peak value of the electric field strength diminishes as  $z$  increases. The surface of constant phase are spherical with a radius of curvature given by,

$$R(z) = z + \frac{(\pi \omega_0^2)^2}{z \lambda^2} \quad (6)$$

At the beam waist where  $z = 0$ , the equiphase surface is planar and as  $z$  increases, the radius of curvature decreases initially reaches a minimum value

$$R_{min} = \frac{2\pi \omega_0^2}{\lambda}$$

and then increases asymptotically to the geometric optics limit. To exploit quasi optical propagation it is necessary to combat beam growth by refocusing the Gaussian beam. In effecting this, adequate clearance should be provided so that the beam is not truncated above  $-20$  dB level from the peak at the beam axis. By employing a combination of lenses and mirrors it is possible to achieve the optimum combination of compactness, low loss and consistency [26]. The Gaussian beam can handle any arbitrary polarization and it has a very high power handling capability since the transverse dimension of the beam is large compared to the wavelength.

Quasi optics has found application for generation of high powers in the millimeter wave frequency range with multiple solid-state sources. Since each of the solid-state devices is small compared to the wavelength and since their individual output is limited by thermal dissipation, power combining by guided wave combiners have been tried out earlier to obtain higher output. However the efforts to couple several devices in a single resonant cavity or coupling of one device per cavity and combining the output of several of them, did not produce stable, spectrally pure, high power, millimeter wave output. In quasi-optical system of power combining, the multiple sources are coupled to a quasi-optical cavity which can be large in terms of the wavelength. Since it also has a well-defined resonant field configuration, it would be possible to couple a large number of active devices. A quasi-optical cavity can be constructed from the two reflecting surfaces placed at any two points along the axis of propagation. It is however essential that the radius of curvature of the reflecting surfaces be equal to that of the beam at the two points so that the RF energy is reflected in the same Gaussian beam

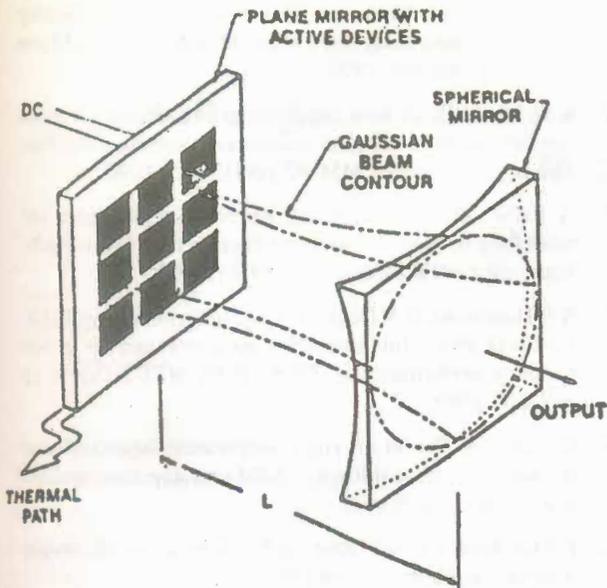


Fig 9 Schematic of quasi-optical power-combined oscillator [26]

mode. The resonance condition applied to the on-axis phase of the Gaussian beam is given by,

$$\phi(z) = \frac{-2\pi z}{\lambda} + \arctan \left[ \frac{\lambda z}{\pi \omega_0^2} \right]$$

for the fundamental mode. If one of the two positions of the reflecting surfaces of the cavity coincides with the beam waist, then the beam front is plane and all devices coincident with the beam waist will be forced to oscillate in phase. The emergent energy has the Gaussian mode distribution as it propagates inside the resonator towards the second reflecting surface. If this surface is partially reflecting, then the Gaussian beam couples out of the cavity. A schematic diagram of a quasi-optical power combined oscillator is shown in Fig 9 [26]. The active devices are placed at the beam waist and form the plane reflector of the quasi-optical cavity. The spherical mirror is the second reflector with a curvature which matches that of the Gaussian beam at that place. Output coupling can be achieved either by an aperture or by making the spherical reflector partially reflecting.

There have been several attempts to build quasi-optical power-combined sources. An interesting experiment is that of a 100 MESFET planar grid oscillator which gave an output of 21 watts of CW effective radiated power with a 16 dB directivity and 20% dc to RF conversion efficiency at 5 GHz [27]. Each of the MESFETs in a microstrip oscillator configuration is only capable of giving 20 mW of output. It has also been verified that the oscillator can be quasi-optically injection locked to an external signal. The planar grid oscillator can be tuned by a reflecting surface behind the grid so that the mirror and the grid form a Fabry-Perot

cavity about a wavelength long. The planar characteristics of the oscillator offers the possibility of a wafer scale monolithically integrated high power millimeter wave source. For example at 90 GHz with a grid period of 0.5 mm ( $\lambda/6$ ) a 2 inch GaAs wafer will be sixteen wavelengths across and will have 7500 devices. It will have a directivity of 30 dB and an ERP of 16 kW.

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# Challenges and Achievements of ISRO Satellite Missions

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I deem it my proud privilege and honour to be chosen for delivering the 24th Bhabha Memorial Lecture of IETE. I would like to thank Prof Indiresan and Prof Sonde for extending this invitation. Dr Homi Jahangir Bhabha was one of the most illustrious sons of modern India with a broad vision. A man of varied accomplishments, in such wide ranging fields as science, technology, scientific policy making and administration. Dr Bhabha also possessed sensitive and trained artistic gifts of the highest order especially in painting, pencil portraits and music. His early recognition of the possibility of economic prosperity and social changes based on science and technology led him to initiate India's atomic and space programmes. He took the first step in the Indian space programme through setting up, in 1962, of the Indian National Committee for Space Research under the Chairmanship of Dr Vikram Sarabhai. The establishment of TERLS near Trivandrum followed and plans for the Space Science and Technology Centre, now VSSC was then put in hand. Bhabha was also the Chairman of the Committee set up by the Government to identify plans for the development of electronics in the country. The subject matter of my talk is essentially an outgrowth of his pioneering efforts in space and electronics.

Long before Kepler, Galileo, Newton, Hertz and others enunciated the principles of celestial mechanics and electromagnetic wave propagation, that form the basics of our present activities in space, man always aspired to go realms beyond the limited confines of his planet, the Earth. The first space scientists to appear were solar system physicists and astronomers, who employed satellite for investigation at wavelengths not observable from ground, especially in the infrared and ultraviolet, X-ray and gamma ray ranges. Subsequent developments occurred in the field of Earth observation, with sub-disciplines including atmosphere, solid surface, water and ice, to be followed by Communication and Navigation.

A satellite for scientific experiments, depending on the objectives, is placed in a variety of orbits; for example for studies of high latitude and polar phenomena including aurora, highly inclined orbits are employed whereas in a

X-ray astronomy mission, calling for minimal secondary background effects, equatorial orbits are preferred in the altitude range 400-500 kms. Highly eccentric orbits with apogee as high as 60 to 100 thousand earth radii are used for magnetospheric studies. For earth resource observations, an important requirement is the constancy of the lighting conditions at a given point on the earth on a day to day basis. Such a condition is possible for the so called sun synchronous orbit where the orbital nodes maintain a near constant solar time and thus the satellite always crosses the equatorial plane at the same local time. This is realized by suitably choosing the inclination and altitude such that the regression rate is  $0.9856^\circ$  per day equal to the daily motion of the Earth round the Sun. Further, in order to realize global coverage, near polar orbits are chosen. A geostationary orbit, one in which a satellite appears stationary relative to the earth, is most widely used for communication satellites. An earth station antenna pointed at such a satellite automatically follows it and elaborate tracking systems are not required. Geostationary orbit lies directly above the equator at an altitude of 35,786 km, the period for which is 23 hours and 56 minutes. Whereas a geostationary orbit, being in the equatorial plane has zero inclination, one can also have geosynchronous orbits, which has the same orbital period as the earth's spin period at some inclination ' $i$ ' but is geostationary as viewed from the fixed location of earth. Such a satellite would appear to move in a figure of eight pattern.

## SATELLITE – AN EXERCISE IN MULTI-DISCIPLINARY TECHNOLOGY

A satellite is the product of a variety of engineering disciplines. Though these disciplines are brought to bear on the realization of a number of terrestrial systems, what distinguishes the application of these engineering principles to a space system is the need to realize systems that would operate unattended and with a high degree of reliability in the demanding environment of space.

Space is characterized by high vacuum, microgravity and radiation. The vacuum, for example at an altitude of

500 km, is of the order of  $10^{-8}$  mbar. Such vacuum level has obviously implications on the heat transfer characteristics of the satellite, since the conduction and radiation process will dominate and convection efforts will be nearly absent. Microgravity environment, typically  $10^{-3}$  to  $10^{-4}$  g, causes modification on the flow pattern and surface tension characteristics of fluids, especially important for the design of propulsion tanks carrying large amounts of fluids as well as performance of heat pipes. Radiation, in the form of energetic protons and electrons as well as UV radiation result in the slow-degradation of electronic components and materials used for thermal control surfaces. For a geosynchronous mission, the particle dosage over a life time of 7-8 years can be as high as  $10^5$  rads. Use of radiation hardened components is important in this context.

In order to make the systems light weight, low power consuming and miniature, high degree of design optimization is called for. The engineering disciplines in a spacecraft encompasses structure, thermal control, power, telemetry, command and tracking systems, attitude and orbit control, electro-optical sensors as well as propulsion systems.

Structure enables safe housing of all the subsystems and adequate shielding against the hostile environment of space. It also provides payloads and other subsystems ability to withstand environment loads arising from ground handling, transportation, launch and orbit phases. The thermal control system enables maintenance of the temperature of the different systems within specified limits while the spacecraft is in orbit. During its normal operation in space, a near-earth orbiting spacecraft receives heat input from the Sun ( $140 \text{ mW/cm}^2$ ), reflected albedo radiation ( $48 \text{ mW/cm}^2$ ), and emission radiation ( $23 \text{ mW/cm}^2$ ) from Earth as well as from internal heat dissipation. Further, the spacecraft radiates heat back into space, which is at a temperature of about  $3^\circ\text{K}$ . The objective of the thermal control design is to realize acceptable equilibrium temperatures for the different systems taking into account various heat inputs and outputs. The power system generates power under different orbital and operating conditions of spacecraft as well as power conversion involving regulation and control of output to satisfy the requirements of satellite subsystems and payloads. Power generation is realized normally by the use of panels with silicon solar cells. Energy storage using chemical batteries such as nickel cadmium batteries provide eclipse and peak power requirement and are characterized by high energy storage density and long life. Power management circuitry call for high system efficiency along with fault tolerance and isolation against user malfunction, and monitoring of the generator and control storage elements. The attitude control of a spacecraft is the orientation of its fixed axis with respect to a desired reference frame thereby providing the necessary alignment for the operation of

payloads, sensors, antenna and even solar panels. The relevant information about the attitude is generated by a system of sensors that sense the direction of certain well-known landmarks in space such as the Sun, the earth's magnetic field, the infrared horizon of the earth or some bright stars. The errors in the pointing are then corrected using elements known as actuators such as reaction and momentum wheels, magnetic torques and propulsion thrusters. Processing of the attitude information, estimation of errors and executing necessary corrections are normally carried out by the attitude control electronics using often microprocessors. The spacecraft propulsion, that impart suitable velocities/torques through expulsion of cold or hot gases, is needed for the orientation (attitude control) and positioning (orbit control) of spacecraft. Satellite use propulsion systems of different types such as, cold gas systems, mono-propellant hydrazine and unified propulsion system based on mono-methyl hydrazine and nitrogen tetroxide. The telemetry, tracking and command (TTC) system, in a space mission performs three primary functions, namely, telemetry, telecommand and tracking. The information gathered from the experiments, various auxiliary on-board instruments as well as about the spacecraft health is normally processed suitably and transmitted to a ground station via satellite telemetry. The telecommand system enables the exercise of control on the spacecraft from a ground station. Operations such as putting the spacecraft in different functional modes and correcting any in-orbit anomalies are carried out using this system. Determination of the location of the satellite at different times during its orbital motion is made possible by the tracking system. TTC systems presently employ S-band or C-band frequencies to provide for higher accuracies, higher performance standards and for compatibility with international tracking networks. Many of the spacecrafts also use mechanism elements to deploy different appendages such as solar panels and antennae.

## ISRO SATELLITE MISSIONS

The ISRO Satellite Missions are primarily applications driven and aim at establishing and operating national systems for several developmental endeavours. Applications such as telecommunications, TV broadcasting, disaster warning systems, rural telegraphy and business communications and meteorological observations are realized through the development of geosynchronous satellites. On the other side, earth resources survey satellites provide key inputs to the National Natural Resources Management System (NNRMS). The attendant efforts include development of a variety of spacecraft technology and techniques including several types payloads such as transponders and electro-optical cameras for communications, meteorology and remote sensing applications. Further, necessary methodologies for on-orbit management of the satellites and setting up of the associated ground systems are also called for.

Additionally, a variety of test facilities such as space simulation chambers, vibration tables, acoustic chamber etc have been systematically established.

The satellite capability of ISRO was evolved in three broad phases. In the first step, which can be termed the learning phase, the basics of the technology were learnt in the process of actually designing, building and operating the satellite Aryabhata. During the next step, which can be characterized as experimental, missions like Bhaskara and APPLE were conceived and executed to gain experience in the conduct of space missions on an end-to-end basis, in respect of specific application goals in remote sensing, meteorology and communications. Essential methodologies like characterization and design of the remote sensing payloads and associated definition of spacecraft platforms as well as three-axis stabilization, orbit-raising and on-orbit operations for geo-synchronous missions were learnt during this phase. During the same period, small 40 kg satellites called Rohini were developed as payloads for SLV-3. These satellites were characterized by high level of miniaturization and light weight and low power systems and had application and technological objectives. The third step involving the design and development of operational satellites is currently underway. The Indian Remote Sensing Satellite, IRS-1A represents the first in a series of remote sensing satellites capable of providing operational services for resource survey and monitoring. In the case of communications and meteorology, the indigenously developed INSAT-2A represents the second generation INSAT satellites with augmented capacity and improved capabilities, vis-à-vis, the bought out the INSAT-1 satellites. A series of 150 kg class satellites known as SROSS are also presently under development for the conduct of astronomy and aeronomy experiments.

### IRS-1 SYSTEM IN RELATION OF NATIONAL RESOURCE MANGEMENT

Since its launch in March 1988, IRS-1A, the first in the series of operational remote sensing satellites, has enabled operationalization of remote sensing services in the country using our own indigenous space segment. IRS-1A imaging sensors, that are CCD based Linear Imaging Self Scanners (LISS-I, LISS-IIA and LISS-IIB) working on push-broom principle, were selected based on specific application needs of the users, state-of-the-art technology and scope for future growth. The camera systems can resolve spatial features on the ground to the level of 72 meters and 36 meters. The three axis stabilized 975 kg satellite, placed in a 904 km polar sun-synchronous orbit with an orbital period of 103 minutes, crosses the equator at 10.25 hours local time and returns to its original orbital trace every 22 days enabling repetitive collection of data over the same area at the same local time with a frequency of three weeks. The satellite has sun-tracking deployable solar panels, four reaction wheel based zero momentum

attitude control system for precision pointing with low jitter, a variety of sensors such as IR earth sensors, sun sensors and dry tuned gyroscopes for pitch, roll and yaw measurements, hydrazine based reaction control system and a TTC system in S-band. Further, the digitized image data, about 25 Mbs, are transmitted through separate X-band and S-band communication channels. Even though designed for a life time of 3 years, the satellite continues to function normally, presently in the 5th year. A second satellite, IRS-1B which is identical to IRS-1A was launched in August 1991. This satellite which has completed one year of operation recently will provide the continuity of services as the life of IRS-1A comes to an end. Presently with both the systems concurrently operating, it is possible to get a repetitive coverage of any location in 11 days thus improving the ability to look at changing phenomena like crop growth with a higher reptitivity. IRS-1A and 1B compare well in their capabilities and performance to the two other presently operating systems, viz Landsat-5 and SPOT-2.

Remote sensing applications in India, under the umbrella of the National Natural Resource Management Systems (NNRMS), with Department of Space as the nodal agency, now cover diverse fields such as agricultural crop acreage and yield estimation, drought warning and assessment, flood control and damage assessment, land use/land cover mapping for agro-climatic planning, wasteland management, water resources management, ocean/marine resource survey and management, urban development, mineral prospecting, forest resources survey and management, etc, thus touching almost all facets of national development. Let us examine three of these in a little more detail.

#### Forest management

Satellite remote sensing is playing an important role in the survey and monitoring of forests because of its ability to provide timely and accurate information. Large areas marked as forests in the vintage maps of 1970's hardly have any trees left due to the immense pressure on land. It was observed, from forest maps prepared using remote sensing data, that in just eight years since 1974, India's closed forest cover have fallen from 14% to only 11% of the total land area. This is against 30% regarded as minimum desirable by ecologist. The amount of area deforested during this period alone is about twice that of the entire state of Kerala. Forest Survey of India is now carrying out on an operational basis, biennial forest mapping for the entire country using satellite remote sensing data. New techniques for forest density and volume estimation are also being developed.

#### Wasteland mapping

About 20% of India's land area is considered as wasteland due to salinity of soil caused by excessive use of fertilisers, improper irrigation procedures, degradation due

to prolonged agricultural usage, use of slash and burn clearance techniques and due to the spread of desert. Recent satellite data have shown that about 45,000 sq km, covering 13 of the 17 districts in the Aravalli hills region, have already become wasteland.

Under the aegis of National Wasteland Development Board, a project was taken up for wasteland mapping of 146 critically affected districts in India. 20 State/Central agencies were involved to carry out this nationwide wasteland mapping. Detailed satellite mapping of wasteland has helped in identifying 13 recognisable wasteland categories; almost half of which, with some efforts, can be reclaimed for agricultural production. Using geographical information system, land use/wasteland information derived from satellite data is being used to generate comprehensive solutions towards reclamation of wastelands. Considering that almost half of the wasteland in India which amounts to about 25 m hectares can be reclaimed for productive use with appropriate agricultural practices, the delineation of the extent and type of recoverable and non-recoverable wasteland at micro level, from space imageries assumes great importance.

#### Ground water potential mapping

The national drinking water mission, initiated in 1987, aims to bring adequate potable water to every one of India's 6,00,000 villages. Under this mission, the hydro-geo-morphological maps, generated using satellite remote sensing data, are being extensively used for locating borewells. The usefulness of satellite data in identifying linear features such as fractures/faults, which are usually the zones of localisation of groundwater in hardwork areas, and certain geomorphic features such as alluvial fans, buried channels, etc, which often form good aquifers is well established. Mapping on 1:50,000 scale has been completed for about 1,60,000 villages which have acute shortage of drinking water. For the first time, the entire country, covering 447 districts, has been mapped on a 1:250,000 scale for ground water exploration. Success rates of better than 90 per cent have been achieved with satellite data compared to about 45% using only conventional means.

#### National Resources Information System (NRIS)

Under NRIS, it is planned to develop digital data base on all natural resources at various levels of decision making, namely, tehsil, district, state and central levels specifically highlighting information essential for the strategic, tactical and operational level planning. The system will contain information on all the natural resources, such as forests, crops, wastelands, land use, minerals, water resources, geology, soils, etc, beside the topography and other terrain conditions. While remote sensing derived information on these resources may form the major inputs, the socio-economic indicators will be

added to the information in the form of Geographical Information System (GIS).

#### INSAT-2A MULTIPURPOSE SATELLITE

The second generation INSAT system configuration studies were started as early as 1979. Detailed exercises were carried out along with user agencies to define the capacity and capabilities required to be met in mid 1990s and to configure the overall system and the spacecraft.

From the studies, it emerged that three distinct services are to be catered to through the INSAT-2 system, viz Fixed Satellite Service (FSS) for Communication, broadcast services for TV which may or may not include direct broadcast and meteorology with VHRR as payload for realizing 24 hour imaging capability. While the first two services are similar in nature, requiring similar specifications on the spacecraft bus, the third has a different kind of requirement. For example, the absolute pointing is an important consideration for the first two services whereas for VHRR, the pointing stability is more crucial.

The design of a 3-axis stabilized dedicated communication satellite can be built on biased momentum principle, similar to that of APPLE. On the other hand, the stability requirement of VHRR can be simply met by a dual spinner satellite. Even the design of VHRR can be simplified as one axis scan can be reduced since spin itself will provide the scan in East-West direction.

ISRO studies involved cost/complexity trade offs of separate satellites vis-à-vis a single multi-mission satellite. The multi-mission satellite becomes complex in configuration and operations due to the cooler requirement of VHRR, which should always look at north to avoid solar radiation. This necessitates single side solar panel (south) and hence a disturbance compensating sail and boom assembly on north face. The control system design must include capability to actively damp the nutation component.

The dedicated satellite scenario would require two communication satellites for meeting the minimum service, with one in-orbit spare and one ground spare. Similarly, for meteorological application, two satellites in-orbit with one ground spare will be needed. Thus, there would be a total of five on-orbit satellites and two spares on ground. Assuming the cost of a communication satellite as X, that of meteorological satellite 0.5 X and the launch cost as 2X, the total cost implication in dedicated mission scenario would be 13.5X. In a multi-mission scenario, the cost of one satellite may be 1.25X and two on-orbit satellites with one on-orbit spare and a back-up on ground would be needed at a total cost of 10X. Further, such a strategy could result in saving of substantial efforts related to the mainframe satellite as only 4 satellites are needed as against 7 in the other case. In terms of on-orbit operations,

it is much more cost effective to maintain three satellites on-orbit against five in the dedicated case. The so called complexity in the multi-mission satellite was assessed to be within the capability of ISRO and hence, the decision to go for multi-mission satellite was taken. An additional aspect of the study related to the realization of a distributed payload using a system of collocated satellites. This led to a potential concept of two collocated identical multipurpose satellites at the primary location operating on orthogonal polarization for FSS. These, together double the FSS payload and increase the eclipse capability of the primary location. They can then be backed by individual satellites at the major path locations either for substituting or augmenting the system capacity in the nominal case. Though the system may appear to be at a disadvantage due to the relatively smaller size satellites, since the required in-orbit spare capacity is reduced to a single INSAT-2 satellite, it becomes quite competitive with a system employing a large satellite backed up by an identical large spare/major path satellite. Also, the all-up system capacity build-up is gradual and not one shot, which enables utilization to be grown in a matched manner. A 406 MHz search and rescue transponder for immediate detection of 406 MHz alert/distress signals too has been added on INSAT-2A and INSAT-2B.

### INSAT-2 spacecraft configuration

The INSAT-2 spacecraft look somewhat similar to INSAT-1, but are about 50% heavier, and have higher capabilities. The dry mass of INSAT-2 spacecraft is about 905 kg and solar panels with a total area of 15.5 sq m are sized to generate approximately 1024 W power at end of life. It is a 3-axis body-stabilized spacecraft using bipropellant micro thrusters and Momentum-Wheels/Reaction Wheels (RW). Two equipment panels on the North and South face accommodate major subsystems and payload modules. The remaining modules are located on the Earth viewing and anti-earth viewing panels. The indigenous 440 Newton bipropellant apogee boost motor is housed inside the cylinder with the nozzle projecting out on the anti-earth viewing side. The solar torque imbalance is counter-acted by the solar sail on the North side. There is also an omni TTC antenna located on the north panel.

Reflectors of 1.77 m size which provides C and S-band transmit functions are located on the East and West faces. A 900 mm antenna fixed to the body on the Earth viewing face performs the C-band receive and DCS, VHRR and S&R data transmit functions.

In the on-orbit mode, the spacecraft attitude stabilization is based on a biased momentum approach using two skewed pitch momentum wheels. A third yaw reaction wheel is available as a back-up. A microprocessor based AOCs employing redundant IR scanning Earth sensors actuates the wheels and provides high pointing accuracy and low jitters. Additional sun-sensors, the gyro-

package, and the RCS are used for station keeping operations.

Each INSAT-2 spacecraft has 18 C/extended C-band, (3.7-4.2 GHz/4.5-4.8 GHz) FSS transponder channels, two high-power S-band transponder channels, a data relay transponder, a 406 MHz search and rescue transponder, and a Very High Resolution Radiometer (VHRR) with improved (2 kms visible and 8 km IR) resolutions.

### INSAT-2A operations

The INSAT-2A spacecraft was launched by the ARIANE-IV rocket from Kourou, French Guyana on July 10, 1992.

After injection by the rocket into the transfer orbit, the spacecraft weighing 1906 kg was put through a number of manoeuvres. Table 1 summarises the major highlights of these operations leading the spacecraft to its final orbital slot at 74°E and realization of the full on-orbit configuration.

As of now, the spacecraft is fully functional with all the payloads being kept on. With the available fuel of about 230 kg taking into account the requirements for NS and EW station keeping, attitude maintenance, deorbiting and few contingencies, one can envisage 10 years of fuel availability.

### Utilization aspect of INSAT

#### Telecommunication utilization

The telecommunication component of the two-satellite INSAT-1 space-segment was designed to provide over 8000 two-way long distance telephone circuits potentially accessible from any part of India. The utilization of the INSAT system for telecommunications is based on (a) the cost-effectiveness of satellite links between places separated by long distances, (b) higher order reliability of satellite services and their negligible sensitivity to terrain, and terrestrial disasters, (c) the comparatively higher order flexibility in routing of circuits, and (d) diversity of media. Unlike the single route, fixed capacity nature of terrestrial wideband transmission links, the satellite offers flexible network management. The satellite medium also offers the provisioning of interim services at short notice.

INSAT-1 telecommunications capacity is used by the Department of Telecommunications for

- (a) Supplementary use of important, long distance trunk routes providing a portion of the total capacity thus resulting in better reliability and flexibility besides greater immunity from breakdowns and natural disasters;
- (b) Remote area, short-term/interim and emergency communication services; and

(c) Special Business Subscribers Networks providing voice, data facsimile and computer communications.

Presently, INSAT-1D system, together with six C-band channels of INSAT-2A operates over 4,500 speech circuits covering 120 routes amounting to 100,000 route kilometres of communication facilities, as against 70,000 route km of terrestrial communication links.

### Television utilization

Availability of INSAT space-segment capabilities have been a major catalyst in the rapid expansion of terrestrial television coverage in India. The total flexibility available for location of the transmitter and use of comparatively simpler equipment like TVRO to establish the satellite link have been the most useful advantages which were fully exploited for realisation of the expansion. Satellite television covers over 65% of the Indian land mass and over 80% of the Indian population.

Two S-band transponders and one C-band transponder of INSAT-1D and two C-band transponder of INSAT-2A provide the following satellite television services in India. (a) National networking service in 2.5 GHz band on CxS1 transponder of INSAT-1D. (b) Educational TV (ETC), West Bengal regional service and Assamese news service in the 2.5 GHz band on CxS2 transponder of INSAT-1D. (c) Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and Orissa Regional services in the 3.7-4.2 GHz C-band on two INSAT-2A and one INSAT-1D transponders.

### Disaster warning system

The INSAT Disaster Warning System (DWS) makes use of the direct to community broadcast capability of the INSAT satellite system. The system enables the Cyclone Warning Center (CWC) to directly and selectively address a particular area likely to be hit by a cyclone. Simple receivers, which are an adoption of direct satellite community TV receivers are located in the coastal villages. These receivers designed for continuous operation in rural coastal environment are tuned to receive specific codes which are assigned to particular locations. The CWC after determining the likelihood of a cyclone hitting a place, selects the appropriate code and sends this signal to the satellite through an earth station on an RN like carrier. The satellite relays the signal back to the ground to be received by all the receivers. But only those receivers tuned to the particular code transmitted activate a siren loud enough to be heard by people in the neighbored. The siren lasts for about a minute and automatically switches off. The CWC comes on the air after this period with the oral warning in the local language giving the details of the likely nature of the cyclone and the precautions to be observed, etc. CWC can repeat this procedure as often as desired and also change the warning message as the events develop. If the cyclone deviates from the course, CWC can

TABLE 1

Operation	Date	Result	Remarks
Launch	10th July	—	Transfer orbit injection within limits ( $a = 35812$ km, $p = 198$ km $t = 10.5$ hrs)
Injection	10th July	18 mins after lift off	—
Orientation	10th July	South panel pointing to Sun	—
First apogee motor firing	11th July	3930 sec burn 641 kg of fuel $V = 1.24$ km/sec	$a = 35821$ km $p = 22405$ km $t = 18.5$ hr
Second apogee	13th July	806 sec 113.4 kg of fuel $V = 282.7$ m/sec	$a = 35818$ km $p = 35210$ km $t = 23.7$ hr
Solar array deployment	14th July	Successful	Reorientation of S/C carried out
Earth acquisition solar array slew	14th July	Normal	Spacecraft in L-mode using one momentum and the reaction wheel
East antenna reflector deployment	15th July	Successful	—
West reflector deployment	15th July	Successful	—
Solar sail deployment	15th July	Successful	—
Three axis Earth point-mode	15th July	S/C in V-mode	Using the two momentum wheels
TTC global selection	17th July	Normal	—
Magnetic torque operation	18th July	Normal	Reduces the duty cycle on thrusters
Station acquisition manoeuvres	23-31st July	74.02°E on 31st July	East-West manoeuvres
VHRR payload operation	27-28th July	Normal	Full/Normal/Sector frames
Communication payloads (i) Ext C-band (ii) DRT ON (iii) SAR ON (iv) C-band (v) Normal (vi) S-band	27-31st July	Normal	Detailed Characterization carried out
Final pitch bias given	31st July	1.29° deg	Beam center points towards 82°E and 22°N

direct the warning to another area and in fact give out different warning to different locations.

100 DWS receivers have been installed along the coastal belts of Tamil Nadu and Andhra Pradesh. The system is being expanded to cover other coastal states which are cyclone prone. The INSAT DWS system in conjunction with the VHRR imagery was successfully used in issuing timely cyclonic warning to the affected areas during the May 1990 cyclone which hit Machalipatnam in Andhra Pradesh on 7th May 1990.

### **Satellite Aided Search and Rescue (SAS&R)**

India is a Member of the International COSPAS-SARSAT Programme which provides distress alert and position location service through the low-earth orbiting satellites. Appropriate ground segment has been operational since 1989 and the special 406 MHz beacons have also developed in India.

While the LEO satellites are well-suited for this service due to their ability to provide alert location information, the time gap between passes, particularly in the equatorial region has been found quite high at times, and the need for reducing such time gaps had been strongly felt. As the 406 MHz beacons, designed for the COSPAS-SARSAT system, operate at a fairly high power level (5W), it was recognised that using a 406 MHz receiver on a geostationary platform could help in almost real time detection of the distress signal, which could help in early mobilization of the search and rescue process. Hence, it has been decided to carry a SAR payload onboard the first two of the INSAT-2 series spacecraft, which will receive the emissions from the 406 MHz beacons, translate the signals to C-band and transmit the same to the ground station. The 406 MHz receiver onboard is integrated with the 402 MHz receiver of the data relay transponder. Necessary ground station equipment, receiver and processor, will be located at INSAT master control facility to detect the signals, which will then be fed to the COSPAS-SARSAT Mission Control Center, at ISTRAC, Bangalore for further action.

Beside the United States, India would be the first country in the world, to incorporate the geostationary satellite component for search and rescue.

### **CONTROL SYSTEM DEVELOPMENT FOR ISRO SPACECRAFT — AN EXAMPLE OF EVOLVING COMPLEXITY**

The realization of state-of-art operational spacecrafts called for the development of a number of technologies. While it is not possible to elaborate the details of each one of these developments, a good idea of the related efforts can be obtained by the examination of the evolutionary trends of the control systems employed in different missions.

*Two of the common methods of attitude control are spin stabilization and three-axis control. Spin stabilization essentially involves spinning the satellite normally about the axis of the maximum moment of inertia and subsequent maintenance of the desired spin rate and spin-axis orientation. Three-axis control, on the other hand, involves a feedback loop for each of the three axes, wherein the attitude errors are sensed by sensors and the control electronics processes this information to implement the desired control laws and drives the torquing devices. Earlier Indian satellites like Aryabhata, Bhaskara-I and II, RS-D1 and D2, with body-mounted solar panels, were spin stabilized. However, as the payloads become more sophisticated, the demands on the specification of attitude errors, body rates and jitter become more stringent. In addition, with the increase in the size and complexity of the spacecraft, the associated power requirement also increase. The natural solution to these requirements is found in the use of deployed solar panels and the 3-axis mode of attitude control. APPLE was India's first experimental geostationary communication satellite wherein our 3-axis control capability was first established.*

Coming to the current programs, the 3-axis, stabilization system for IRS is based on a 'zero momentum' four reaction wheel configuration for the normal mode and Reaction Control System (RCS) thrusters for acquisition and orbit control modes. Unlike the case of APPLE, IRS has stringent specification on the platform stability of  $3 \times 10^{-4}$  deg  $s^{-1}$  during the payload operation to reduce the image smear. This was perhaps the single most challenging feature in the IRS control system design and was eventually achieved with the implementation of a suitable compensation for the momentum coupling of the roll and yaw wheels and an extended Kalman filter which estimates the uncompensated coupling torques in addition to the attitude errors and rate. Another salient features is the automatic detection and reconfiguration of the reaction wheel system in the event of a failure in one of the wheels, without any interruption in the control system performance.

The overall control system design has to be fairly robust in the presence of parametric variations, noise and single-point failures, and yet has to be simple and reliable. This makes the dynamics modeling and control system design rather involved, and has to be backed up by extensive computer and hardware-in-the-loop simulations, incorporating all the characteristics of the hardware elements, nonlinearities, noise and scale factors.

While the computer simulations form the heart of the overall control system design, an important concept in the design validation, particularly for high performance spacecraft like IRS entails the use of a 3-axis servotable. Here, the servotable reproduces the computer simulated motion with high accuracy. The various sensors are mounted on the servotable with earth and sun simulators

and other hardware such as the control electronics and actuators are kept in environmental chambers. The computer interfaces with these components in real time and collects all the relevant data which, in turn, are fed to the spacecraft dynamics model in the computer.

In the case of INSAT-2, the control system design was a complex and innovative task due to multimission requirements of communication and meteorology. A microprocessor-based system was chosen as it would facilitate the implementation of sophisticated control techniques as well as the safety features of wheels, RCS, sensors and automatic redundancy management at the subsystem level. An important constraint that has to be satisfied at all times, including during any of the complex control manoeuvres and contingency operations, is that the Sun should not be in the field of view of the Very High Resolution Radiometer (VHRR) cooler.

The attitude orientation requirement for Liquid Apogee Motor (LAM) calls for attitude manoeuvres and advanced in-orbital attitude propagation algorithm using quaternion has been adopted. This also provides reference during the transfer orbit where only two axis information is available from the sun sensor.

Two other major areas that have to be addressed additionally, are the effects of liquid sloshing and interaction of control with flexible structure. INSAT-2 during launch carries about 1000 kg of liquid propellant. A detailed analysis has been carried out to ensure that the presence of such a large amount of fluid does not introduce any adverse dynamic condition and the 'slosh' does not cause instability in any of the modes. Regarding the second aspect, with a solar sail on the north face for balancing the disturbance torques due to the action of the solar radiation pressure on large array of solar panels on the south face, a detailed study on the control-flexible appendage interaction becomes indispensable. This would essentially involve modeling of the flexible body dynamics in terms of the frequencies and mode shapes for the flexibility modes and using this information together with the control torques to compute the reflected torques developed on the spacecraft body. The performance of the control system is then evaluated through elaborate computer simulations.

Coming to the control electronics, the Attitude Control Electronics (ACE) does the onboard processing needed for spacecraft control and generates the control signals for driving the actuators. As the control system requirements become stringent, the ACE is required to carry out many functions involving a lot of high speed computations. Although some of the earlier spacecraft such as BHASKARA-I and II and APPLE had entirely discrete IC-based hard-wired systems, partially microprocessor-based control electronics were developed for RS-D1 and D2, SROSS and IRS satellites. Microprocessor-based

systems offer high flexibility such as remote programmability and multimission adaptability. The initial development was on 8 bit RCA 1802 microprocessor, only one available with requisite reliability in the early eighties and same was used in SROSS and IRS programmes. For INSAT-2, needing more complex and fast execution of algorithms 80C86 radiation hardened microprocessor from Harris is being used.

As a part of control system technology development, several challenging efforts were undertaken in the area of actuators that led to the successful realization of indigenous reaction wheels, momentum wheels, magnetic torquers, nutation dampers and monopropellant and unified biopropellant reaction control systems. Similarly, several types of attitude sensors, such as IR horizon sensors, digital and analog sun sensors, dry tuned gyroscopes, star sensors and magnetometers have been developed. In a nutshell, the challenging demands of the current generation operational spacecrafts, characterized by precise pointing accuracies, low jitter and drift rates and long-life have been successfully met by these developments.

## RELIABILITY ASPECTS

For the operational satellites like IRS and INSAT, the realisation of planned reliability levels during the design life times of satellites is the crucial factor in determining the success of a mission. Planned life times for the IRS class of near-earth orbiting satellites are of the order of 2-3 years, whereas for the geosynchronous INSAT-2 class, it is 7-9 years. The quality and reliability aspects are brought to bear on several facets of spacecraft activities that include choice of proper materials and components, well-defined fabrication methodologies, rigorous test and evaluation plans at sub-system and system levels, as well as carrying out analysis such as fault-free analysis, and failure-mode effect and criticality analysis that could provide valuable inputs to the definition of satellite configuration. Typical failure rates for onboard electronic components lie in the range of  $10^{-12}$  to  $10^{-15}$  per hour. At the system level, the reliability and quality aspects are ensured through comprehensive test plan which includes vibration and acoustic environments for launch phase as well as thermovacuum and solar simulation test for orbital phase. A major 9 meter large space simulation chamber has been established with 4 m solar beam for carrying out solar simulation test for INSAT and IRS class of satellites. The successful operation of IRS-1A for the last 4½ years and IRS-1B for the last one year, fully testifies to the quality control and reliability aspects being followed in the ISRO satellite programmes. Further, the recent flawless commissioning of INSAT-2A through a series of difficult manoeuvres validates several aspects of test and evaluation of this complex satellite. As an illustrative example, the deployment mechanisms onboard INSAT-2A employed nearly 8,500 fabricated and standard

components. The design, development, qualification and simulation on ground generated nearly 5,000 pages of documentation. About 1,700 man months of effort were expended for their realization.

### FUTURE DIRECTIONS

With the ISRO satellite program entering the operational era, the primary emphasis of future activities will be to ensure continuity of service through IRS and INSAT, besides expending and strengthening some of the services. Other dimensions to the future directions could be to develop new and more versatile versions of space platforms and plan scientific missions as for planetary exploration.

### IRS series

The second generation of IRS series, IRS 1C/1D, will have enhanced capabilities in the form of higher resolution cameras operating from 817 km polar sun-synchronous circular orbit. Three cameras - one operating in panchromatic band and the other two in multi-spectral bands - have been included in the configuration. The panchromatic camera will have off-nadir viewing capability which will help in revisiting a place within 5 days. Off-nadir viewing angle can be controlled from ground up to a maximum of  $\pm 26^\circ$ . Panchromatic camera provides imagery better than 10 meters resolution covering a swath of 70 meters. The multi-spectral camera incorporates middle infrared band in addition to visible and near-infrared bands. It will provide imageries at a resolution of about 23 meters covering a swath of 140 km. The third camera, named Wide-Field Sensor (WIFS), will operate in two visible bands to provide imagery at a resolution of 180 meters covering a swath of 770 km. WIFS camera will provide data with a repetitivity of five days and will be useful in generating vegetation index information.

Parallely, a detailed study and some developments are also in progress in respect of a possible satellite microwave remote sensing mission towards the end of this decade. It may be mentioned that remote sensing at microwave frequencies with a synthetic aperture radar offers unique capabilities because of the ability to see through the clouds and being not dependent on the reflected radiation of the Sun.

### INSAT series

INSAT-2B, the second in the series of second generation INSAT satellites, is presently in advanced stages of integration and is slated for launch in the first half of 1993. It will be identical to INSAT-2A. The configuration details for INSAT-2C, 2D and 2E are also being presently finalised. Some of these satellites will carry transponders operating in Ku-band besides the

present C-band frequencies. Further, possibility of including improved resolution imaging sensors with CCDs for cloud and land cover imaging are also under consideration. Such sensors will have resolution of the order of 200 meter. Further, since it may not be necessary for all the spacecraft of INSAT-2 series to carry VHRR, possibility of reconfiguring with spacecraft bus with symmetric solar panel configuration, is also under study. Preliminary studies are also in progress in respect of defining a satellite mission called GRAMSAT, which would provide a variety of dedicated services in the area of rural development. GRAMSAT will be primarily a derivate of INSAT configuration and will carry 6-8 high power C-band transponders and 2-3 high power spot beam Ku-band transponders. The satellite will broadcast programmes which are region specific, language specific and culture-specific and the system may employ video compression technique. The applications would include rural education, instructions on agriculture practices, upgradation of skills in the shop-floor, lessons on health and hygiene, etc.

### AN INDIAN SPACE MODULE

Studies, presently being undertaken for the Indian Scientific Module (ISM), are at conceptional stage. According to preliminary studies the ISM could be launched onboard GSLV by the end of this century and could be placed in orbit of, say, one of the existing MIR space stations. The automated docking unit compatible with MIR docking ports will be developed jointly. The total weight of ISM could be about 8-10 tons out of which the scientific payloads complex could weigh about 2 tons. The outer dimension of ISM should be compatible with GSLV heat shield with the undeployed stage of ISM not measuring more than 3.6 m in outer diameter and 9 m in length. The length includes the thickness of coupling rings for GSLV top stage on one end and the docking unit on the other end. The effective usable length of the module will be about 8 m for housing the scientific experiments about 8 m. The power requirements of the experiment could be met through deployable or body mounted solar panels to generate 1 kW continuous power.

Some of the specific experiments envisaged on-board MIR space station/ISM are high resolution UV telescope with its own pointing platform, Long duration cosmic ray study, Atmospheric emission imaging, Differential Absorption LIDAR (DIAL) and Doppler LIDAR, material processing and human physiological/biological experiments.

### AN INDIAN PLANETARY MISSION

Generally, planetary missions are extremely complex technological exercises and are very expensive. Numerous planetary probes have been launched by the USA and the erstwhile USSR for exploration of the Moon, Mercury, Venus and Mars. Only fly-by's have been possible in case

of Jupiter, Saturn, Uranus and Neptune. Given this global scenario of planetary exploration, any possible Indian planetary mission has to take into account the wealth of likely scientific returns in addition to the technological fallouts. In view of this, a detailed study has been carried out to analyse the possibility of an Indian planetary mission with the framework of the goals of Indian space technology. The study has recommended an Indian mission to Mercury – first as a fly-by and then as an orbiter.

Since Mariner-10's maiden sojourn with the planet, there have not been much effort to revisit Mercury. The planet is a peculiar member of the solar system due to its 3:2 spin-orbit coupling and high density ( $5.45 \text{ gm/cm}^3$ ) as compared to its size. These characteristics make Mercury a very interesting planet for studying the gravity field, seismicity, magnetism, heat transport, volcanism, interior and surface geological features etc. There are no plans at present by NASA and other space agencies for a mission to Mercury in the current century. The main question about Mercury which still need to be resolved are

- (a) Is the unimaged half of the planet similar to the imaged one or are there different types of surface features which could significantly alter the current interpretation of the planet?
- (b) Is the core largely molten? What is the reason for the origin of the magnetic field? What is the detailed structure of magnetic field, and does it fluctuate in intensity and reverse polarity similar to the earth's field?
- (c) What is the surface composition and how does it differ from that of other terrestrial planets?

The development programme of India's satellite launch vehicles, particularly the recent advances made in the realisation of a geosynchronous launch capability (GSLV), has led to a few studies to explore the possibility to conceive an Indian planetary mission by the turn of the century. The results of such analysis are quite encouraging and it appears feasible to use GSLV for a mission to Mercury either as a fly-by or as an orbiter to the planet using the gravity assist trajectories of the planetary probe due to Venus and Mercury itself. The results of the study show that Mercury itself could be used through multiple swingbys prior to orbit insertion. GSLV would launch the spacecraft first into a 300 km orbit and later boosted to heliocentric orbit. The spacecraft would be designed to provide three axis stabilisation using the Sun for pitch and yaw control and a star as the roll reference. While flyby of Venus & Mercury would provide some opportunity to have a short glimpse of these planets, the Mercury orbiter could carry a number of instruments for imaging the surface and for remote measurements of the surface parameters & environment of the planet. In-situ particle detectors, plasma probes and magnetometer on board the orbiter

could provide vital information on solar wind and associated phenomena. The instruments carried in such an orbiter could include UV spectrometer for determining elements composition of rare and other gases, plasma analyser to measure solar wind particles in the transitional atmosphere of the planet, imaging with television or CCD cameras at a high resolution of 50-100 m in different visible & IR bands (only about half of the planet's surface has been photographed by Mariner-10), gamma ray, x-ray and IR spectroscopy to study the composition of the surface material of the planet, IR & microwave radiometers to measure thermal emissions from the planet and magnetometer for mapping the magnetosphere of the planet which may have arisen due to the internal dynamo field.

### CONCLUDING REMARKS

Phased development of the capabilities in the area of satellite technology over the last two decades, has enabled ISRO to reach contemporary levels in the area making India, one among the handful of countries capable of building and operating state-of-art remote sensing and geosynchronous multipurpose satellites. The efforts included design, development and qualification of a variety of related technologies and techniques, establishing design, fabrication and test facilities as well as evolving and implementing complex managerial approaches such as configuration control involving multiple agencies. Consistent with the goals for self-reliance, many of the technologies at the component level and nearly all technologies at sub-system and system levels have been indigenised. The successful operation of IRS-1A beyond the planned life time and the recent on orbit commissioning of INSAT-2 have unambiguously demonstrated the validity of design, reliability and test methods adopted by ISRO. The efficient on-orbit management of IRS-1A and 1B, SROSS and INSAT-I and II satellites, clearly points to the high degree of performance of the ISRO TTC network with the associated hardwares and softwares. To ensure that the benefits of these space systems reach the grass roots of national development, innovative national systems involving a number of user agencies have been set up. NNRMS for IRS and Interministerial Coordination Committee for INSAT are two such examples. In order to ensure continuity of services from such systems, Department of Space has drawn up a ten year profile that envisages building of similar as well as more sophisticated class of IRS and INSAT satellites.

Plans for India building satellites were initiated by Prof Sarabhai. The related activities took concrete shape when Prof Dhawan took over as Chairman, ISRO in 1972. Prof Rao, presently Chairman, ISRO, played a central role in the developments outlined in this talk. I recall with pleasure and gratitude my own association with these Indian space pioneers, in this exciting adventure.

## Some Challenges in Telecommunications

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I am greatly honored by the invitation to deliver this 25th Homi J Bhabha Memorial lecture. Echoing my title, may I say first that the lecture itself presented many challenges. One cannot but be daunted by the distinction of the past lecturers; the first three were Dr V Sarabhai, Dr S Bhagavantam and Mr A S Rao. Thanks to Professor Sonde, I had the advantage of access not only to their addresses, but also to all the previous Bhabha lectures, the Sarabhai lectures, and all the IETE Presidential Lectures. They provide much material for reflection on the development of Electronics and Telecommunications in India over the last four decades.

Generally speaking, the previous lectures fall into two categories - they either review a technical field related to the major interests of the speaker or they provide liberal doses of various kinds of advice. I had difficulties fitting into either mold. My own work has been somewhat abstract and mathematical, and while it was generally done with certain future applications in mind, it is difficult to describe to a general audience (a circumstance that makes things difficult for my wife when people wonder what exactly it is her husband does). The following story helped make up my mind on this issue. Dr Chaim Weizmann, a very distinguished chemist and first President of Israel (from which we welcome a distinguished delegation today) was traveling by ship across the Atlantic with Dr Albert Einstein (no introduction needed to any audience). "Every morning Einstein would explain his theory of relativity to me," Weizmann wrote, "and by the end of the voyage, I was fully convinced that he understood it!"

As for the second category of lectures, any temptations I had harboured about indulging myself in that way were scotched by the recollection of another story, involving someone who never shied away from giving advice. George Bernard Shaw used to write a weekly column for (I think) the *New Statesman and Nation*. One day in 1941, he had a long article with the bold headline: "Why Hitler will not invade Russia." As fate would have it, that very night, the German armies began their offensive into the Ukraine! Everyone was waiting (among other worries, of course) to see what Shaw would have to say the next week. There was

only a short letter to the Editor: "Sir, I am constantly making mistake in this world" (could that be GBS?)" by always assuming that other people are as clever as I am myself."

So what does that leave for me to do? To steer between these two rocks, I thought it would be the safest for me just to offer some reflections on what I have heard and read and seen, especially in recent weeks, on Telecommunications in India. Lots of very competent people in India are studying and writing about various issues in Telecommunications in India, e.g., at the Centre for Telecommunications Management and Studies in this very city, and at several other institutions and fora. The *Economic Times* seems to have at least an article a day on the subject. With all this background, my selection of topics and comments must perforce be limited in various ways, and some of you may find them rather shallow. But I hope that at least some of my remarks may inspire some of you to a deeper study; that after all is the proper role of an academic.

To begin with, the previous Bhabha lectures have naturally contained many perceptive comments and anecdotes about Dr Bhabha himself. He was indeed a Renaissance man. So one may not be surprised to see that in a bibliography of his works, besides papers in science, mathematics, policy, and collections of painting, drawing and sketches, is a 1952 article, "Leonardo Da Vinci, Five Hundred Years." Bhabha, too, was a remarkable visionary. We may recall his now well known remark, in a 1943 proposal on setting up what is now the Tata Institute of Fundamental Research, about the time, "say, a couple of decades from now, when nuclear energy has been successfully applied for power production." Very few contemporary physicists looked in this way beyond their heavy (and secret) labours on making atomic weapons. But this was not an isolated or accidental event. A few years later in 1948 Bhabha proposed the creation of the Atomic Energy Commission, then in 1954 the Department of Atomic Energy, the Space Research Committee in 1962, and the Electronics Commission in 1963. He was indeed someone with remarkable vision, a key ingredient in a leader. You may recall the ancient saying, "Where there is no vision, the people perish." Given this history, might not this audience in particular feel that but for his untimely

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passing Bhabha would surely have foreseen the critically of telecommunications development for India, and taken step to accelerate it? Would we have had to wait for another twenty-odd years, till 1989, for the creation of a Telecommunications Commission? And that too, through the efforts of an outsider to the system, Mr Satyen (Sam) Pitroda.

Not that by any means, the slate was completely blank during this time. In fact, I would like here to pay a tribute to my teacher (and President Sonde's), Professor S V Chandrasekhar Aiya, himself a research worker in the mid-forties with Bhabha, who in 1948 set up at the Poona Engineering College one of the earliest departments of Telecommunications in India. I can safely guess that several of you in this audience were his students, or may have worked with him or one or more of his many students. Some of you must have been present with Professor Aiya and many other distinguished confounders at the early meetings of this Institution of Telecommunication Engineers, when many glorious hopes were expressed and many directions laid out for the rapid development of Telecommunications in India. Thus the Chief Engineer of the P&T, Mr B R Batra, spoke eloquently in the first inaugural address of this Institution of Telecommunications being "one of the 'Thrimurthis,' along with Defence and Finance, vital to the existence and stability of the nation, alike in peace and war." Through it, he envisaged being able to "change living habits, expand knowledge, speed commerce, strengthen national security, disseminate education, improve standards of living and add to the health, comforts and pleasure of our fellow men." He also clearly outlined the importance of R&D cycle "... factories will produce the equipment required by the engineers, who will use it and by collecting operating data, point out the defects and the improvements required, the research wing tackles the problems of the engineers with the help of the data produced by the scientist, and then evolves new prototypes which will be sent to the factory for mass production; and the cycle will go in spirals marking milestones in the progress of the nation in the field of telecommunications!" These were the noble, almost utopian early hopes. Similarly, I quote from the 1956 address of Mr J C Ghosh, member of the Planning Commission: "We in India are becoming more and more conscious of telecommunications as an integral part of modern existence. (A panel of scientists convened by the planning Commission) brought home the conviction that an industry which is 'research-based' cannot thrive in a competitive world, if it is not continually improved upon by new discoveries and inventions. It is accordingly expected that every industrial unit in the public sector will be strengthened by a research and development section."

But despite many such hopes and assurances most observers would agree that the pace of development in Indian electronics and telecommunications has been

woefully inadequate. Not that there has not been perceptible progress over the last two decades. I can remember in 1970, to be personal for a moment, my wife and I dozing in the ECE department of the IISc in Bangalore because we had booked a call to the USA and it was expected to come through sometime between 12 am and 4 am (and it was inconceivable for a one-year visitor to get a home phone). Now-a-days you can wander around the countryside, as we did recently in Kerala, and it is easy to find an STD/ISD booth where at any time you can almost instantaneously make a call around the world. So certainly that is progress. But despite these clear signs of progress, I think to be honest we must say that the general level of availability and service and cost is very depressing. I do admire the patience and the stamina of our many entrepreneurs and industrialists and workers who have to carry out their endeavors within such a system. But just imagine what we might have accomplished with a better communications infrastructure.

The late 60's and early 70's were the time of rapid developments in electronics, with integrated circuits and microprocessors coming to the fore. We seem to have completely missed that revolution, lagging behind even countries such as South Korea and Taiwan. The secret was in attention to manufacturing, but our scientist administrators of the time, from what I have gathered, turned down many overseas proposals for assembly plants, TV manufacturing units, etc. India had its sights, they said, on higher level targets: computers and radars rather than calculators or color TVs. After all, unlike our neighbours, we had very much more to offer than cheap manual labour. Certainly true, but where are we now and where are South Korea and Taiwan? Even today, when we do contribute some innovative designs, we need to have them manufactured elsewhere. Even for low tech products such as radios and TVs, the level and quality of many of our leading factories lags those of the rest of the world. Not, I hasten to say, that we should now rush into the most modern submicron manufacturing technologies, the whole nature of which is currently under change. A billion dollar facility may not be the most appropriate for our internal and external demands and opportunities; there is a huge demand in India and many other markets for consumer products based on much less advanced technologies, which may now-a-days often be acquired at throwaway prices. But all that is a different issue, though it will add to the point to be made presently about the value, indeed the necessity, for decentralizing such technology decisions.

To return specifically to telecommunications; it is certainly not too late, with the right leadership and vision, to vigorously make up for the deficiencies of the past. In this regard, one might study developments in China. Till a few years ago, China was barely mentioned, and perhaps rightly so; they had many different handicaps, and in many ways they still do. By no means do I mean to imply that China is a model for us, even in technology. My remarks

are very specific and very limited. My wife and I were in China in 1981, just a few years after the end of the Cultural Revolution. Of course, one of our interests was to see how China compared with India. We didn't see there the degrading poverty one can see in many big cities of India. But nevertheless, our overwhelming reaction was the following: how wonderful it is that India is a free country, and what potential that offers for India to advance. But at least in telecommunications the record has been different. A few months ago, in July 1993, there was a special issue of the IEEE Communications Magazine, nearly a 100 pages long, devoted to Telecommunications in China. There is a lot to ponder in that report. Let me just refer to a couple of items. In 1950, China and India had roughly the same number of telephones. Then, as you know, for roughly the next 30 years there was hardly any scientific development in China, because of the Great Leap Forward, the Cultural Revolution, and so on. But at the end of 1992 China had 19 million telephones, while India had a little over 6 million. In fact China added 6 million telephones in 1992 alone; *their goal for 2000 AD is 65 million telephones, while I believe our target is 20 million.* There is an exponential difference in their rate of growth; compared to what we even envisage. Should we be content with our targets? Will it be useful to be more aggressive? These are topics the IETE may well take a lead in studying. An IETE position paper can certainly have an impact on current government thinking. It is a good challenge.

Here is another quotation from that IEEE special issue that should make our decision-makers take notice (not that it is particularly original): "During the '80s the growth of telecommunications was fuelled by and followed the growth of the economy in China. Today the roles are reversed. It is now the telecommunications infrastructure that is propelling the expansion of China's economy, especially in South China. So, industries that were initially national in scope are fast becoming international to allow them to compete in the global market place and with this internationalization comes the need for a first class global telecommunications network."

Many of you probably know better than I do the steps that we are now taking, but it is my feeling that drastic and difficult changes are much overdue in our approach to high technology development if similar statements are to be made about India. I can only offer you a few suggestions and they are conditioned by my background. As an academic, I hope you will forgive me for saying that one of the things we might do is to carefully and analytically study the patterns of the past, so as to identify and keep the good, and to understand and avoid the bad. A few IETE lecturers (notably R Narasimhan, P V Indiresan, and P S Deodhar) have made perceptive contributions to identifying our problems. There have been some thoughtful articles in popular magazines; I have already mentioned the CTMS in Hyderabad. But one of the things I noticed while preparing this lecture, is the absence of

critical studies of even Dr Bhabha's role in the development of Indian science and technology, or even a comprehensive analysis of the impact of Dr Bhatnagar, Dr Sarabhai, Dr Kothari, Dr Menon and other major scientist-administrators and decision-makers on Indian Science and Technology. If they in fact do not exist, perhaps the IETE can sponsor such studies; few doctoral theses could come out of them. A provocative question would be to examine how well we have been served by our predilection for endowing a few individuals with vast powers and diverse responsibilities? What new structures may be appropriate for a new world made so much smaller by modern communications and information technology? There is no shortage of issues, and I imagine no shortage in India of qualified people to study them. What may be missing is the authority and status of an institution such as yours in encouraging or sponsoring such efforts.

There are no doubt many reasons (some clear only with hindsight) for our current situation, and I am sure all of you can think of several of them. *The scientific and the political cultures both bear responsibility. Here I only want to focus* on the fact that when technologies are changing as rapidly as they are now-a-days in the communications field ("lightning speed," "bewildering speed," "astounding speed," are phrases increasingly seen in the trade literature), very few individuals can keep up with the pace of change. An exceptionally competent staff can help, but governments the world over find it difficult to attract the best people to middle level positions. My own experiences of working with the Indian government a couple of decades ago, in connection with the so called ADGES (Air Defense Ground Environment System) radar project, certainly did not leave me with a lot of confidence that things were different in India. And some things are the same the world over. In Lord Acton's famous words, "Power corrupts and absolute power corrupts absolutely."

Not that there have not been many successes for Indian science and technology. In this audience itself I see people, who I won't embarrass by naming, who have made notably successful contributions in the face of many difficulties thrown up by the system (and by human nature). In fact, it should be noted that some of these successful projects grew out of collaborations between Defense laboratories and the Centers for Advanced Electronics Research set up at six academic institutions (the five IITs and the IISc) under the ADGES scheme. It was the then Defense Secretary, Mr H C Sarin, and his handpicked Joint Secretary, the late Mr S Krishnaswamy, who had taken the bold step of setting up this Rs 300 crore 10 year Indian Air Force project in 1970 in the face of many high-powered, but incredibly expensive offers to set up the system on a turnkey basis. I was on sabbatical at the IISc and Professor Aiya had recommended me as a consultant on troposcatter communications. In applauding their decision to go it alone, I had the happy idea of suggesting that a very small fraction of the Rs 300 crores could be well invested in

building up the human resources to maintain and update the system in later years. Mr Sarin's first reaction was to suggest a few scholarships, but he very quickly saw the potential of arrangements such as the largely defense-funded Research Laboratory of Electronics at MIT and the Electronics Research Laboratory at Stanford. With advice from Dr D S Kothari, Dr A Ramachandran and others, Sarin and Krishnaswamy obtained sanction in record time for Rs 6 crores to support six electronics research centers. Knowing the lack of experience at that time with sponsored research schemes, I had suggested starting with a couple of centers, but for reasons of regional equity (among others), Mr Sarin decided on the larger number. I remained a consultant to the centers for some time. Looking back, the record of the centers has been mixed, with many of the disappointments arising, in any opinion, from structural and management failures. However, Dr R P Shenoy, former Director of LRDE, reassured me the other day that just two successful defense projects (the APSOH sonar and the LFD radar), that had drawn heavily on technical staff trained at these centers, had contributed far more to the country than the few crores invested in setting up the centers. So also, though this is a topic that again needs more discussion, in my opinion, the overall record of C-DOT makes it another such success. We cannot afford not to have projects of this kind, but good management and leadership are essential. Of course missteps and failures are encountered in all societies - the advantage is to those systems that attempt to provide greater chances for success. I should also remark, borrowing from Cassius, that "the fault is not (all in our leaders or) in our stars, but in we ourselves, that ...". As a people, we tend to be far too deferential to people in authority. And on the other hand, many of us tend to be too tolerant of shoddy work by our peers and subordinates. We may recall that Dr Bhabha certainly insisted on excellence in things big and small - take a stroll through the TIFR and compare it to the depressing ambience of many of our leading public institutions today. No doubt we all get the service and the government that we deserve.

But the short answer to the above problems is that the powers of individuals to rule by fiat on future directions of technology should be drastically reduced. The responsibility is just too much - technology is changing too rapidly for any single individual's (or company's or organization's) knowledge and abilities. A first step must surely be to allow greater room for market forces to assume the risk and for market competition to help decide the best technologies for the appropriate periods in time. Anyone who lives in Silicon Valley, as I have for the last 30 years, can see how quickly everything seems subject to change - it is not just the Goliaths of old, such as IBM and DEC, that are reeling under the attack of smaller and nimbler opponents, but the roaster of leaders is constantly changing. No one can rest on their laurels for very long. Many others are exploring and developing new methods

and new strategies to displace you from the lead. The winner is the public, as the price history of electronics and information technology products of this arena; and I congratulate the organizers for picking such a topical theme. It is the first of the Seven Grand Challenges for Electro Technology recently identified by the IEEE.

- To make any person anywhere in the world reachable, at his or her discretion, at any time by communication methods independent of connecting wires and cables.

The next two are

- To provide instant global access to information sources through such technologies as computer databases, high-speed communications links, and flat-panel displays and interfaces.
- To allow a person to be present, by his or her choice, in any place at any time through the technologies of virtual presence and virtual reality.

Even before such a millenium, the popular vocabulary will change as we see the convergence of communications and computation, television sets and workstations, education and entertainment; "Edutainment" and "Infotainment" are some of the buzzwords floating around. The impression I get is that currently India's attention is heavily focused on voice communications. But as globalization proceeds, one will have to pay even more attention to data communications, data networks, etc. And the scenario there is even more psychedelic-with LANs, WANs, MANs, any LANs (the product announcement on September 23, 1993 from HP and IBM), ATMs, etc, etc.

A popular author on future technologies, George Gilder, wrote recently about the driving force behind such recent developments as being "fierce business and technical rivalry in the marketplace. In the real world the ruling principle of network development is not imposed standardization by government, but spontaneous order. It springs from the interplay of human creativity and entrepreneurship with the inexorable laws of physics and technology." The major role of government in such conditions is that of ensuring adequate and fair competition in the national context. The risks involved in various technological choices must be borne largely by the market players themselves. The skill of our administrators is in the proper decision making in such new environments. New methods have to be explored in all countries. Even in the USA, which of course is far beyond India in its degree of reliance on market forces, the Federal Communications Commission has just launched the radical innovation of auctioning-off spectrum for various new communications services, especially PCS. Also in each location, at least four companies will be licensed to offer such services, and they have to stick to a particular schedule for providing services, if the licenses are not to be withdrawn. The Indian scenario is different but we have

much further to go in terms of allowing competition in our communications services.

However I am very happy to note, as I said in my abstract, that over the last several months there is increasing and heartening evidence of a sea-change in government thinking in the telecommunications area as well. I read that the DoT is finally to be reorganized, clearly separating into different units its service, production and regulatory functions. That would be very welcome. One of the first computer companies in India was founded by a couple of my students from Stanford. Many years ago, they had designed good metering systems for toll calls; they also had many innovative ideas for using DSP technologies for enhancing the capabilities of existing exchanges. But with this conflicting tangle of responsibilities in the DoT, and no doubt for other reasons as well, they could never get through the system. And I know other small companies that have faced similar problems. I haven't met Mr Vittal, who assumes office today (October 1, 1993), as Secretary of DoT. But press reports of interviews with him and others, and reading some of Mr Vittal's own articles on various topics, seem to indicate that the winds of change (having done, it seems, their magic in South Africa), will be blowing even more strongly through the corridors of power in New Delhi.

Nevertheless, as this point, I cannot resist repeating a recent statement attributed to Minister R Kumaramangalam: "There is always good news and bad news. The good news is that certainly things are now happening in India. The bad news is that there is a premature celebration of its accomplishments." So skepticism is no doubt in order, even though things do seem to be different this time

around. The road ahead is by no means easy in the world of today. There are many special cautions to keep in mind for India, especially in defining and enhancing the role of indigenous R&D and of indigenous entrepreneurs. There are no easy answers, and this Institution could well take the lead in focusing the issues.

But I would like to conclude with the thought that Telecommunications is still a field in which there is plenty of room for new developments. All the wonderful new possibilities that you may have read about (the Information superhighway, and so on), are really only the tip of the iceberg. There is tremendous scope for contributions by small companies, in India as in the rest of world. There are new methods of data compression still to be invented, smart antennas to be developed, encryption strategies for different applications, new wireless schemes and many more.

Your Institution has had a good record of drawing attention to very new technologies, as the program of special talks for this 40th anniversary convention itself shows. Many of the above developments are well within the range of our very talented and ambitious young engineers, including many in this room. I am sure, and our equally talented industrialists and entrepreneurs. It is by no means simple to find ways of properly mobilizing and releasing their energies and talents and ambitions, to help not just India but also the wider world. But, in my opinion, properly rising to this challenge will be our real tribute to the vision and the memory of Dr Homi Bhabha.

Thank you, ladies and gentlemen, for your patience with my musings and recollections on this 40th anniversary of your Institution.

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# Engineering Research and Nuclear Power — the Present and the Future

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I am deeply honoured to have been asked to give the 26th Bhabha Memorial Lecture of IETE. My satisfaction is all the greater because my first job, in which I still continue, was with the Research Centre set up by Dr Homi J Bhabha, and also because the subject of my talk pertains to the Indian nuclear energy programme and the related research edifice and industrial infrastructure initiated by this versatile genius.

Dr Homi Bhabha, the architect of the Indian atomic energy programme was indeed a great visionary. Way back in 1954, he not only foresaw the need for India to use nuclear energy for the generation of electricity, but more than that pursued this goal relentlessly and methodically. In the process, he generated a vast dynamic multidisciplinary research and development base for nuclear science and technology in the country, which is unparalleled in the history of developing countries.

## ELECTRICITY GENERATION OF A COUNTRY – A MEASURE OF DEVELOPMENT

A recent UN report talks of Human Development Index (HDI), says that human development has three components: national income on a per capita basis, adult literacy and life expectancy. All these put together give a composite measure of national progress or the HDI of a country. Measured on this scale, India does not come off very well. Our HDI is a low 0.308, while developed countries like the US and Japan have figures of 0.976 and 0.993 respectively. However, I personally feel that the HDI for a country like India should be measured not on the basis of these three parameters which are defined by the UN, but on the basis of just two other parameters: for adult literacy, I would like to substitute female literacy, and instead of national income and life expectancy I would like to use per capita consumption of electricity. Let me give you the reasoning behind this conclusion.

Female literacy is a very important development parameter for India and if we are able to increase it, many health parameters will improve significantly. Not only will there be a decline in the birth rate and infant mortality rate, but the health of the children will also improve. All this is clearly seen when we study the situation in Kerala vis-a-vis other states. In every state of India, female literacy is lower

than male literacy and more the difference, lower is the average literacy. Female literacy is a measure not just of literacy but also of social justice in that particular societal group.

Regarding the other measure of national development, everybody knows that the per capita gross national product is directly related to the per capita electricity production in the country. What is not so obvious is the fact that the per capita consumption of electricity is directly related to life expectancy. If you take the world statistics and plot per capita consumption of electricity (on a logarithmic scale) against life expectancy, you get a very interesting S-shaped curve. India is right in the middle of the linear portion with a life expectancy of about 60 years. This really means that additional inputs into the electricity generating systems of the country will lead to a sharp increase in life expectancy. It is my view that this can be attributed to the fact that any increased availability of electricity will make it reach smaller towns and villages and this will have an immensely beneficial effect – leading to better drinking water, better sewage treatment and better health care and therefore a higher life expectancy.

This implies that if we concentrate on improving primary education, particularly female literacy, and on improving electricity generation, there will be a significant acceleration in India's development.

## ENERGY RESOURCES AND THE NEED FOR NUCLEAR ENERGY

Having established the significant role of increase in per capita electricity consumption in the overall development of a nation, one should examine the way of achieving this goal. The developed countries have used in the past and continue to use the world's resources in a wasteful and extravagant manner. Fortunately, we in India have a somewhat ascetic life-style.

One can first look at the possible sources of electricity. There are three main electricity sources in India, namely, hydel, thermal and nuclear. Additionally, there are other sources of energy such as solar, wind, bio-mass and bio-gas. These non-conventional energy sources do have an important function in Indian society, particularly in places

where the transmission of electricity is not possible or prohibitively expensive. However, the assessment that every Megawatt of electrical power requires five hectares of solar cells or 7000 sq meters of mirrors or 50 wind turbines, shows the magnitude of effort required to harness power from such sources, apart from the higher cost of generation itself. Further, their environmental impacts are yet to be fully studied. There is no doubt, however, that all sources, conventional and non-conventional, have their roles in contributing to the nation's power requirements.

Therefore, while examining the different sources of electricity, one should look at the pros and cons of each of them. Hydel resources are cheap, renewable and have the potential of downstream uses of the water for irrigation and are, therefore, in my opinion the best sources of energy, though they have to depend on the rains. One problem is the submergence of large areas, typically 2000 to 5000 hectares for a 1000 MWe plant. This results in ecological disturbances. There is also concern about the large number of people who have to give up their land for such projects.

Thermal power plants are very important for this country for the next two to three decades. However, there are problems on the horizon if we were to continue to depend on this resource. For example, these plants will require an enormous amount of coal: a 1000 MWe coal fired plant will require nearly 4 to 5 million tonnes per year, which has to be transported from mines to the power stations. They also release carbon dioxide, sulphur and nitrogen oxide gases and there are global concerns about acid rain (not a significant problem in India till now) and about the possible green house effect. All this is further compounded by the high ash content of Indian coal, which in turn magnifies the problems of waste disposal. Looking at the resource scenario in India, we have an estimated 200 billion tonnes of coal, though not of good quality. In 75 years time, these coal deposits are expected to get substantially exhausted and other sources of energy would have to be exploited.

What about nuclear power plants? The fuel required is very small in volume and so there are no problems with respect to transportation. The waste produced is extremely small in quantity and though radioactive, can be safely handled. Energy experts the world over are coming to accept the fact that nuclear power generation is one of the more "eco-friendly" forms of generating of electricity. The relatively small magnitude of fuel requirements for nuclear power stations also enables a country to use this option as a route to 'energy independence'. It is for such reason that countries like France, Japan and South Korea meet a large portion of their electricity requirement through nuclear energy. China also has an ambitious plan to develop nuclear power.

Consequently, resorting to nuclear power generation in a big way becomes inevitable for India in the long run.

### THREE STAGE NUCLEAR PROGRAMME DRAWN UP BY H J BHABHA

Dr H J Bhabha drew up a charter on nuclear energy in the form of a 3-phase programme, whose basic validity and importance still form the bedrock of our present day activities. In the first phase, this envisaged establishing Pressurised Heavy Water Reactors (PHWR) using the natural uranium resources available within the country to produce electric power and plutonium. In the second phase, the plutonium extracted by reprocessing the spent fuel discharged from PHWRs was to be utilized in Fast Breeder Reactors (FBRs) to produce electric power and Uranium-233. And the third phase envisaged utilisation of thorium and Uranium-233 in advanced reactors for production of electric power and additional Uranium-233. Such a programme will enable us to generate about 350,000 MW of electricity using the available resources of natural uranium in PHWRs and extending their life in FBRs with the plutonium thus produced (in the PHWRs). The long range potential of nuclear energy in India depends on thorium whose reserves are estimated in excess of 360,000 tonnes - one of the largest in the world - which can be considered equivalent to about 600 billion tonnes of coal.

### THE INDIAN NUCLEAR PROGRAMME TODAY

The Indian nuclear power programme commenced with setting up of two Boiling Water Reactors (BWR) at Tarapur, Maharashtra on a turn-key basis with the assistance of USA. This was followed with the setting up of two Pressurised Heavy Water Reactors (PHWR) of almost similar capacity at Kota, Rajasthan in collaboration with Canada. Subsequently, work was taken up on several 220 MWe PHWR units based on our own indigenous capabilities. These were the two units each at Kalpakkam near Madras, at Narora in UP and at Kakrapar in Gujarat. Two units each at Kaiga in Karnataka and Kota, Rajasthan are more than half-way through in their construction. A beginning was also made in the utilisation of thorium in our nuclear power programme when thorium bundles were introduced into a PHWR for the first time in Unit-1 of the Kakrapar Atomic Power Station. This was done to achieve more efficient power flattening.

The present installed operating capacity is 1720 MWe comprising of all these reactors from Tarapur Unit-1 up to the Kakrapar Unit-1. The second unit at Kakrapar is to be commissioned very soon. (This unit became critical on January 8, 1995 and was synchronised to the grid on March 1, 1995.) The remaining four units totaling capacity 880 MWe, are in various stages of construction. The Nuclear Power Corporation of India Ltd (NPCIL), which is responsible for designing, constructing and operating nuclear power stations in the country, is also in the process of commencing construction of two indigenously designed 500 MWe PHWRs at Tarapur.

## R&D BASE AND EVOLUTION OF PHWR TECHNOLOGY

The two decades since the commissioning of the Tarapur reactors have witnessed a period of development and growth of the Indian PHWR programme. The current version of the 220 MWe PHWRs under construction is of an advanced design with respect to improved safety features, material reliability, advanced operator information system in the form of data acquisition and processing systems and other state-of-the-art features. The advanced safety features cover aspects like improved containment, seismic design, redundant safety shut down systems, using liquid poison and augmentation of emergency core cooling systems. These developments have been achieved against the background of various technology control regimes enforced by developed nations in the context of India's independent stand on the discriminatory aspect of the Nuclear Non Proliferation Treaty (NPT). Today India has reached a matured state in reactor technology with the capability to design, construct and operate PHWR reactors. Self-reliance, which was an option initially, became a necessity for us. This has been possible because of the extensive multi-disciplinary R&D efforts within the infrastructure base that has been created and nurtured from the very inception of the Indian nuclear energy programme. This was in the form of well equipped modern facilities and well trained man-power and creation of specialised groups.

This R&D programme covered various high technology areas such as: reactor engineering, materials development, fuel technology, electronics and control instrumentation, computer technology and advanced software, system engineering, advanced concepts of safety engineering and environmental protection, development of advanced materials and components, remote handling and robotics systems, to mention a few. Other developmental activities included analysis and evaluation of fuel, development of coolant channel hardware, analysis and evaluation of major components like calandria and end-shields, design, fabrication and installation of fuelling machines, endurance testing of primary heat transport pumps, analysis of steam generator etc (Fig 1). The R&D inputs emanated mainly from various divisions of the Bhabha Atomic Research Centre (BARC).

### Reactor engineering of the 220 MWe PHWR

The design of the PHWR system which is the mainstay of the first stage of our nuclear power programme has evolved continuously. The process of evolution in the initial years was guided by the need to indigenise manufacture and construction of nuclear power plants. Simultaneously, the desire to upgrade safety features, particularly in the area of containment design, also influenced this evolution process. With a view to arrive at a standardised design consistent with prevailing safety philosophy, the design of reactors from Narora onwards

saw considerable improvements. Today, the design of 220 MWe PHWR can be considered to have stabilised and is a standardised one. Thus, it is possible to construct these reactor units in relatively shorter periods. However, we have to recognise that technology cannot remain static as it has to be continuously updated to take advantage of the latest development. Nuclear technology is no exception to this and it has and will continue to see such improvements over time.

Apart from the challenging task of evolution of design, originating from operating experience and safety considerations, there was a significant demand on the R&D teams for major backfits and repair exercises, to ensure safe and continuous operations of the power stations. The replacement of sparger tubes at Tarapur, the repair of the End Shield at RAPS-1, the rehabilitation of the MAPS units after repairs to its moderator inlet manifolds, are a few examples.

### Development of the Indian 500 PHWR

With a view to step up the rate of growth in nuclear power generation and also to take advantage of economies of scales, it was necessary to design a larger PHWR system. The 500 MWe PHWR was evolved to fulfill this need. Its design incorporates several advanced features. These include: a pressuriser to smoothen the pressure fluctuations during a transient, a new secondary shut down system to inject neutron absorber into the moderator, zone control system, special reactivity mechanisms with capability to step back in power, and improved plant and piping layouts. A significant contribution has also been flowing from the R&D base towards the design of the 500 MWe PHWR unit. To arrive at the new design features and also to work out the design of individual components and equipment, it was necessary to launch a systematic R&D programme. This involved bringing together several specialised disciplines such as reactor physics, structural mechanics, thermal hydraulics, reactor physics, control and instrumentation and

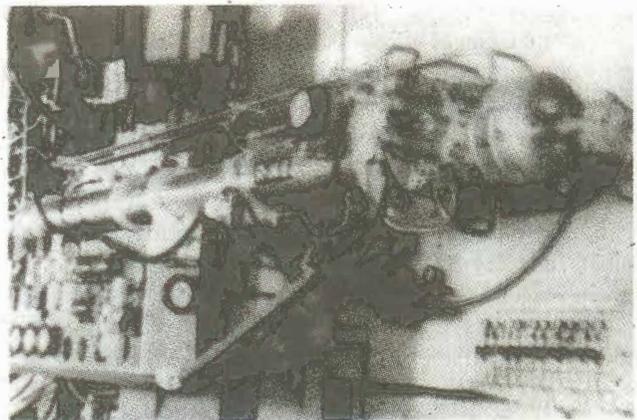


Fig 1 Fuelling machine used in the Indian PHWRs: which can load and unload the nuclear fuel even when the reactor is in operation

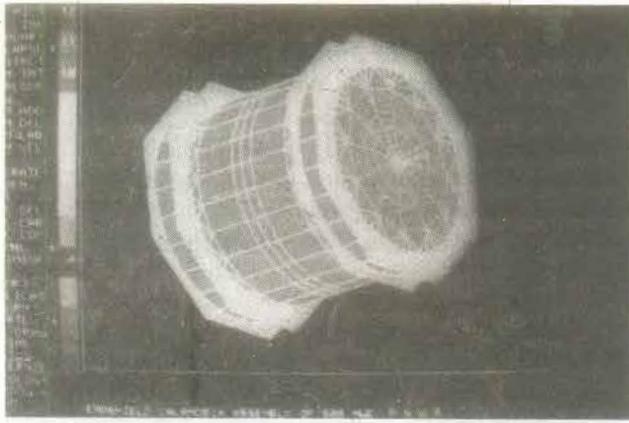


Fig 2 Finite element analysis of a component of the 500 MWe PHWR being carried out at BARC

so on (Fig 2). The work has largely been completed and we are well set to get on with the programme of construction of the 500 MWe PHWR units.

### Life extension programme of nuclear power reactors

While work was pursued in evolving new reactor systems, attention also had to be paid to our older reactors. Maintenance of nuclear power reactors is a specialised discipline. It involves carrying out preventive and predictive maintenance, repair, testing and inspection, using some of the most advanced techniques. Further, in several instances, one has to resort to specialised remote tooling and robotics to accomplish these tasks. As the plants age, not only do these requirements increase, but it also becomes necessary to carry out additional activities to judge the health of plant and carry out replacement as necessary. Addressing these needs, requires the bringing together of a diverse set of disciplines specialised in remote working and automation, non-destructive examination, methodology for assessment of fitness for service, and repair and replacement technologies.

The replacement of reactor coolant channels which is a highly complex task specific to PHWRs, can be considered as an example of one such major activity. While it is necessary to develop systems to carry out this work in a short time and in an efficient manner, the reactor gets a new lease of life after completion of this activity – a feature not available in other reactor systems. The development of a suitable engineered system for in-service inspection of coolant channel and associated components of the reactor has been completed (Fig 3). The development of suitable equipment for remote replacement of the coolant channels is also nearing completion. In addition, the technology of fabricating coolant channels made of a zirconium-niobium alloy which have a longer life compared to zircaloy, has been developed and this is being used in the new reactors starting from the second unit at Kakrapar.

### Success in reduction of background radiation fields

Reduction of the background radiation to minimize exposure of operations and maintenance personnel to radiation – which is inevitable during essential maintenance works – is a continuous objective in nuclear power technology. Specific solutions have been developed which are being implemented in specific areas of nuclear power stations and good levels of decontamination have been achieved. The removal of Tritium from heavy water used as both coolant and moderator in PHWRs, can significantly reduce the radiation exposure to operating and maintenance personnel. This has been achieved by a process that combines the exchange of heavy water and deuterium gas, followed by cryogenic distillation over a catalyst. India is among the few countries which have established this technology and a pilot plant for this purpose has been commissioned in Trombay.

### Development of structural material for PHWRs

The choice of appropriate and reliable structural materials is a key factor in nuclear power technology. The materials used for various components in the reactor system have different roles and hence have different specifications. Generally, they require a high degree of corrosion resistance, and good mechanical properties under high temperature and pressure conditions, all of which have to be retained in a radiation environment. The materials used for end shields, Calandria, pressure tubes, Calandria tubes, fuel cladding are examples of these.

A combination of several attractive properties like low neutron absorption cross section, excellent corrosion resistance in water and good mechanical properties at elevated temperatures has given zirconium alloys a distinctive position amongst various structural materials

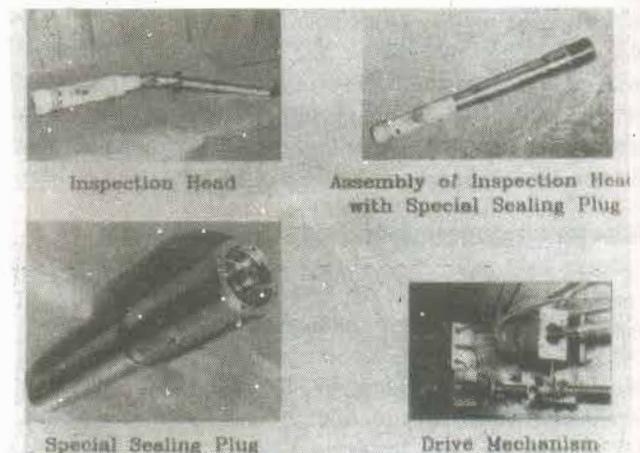


Fig 3 BARCIS - (BARC Channel Inspection System) has been developed in recognition of the need for a system capable of performing a wide range of measurements quickly and with minimum radiation exposure to its operators

used in thermal reactors. BARC has developed the technology of zirconium and has passed on the know-how to NFC for industrial fabrication of zircaloy components. The most important requirements of the pressure tubes are strength at the operating temperature of about 300° centigrade, and the in-reactor creep rate. Ideally, the life of the pressure tube should be as much as the design life of the reactor. The life limiting factors of pressure tubes are the creep strain and the progressive build up of hydrogen concentration. The fabrication parameters of pressure tubes are so chosen that apart from fulfilling the strength and ductility requirements, micro-structural parameters like dislocation density and crystallographic texture are controlled for achieving the best long term properties in a radiation environment. BARC has developed the zirconium-2.5% niobium alloy and coolant tubes of this material and these are being manufactured in NFC for use in the current generation of PHWRs. The extended life of the coolant tube contributes to the extended life of the reactor itself.

The higher strength of the 'Zr-2.5% Nb alloy substantially reduces the parasitic material in the core, effecting a corresponding improvement in neutron economy. A much better in-reactor creep resistance and a lower rate of hydrogen pick up in this alloy lead to an enhancement of the pressure tube life. While introducing this alloy for the manufacture of pressure tubes, a new fabrication route has been adopted.

An extensive investigation has been undertaken with a view to delineating the hot deformation behaviour of zirconium and its alloys, with special reference to those alloys which are pertinent to the product mix of NFC. The primary aim of this study has been to optimise hot workability – a major factor in the fabrication of zirconium base alloys.

#### Fuel for nuclear reactors

Ensuring a continuous supply of fuel for the reactors is vital to any nuclear power programme. The fabrication of nuclear fuel is a complex technology demanding a high level of competence in several fields such as process engineering and technology, extractive and physical metallurgy, materials and manufacturing technology, and modern quality control and inspection based on NDT techniques. The density, dimension and particle size have to be critically controlled. For the fabrication of plutonium based fuels, a Grade-I 'Hot Laboratory' with good alpha handling facility is a pre-requisite.

From the very beginning of the Indian Atomic Energy programme, emphasis has been given towards indigenisation and self reliance in nuclear fuels for both research and power reactors. During the last four decades, a wide variety of metallic, ceramic and dispersion fuels have been developed and fabricated on an industrial scale at BARC and NFC.

Zircaloy clad high density natural uranium oxide pellets form the fuel for PHWRs – including those under operation and construction. Our R&D programme also included an advanced fast reactor fuel with a high breeding ratio, namely mixed Uranium Plutonium mono-carbide for use in the 40 MWt Fast Breeder Test Reactor (FBTR) at Kalpakkam. India is unique in using this fuel for the core of a fast breeder reactor. Development of suitable fuels for the Prototype Fast Breeder Reactor (PFBR) is also in progress at BARC and IGCAR. Though the uranium-plutonium oxide fuel has been chosen as the reference fuel for the PFBR, alternative advanced fuels area also being developed. Since commercial LMFBRs would be introduced only after 2000 AD, some of the plutonium stockpiled from PHWRs is expected to be re-cycled in PHWRs and in the BWRs (at Tarapur) as mixed uranium-plutonium oxide fuel. Two indigenously fabricated MOX fuel bundles have already been introduced in the Tarapur reactors. Alternatively, the plutonium could also be recycled in PHWRs, in combination with thorium.

The fuel production facilities set up at Nuclear Fuel Complex (NFC), Hyderabad, were the culmination of R&D works in BARC that were started in early fifties. This complex has been indigenously fabricating fuel structural materials catering to a wide variety of research and power reactors (Fig 4). In addition to this, they have also fabricated the thorium blanket for FBTR and developed structural material and fuel components for the 500 MWe PFBR, BARC has also developed several advanced fuels for testing in the FBTR.

The post-irradiation examination (PIE) and failure and performance analysis of nuclear fuel bundles and other in-pile and out-of-pile reactor components is an unique aspect of the nuclear fuel cycle. In India, these are carried out at the hot cells of BARC and IGCAR. The PIE data generated at BARC has provided useful feed back to the designers, fabricators and reactors operators.

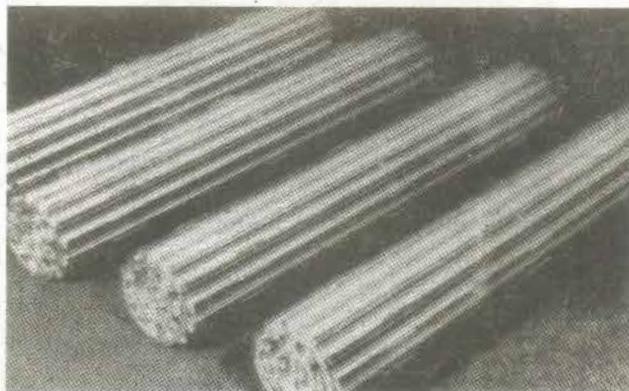


Fig 4. Natural uranium fuel bundles for Indian PHWRs manufactured at the Nuclear Fuel Complex, Hyderabad

### Development of technology for reprocessing and waste management

India has always held the view that fuel reprocessing technology is a critical component of its atomic energy programme and has therefore invested in developing in-house know-how for the same. Today, reprocessing plants are in operation at Tarapur and Trombay. In addition, a modern plant is nearing completion at Kalpakkam. The first plant at Trombay was designed from first principles, with limited laboratory facilities, and limited data on pilot plant and hot cell technology. However, the design of the plant at Kalpakkam incorporates various innovations and new concepts which are based on experience gained in the operation of the Tarapur plant and R&D studies carried out at our test facilities (Fig 5). The reprocessing development lab at Kalpakkam has established the process know-how, and developed equipment to reprocess the mixed carbide fuel from FBTR. Our R&D facilities has been successful in separating Uranium-233 from irradiated thorium rods.

We have also evolved process and technologies for handling various types of radioactive wastes. A plant for immobilising highly active waste in a glass matrix is operational in Tarapur. Based on this experience, additional waste management facilities are being set up at Trombay and Kalpakkam.

### Control and instrumentation for nuclear reactors

Development of nuclear instruments and systems commenced in BARC in the early sixties and a public sector unit, the Electronics Corporation of India Ltd (ECIL)

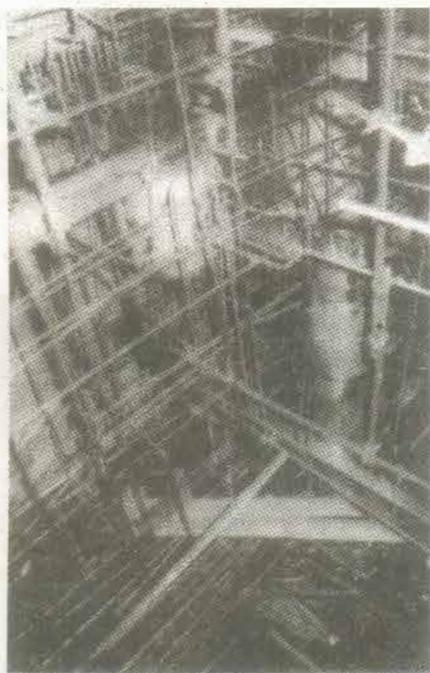


Fig 5 View of the inside of a reprocessing plant, showing the extensive piping involved

was set up to commercialise the benefit of these development activities on a large scale for utilisation at the nuclear power stations.

Computer systems are used in areas such as data acquisition and monitoring, alarm annunciation, control, safety and protection systems, all of which aid in efficient operations, and in handling off-normal operating conditions. The safety and protection systems automatically ensure that appropriate actions are taken to ensure safety of the plant and the environment.

The other systems developed and installed at our nuclear power plants include Fuel Handling System, Data Acquisition system, Channel Temperature Monitoring system, Disturbance Recording system, Reactor Regulating system and, Programmable Digital Comparator.

Considerable improvements have been made in the area of instrumentation and control and today computerised I&C systems are implemented on a significant scale at nuclear power plants. The newer generation reactors incorporate computer-based real time systems as part of their I&C design on a significant scale.

Development work is also in progress in several other areas like Distributed Computer Control, Advanced Fuel Handling Control, Advanced Operator Support, Computer Based Safety, Plant Simulation, and a System Test Facility to aid in control algorithm development and testing.

### Robotics and remote handling technology

The traditional concepts of remote handling are inadequate under for radioactive environments and considerable R&D efforts have been made to develop robotic systems for use at various nuclear installations like the fuel fabrication facilities, power plants, fuel reprocessing plants and waste handling installations. They are also essential for in-service inspection of nuclear reactors. The first generation robots developed by BARC are the pick and place type used for various applications in chemical laboratories, pathological laboratories etc. A five axis AC induction servo motor robot has also been developed. Other types of robotic systems under development are a computer aided tele-manipulation system supported by an intelligent vision system, mobile robots multi-legged steerable robots (Fig 6). Extensive use of this technology in nuclear power plant applications are foreseen in the coming years.

### Advances in computer technology

A spin-off of the work in nuclear technology has been in the field of computers, since computers are used extensively both for design purposes as well as in actual nuclear power plant operations. Neural network techniques are being developed for nuclear applications such as reactivity monitoring of nuclear reactors, power control of

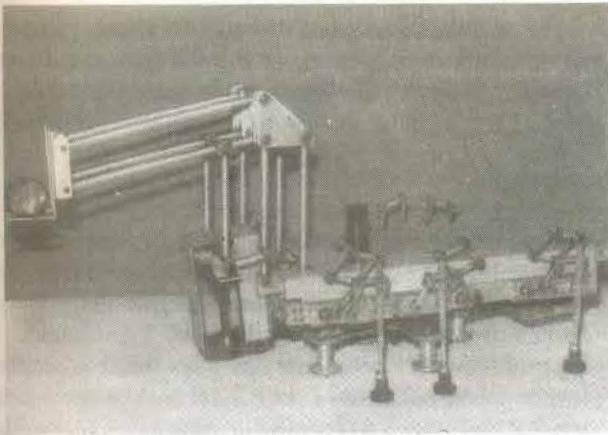


Fig 6 Walking robot developed by BARC

nuclear reactors through learning process and analysis of nuclear spectra.

In December 1991, BARC entered the field of parallel processing by developing a five node parallel processing system named 'ANUPAM'. This system has been upgraded to 32 nodes and gives a performance of about 190 MFlops which is almost the same as the speed of CRAY X-MP type of super computers. This system is being upgraded to 64 nodes, when it is expected to give a speed of about 350 MFlops. The 32-node ANUPAM is already being used for more than fifty large computer-intensive jobs both within and outside the family.

Many advanced software packages have been developed for scientific visualization using high speed graphics workstations and also a combination of graphics workstations and parallel processing system ANUPAM. A plant layout package has been developed for visualizing the layout of large manufacturing plants. Another walk-through package has been developed for simulating a walk through into complex molecular structures.

### Fast breeder reactor programme

The Fast Breeder Test Reactor (FBTR) at the Indira Gandhi Centre for Atomic Research (IGCAR), has been in operation for some time and has attained a power level of 10 MW thermal. Its successful completion marks the commencement of the second stage of the Indian nuclear power programme. The major components of the FBTR were indigenously fabricated. As mentioned earlier, the reactor uses a unique fuel comprising a mixed carbide of uranium and plutonium which has performed well, with its burn-up exceeding 10,000 MW/day per tonne. The coolant used is liquid sodium purified to nuclear grade, which has been produced within the country.

IGCAR has several well-equipped modern laboratories engaged in developing technologies for the fast reactor and its associated fuel cycle. These laboratories carry out development relating to production and handling of

sodium, fuel, materials, reprocessing of spent fuel, post irradiation examination of spent fuel and safety research. In addition, the centre is engaged in the design and technology development for a 500 MWe sodium-cooled Prototype Fast Breeder Reactor (PFBR) whose design is in an advanced stage. A separate facility has been set up for testing large components of the PFBR. The centre has also been specializing in characterizing, manufacturing, testing and assessing the performance of ferritic and austenitic stainless materials.

The challenges posed to materials scientists and engineers in the development of fast reactor technology cover several areas, such as alloy development, structure-property correlation through testing of physical, mechanical and corrosion properties, fabrication methods including welding, non-destructive evaluation and sodium purification and monitoring. In comparison to the PHWRs, the environmental conditions in these reactors are relatively more severe, especially with respect to temperature, neutron energy, neutron flux, and chemical reactivity of the coolant. The materials used in the reactor core like fuel cladding and sub-assembly wrapper tubes require good high temperature creep and fatigue properties, resistance to swelling and to creep due to radiation. The alloys for the fuel cladding have also to be resistant to possible helium embrittlement.

An indigenously developed Austenitic stainless steel designated as D-9 has been found to satisfy the design requirements of the PFBR. Its development required rigorous melting trials, characterization of phases and evaluation of mechanical properties. The strength and ductility of D-9 were found to be comparable or even better to that of other stabilized grades of Austenitic stainless steels used for similar applications. Based on the experience gained in the development of alloy D-9 at IGCAR, this material was prepared by M/s Midhani and the production processes for the manufacture of clad and hexagonal wrapper tubes are being developed at NFC.

Various Non-Destructive Testing (NDT) techniques have also been developed for the FBR programme. In fact, the specialized ultrasonic testing techniques have culminated in the development of expert systems for wider use in the industry.

### Safety regulations and preservation of the environment

The high emphasis on safety and preservation of the environment has been a feature of our programme from its very inception. This was long before environmental issues assumed the importance and priority it has today in other industrial activities.

Our R&D programme also addresses issues of safety and environmental protection. The release of effluents at all nuclear facilities are in conformity with the limits set by the

Atomic Energy Regulatory Board (AERB), which in turn takes into consideration the international criteria recommended by the International Commission of Radiological Protection (ICRP). A three-tier regulatory control system is in place for surveillance of all radioactive effluents. This includes independent monitoring of the environment by the Environmental Survey Laboratory (ESL) of BARC located at each of the major nuclear facilities.

The ESLs also carry out site-specific studies on micro-meteorological parameters to understand the dispersion characteristics at each site as well as other studies to identify exposure pathways. A SODAR system has been installed at the site of the Kaiga Nuclear Power Project to study in detail the dispersion characteristics of atmospheric effluents and the influence of the local topography on the dispersion patterns. The SODAR is a versatile system which probes the atmosphere in the surrounding area up to about 1000 meters height and gives detailed information on the vertical structure of three components of the wind at a number of pre-selected elevations.

A Quality Assurance Programme in which results of selected measurements are compared with international standards such as those of the World Health Organization (WHO), the International Reference Centre (IRC), France, and the International Atomic Energy Agency (IAEA), Vienna, ensure the quality of measurements and data. Although the primary emphasis is on samples that are relevant directly to the estimation of dose such as drinking water, edible food items, air, etc, a number of other samples are also taken to observe the trend patterns or used as sensitive detectors or markets. Examples of the former are sea water, sediment and of the latter are goat's thyroid which concentrates the radio-nuclide Iodine-131.

Measurements carried out over the years have demonstrated the negligible contribution due to releases by any nuclear facility and these small additional exposures are insignificant in comparison to the large variations of the natural background radiation itself.

As a measure of enhancing overall safety, emergency preparedness plans to manage even unlikely accident scenarios have been drawn up at major facilities. These include measures to adequately manage and mitigate the consequences of such accidents. Comprehensive emergency preparedness programmes exist at all nuclear power station sites and based on the feed-back from drills and exercises, they are under constant review for enhancing their effectiveness.

#### **Information management at R&D centres**

Information networks have become extremely important today for the scientific and engineering community for a wide range of applications, ranging from complex graphics and visualization techniques to routine data retrieval systems.

E-mail and bulletin board services also have provided a useful platform for sharing of scientific information with the fellow researchers. Research institutes under DAE are on the Educational & Research Institute Network (ERNET) which has a gateway to the worldwide INTERNET family of networks.

The library at BARC has a major computerization programme using CD-ROM data bases. International databases are also being accessed through Gateway Packet Switch of Videsh Sanchar Nigam Ltd. BARC also has an internal network operational on ISDN lines. In addition, several Local Area Networks (LAN) are also operational. IGCAR and other R&D centres are also developing similar information networks.

#### **Proven capability over the entire nuclear fuel cycle**

Mastering heavy water production technology has been yet another success story of our nuclear energy programme. The process technology of the Hydrogen Sulphide-Water Exchange process was developed indigenously and today large scale plants based on this technology are operating at Kota and Manuguru. India has also developed know-how for setting up large capacity heavy water plants based on the Ammonia-Hydrogen Exchange process, at Thal and Hazira. Full scale plants for upgrading heavy water are also in operation. One can proudly claim that India is probably the only country with the widest experience in heavy water production technology. In fact, our high production now enables us to even export heavy water.

Consequently, the four decades of intensive activities in the atomic energy programme have resulted in India acquiring comprehensive capability in the design and operation of plants and facilities covering the entire fuel cycle of nuclear power reactor – right from mining, milling and production of uranium concentrates, and fabrication of nuclear fuel, production of heavy water, to that of nuclear fuel reprocessing and management of radioactive wastes. All these technologies are of strategic importance and our establishing self-reliance in them has been a major factor contributing to the success of our programme.

#### **NUCLEAR R&D IN THE COMING YEARS**

The thrust of R&D in future will be focused in maximizing the operating factors of nuclear power plants, achieving reduction in cost of power generation, increasing the operating life of existing plants, maintaining and improving safety standards, and working on advanced reactors designs based on thorium. Work will be continued in specific areas of heavy water production, nuclear fuel fabrication and reprocessing techniques. Immediate efforts will be concentrated on life extension strategies for the operating reactors and providing support to the 500 MWe PHWRs that are expected to be set up in the coming years. Programmes have already been initiated for the

development of remote tools, robotic inspection and maintenance systems, and advanced NDT techniques. Work on decontamination techniques, installation of decontamination plants aid this objective.

At IGCAR, the R&D efforts will focus on developing technology for the fabrication of large components for the PFBR, research investigations on evaluation of alternate structural material applications would be continued.

There is considerable scope for further development and deployment of computerized instrumentation and control systems, in the nuclear power programme. It could extend to utilization of distributed computer control systems, advanced fuel handling control systems, advanced operator support system, and computer based safety and protection systems. Advanced simulators and man-machine interface systems will find priority in this regard.

### **GLOBAL SCENARIO OF NUCLEAR POWER**

At present, there are about 430 nuclear plants operating in 32 countries with a installed capacity of nearly 337,000 MWe. They generate about 17% of the world's electricity. There are also about 60 units under construction which will add a capacity of 54,000 MWe. About a dozen countries derive more than one third of their total electricity needs from nuclear energy. The USA has the largest number of

reactors : there are 109 units generating about 90,000 MWe. France produces as much electricity from nuclear power as is generated in our country from all means of power generation, and gets about 80% of its electricity from nuclear energy alone. Japan has plans to double its nuclear power generation capacity within the next 15 years. Among other countries in the Asia, South Korea and China are firmly committed to increasing their nuclear power generation capacity in a significant manner during the coming years.

### **CONCLUSION**

India has matured in reactor technology and is considered as a developed nation amongst the developing countries in this field. Considering our natural resources and the state of development of other related technologies, thermal power based on coal and nuclear power can together meet our future demand of electricity. The Indian nuclear power programme today is in a position to play a prominent role towards this national objective of power generation. For India, nuclear power will be an inevitable option to satisfy our future energy needs.

### **ACKNOWLEDGEMENT**

I am grateful to Shri G R Balasubramaniam and Shri K Muralidhar for discussions and help in the preparation of the manuscript.



The following information is provided for your reference:  
 - The first section discusses the importance of maintaining accurate records.  
 - The second section outlines the procedures for handling sensitive data.  
 - The third section details the requirements for system security.  
 - The fourth section describes the process for reporting incidents.  
 - The fifth section provides information on data backup and recovery.  
 - The sixth section covers the topic of user access and permissions.  
 - The seventh section discusses the role of documentation in system management.  
 - The eighth section provides a summary of the key points discussed.  
 - The ninth section includes a list of references and further reading materials.  
 - The tenth section contains a glossary of terms used throughout the document.

This document is intended to serve as a comprehensive guide for all users.  
 It is important to read this document carefully and to follow the instructions  
 provided. If you have any questions or need further assistance, please  
 contact the support team. We are committed to providing the highest  
 quality of service to our users. Thank you for your attention and  
 cooperation.

## Exploration of the Radio Universe

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In the first part of the lecture origin and evolution of the universe and the observed large scale structure is described. This is followed by a description of the Giant Metrewave Radio Telescope (GMRT). GMRT has several outstanding astrophysical objectives, including detection of massive neutral hydrogen clouds which are expected to exist prior to the formation of stars and galaxies in the universe. Consisting of 30 fully steerable parabolic dishes of 45 m diameter each, GMRT will become the world's largest radio telescope operating in the frequency range of about 38-1430 MHz. GMRT is now in advanced stage of completion and will become fully operational by mid-1996. It will be a versatile instrument and will be able to study radio waves being emitted by planets and the Sun, a wide variety of radio sources in our galaxy, nearby galaxies and the very distant radio galaxies and quasars. The design efforts of GMRT have not only led to a breakthrough in the development of low-cost large diameter antennas but also led to design of state-of-art electronics systems, having the potential of wider applications in the country.

**R**ADIO astronomy began when Karl Jansky of Bell Laboratories discovered in 1931 that radio waves are being emitted by our Galaxy in the form of random radio noise. Over the last few decades radio waves have been detected from many exceptional class of objects and their studies have revolutionized our understanding of the universe.

Astronomers have found that a small fraction of distant galaxies are extremely powerful sources of radio waves. These are called radio galaxies or quasars (quasi-stellar radio sources), depending upon the properties of the associated optical objects. It is inferred that a super-massive body like a black hole of millions of solar masses exists in the nucleus of an active galaxy. Accreting matter from the surrounding galaxy gives rise to energetic relativistic plasma which escapes in two opposite directions along the rotation axis of the super-massive body. The relativistic electrons get randomized by the intergalactic medium and give rise to synchrotron radio emission in the presence of magnetic fields. Radio galaxies and quasars can be seen up to billions of light years away and therefore, serve as valuable probes for studying evolution of the universe with its age.

Radio astronomical investigations have given us valuable insight concerning the origin and evolution of the universe. It is widely believed that the universe originated in a Big Bang about 10 to 15 billion years ago from an extremely energetic and dense state and has been expanding ever since. Although several predictions of the standard Big Bang model have been verified over the last few decades [1], there is still considerable uncertainty about the formation of galaxies and large scale structure in the universe. An important prediction of the Big Bang

model is that prior to the formation of stars and galaxies in the universe, there are likely to exist massive cold hydrogen clouds everywhere. It may be noted that hydrogen is the basic building block of the universe. Cold hydrogen clouds emit faint radio waves at a wavelength of 21 cm which gets red-shifted to metre wavelengths. Search for these cold hydrogen condensed at high red-shifts, i.e. at very large distances is one of the most challenging problems in astro-physics as discussed in next chapter. This is one of the primary objective of the Giant Metrewave Radio Telescope (GMRT) which is being set up by TIFR about 80 km north of Pune as described later.

### EARLY UNIVERSE

In 1929, Hubble made a great discovery that farther a galaxy is located, faster it is moving away from us. This meant that the universe is expanding. This is indeed a most remarkable discovery, which led to the concept of the Big Bang model according to which the universe was extremely energetic with a very high temperature in the beginning and expanded rapidly soon after. The expansion is slowed down by gravity which depends upon matter density. In the Grand Unified Theories (GUT); the strong and weak nuclear forces and the electromagnetic force are unified at very high temperatures. As the universe expands, it cools and undergoes a symmetry breaking phase transition, resulting in separation of the strength of these three forces. In the process an inflationary expansion of the universe by an extremely large factor can take place [2].

One of the greatest success of the standard Big Bang Model is in explaining the observed abundances of light elements in the universe now, such as hydrogen,

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## IT, Space and the Society

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I am indeed privileged to be here on this IETE Annual Technical Convention to deliver the 31st Bhabha Memorial Lecture, Dr Bhabha was perhaps the first scientist to engineer the development of this country. Second being Dr Sarabhai, then Prof Dhawan and so on. Born in a rich aristocratic family on 30 October, 1909 at Bombay, Dr Bhabha did his engineering in 1930 from Cambridge University, subsequently, he became interested in theoretical physics, received his PhD in 1935 and remained in Cambridge until 1939.

Dr Bhabha was on a holiday in India when II World War broke out and he decided to stay in India. Sir C V Raman persuaded him to join Indian Institute of Science, Bangalore in 1940. Bhabha's scientific contributions include identifying the elementary particle called "mesons" and determination of cross-section of electrons scattering positrons. This phenomenon is now known as Bhabha Scattering.

In 1945, he founded Tata Institute of Fundamental Research (TIFR) and became its first Director. In 1948, Bhabha became the first Chairman of the Atomic Energy Commission of India, and then onwards a symbol of Atomic Energy programs in the country. The Department of Atomic Energy was set up in 1954. The first atomic reactor 'APSARA' went into operation in 1956 and the first atomic power station was established at Tarapur. He chaired the first committee to organize electronics in the country.

Married to creativity (he was a bachelor), an able administrator, a very good painter with deep knowledge of art and literature, a good orator, Dr Bhabha will always be remembered in this country as a worthy son and chief architect of India's Atomic energy Program. His sudden death in a plane crash in January 1966 was a national loss.

### IT AND SOCIETY

Information Technology has been preceded by related revolution "communication". For decades, this planet is being called a "global village". The basic concept behind this is that whatever happens of significance in one remote corner of the world is immediately known throughout. The recent expansion of this communication through TV media, with the lead taken by CNN during the gulf war, practically bringing the war to the drawing room, has

added a new dimension to this concept of global village. This advancement in communication has brought the world together in many ways, most important, emotionally. In the early part of this century, it was the spread of "plague" killing millions in India and elsewhere, the flight of an aircraft by Wright Brothers, the nuclear bombing of Hiroshima and Nagasaki, the death of the Mahatma in 1948, landing by Neil Armstrong on the Moon in July 1969 and recently earthquake in Turkey. The information has reached everywhere almost instantly and people across the world have felt the same-way. Elated, sorry, disgusted, happy or in heaven, depending upon the event.

Information Technology is now another dimension. We are more talking of events of significance to the whole world. The emphasis has shifted from global to local. Information is now a resource, a personal resource, in this context. Information is now supposed to contain "knowledge" which can be used to generate money. Information Technology is about making available the right information to the right person, at any time, anywhere in the world, at an affordable cost. I am not going into the details of technology, nor the future or emerging concepts, nor looking at the capability you may have sitting in your drawing room, e-commerce etc, that is the subject for discussion in the technical convention that you would be attending during the next few days. What do we mean by "world" when we call it a global village? What is our perception about our own people? What percentage of people in India shared those sentiments; barring perhaps the death of Mahatma Gandhi? The capability you or me will have in our drawing room is of relevance to what percentage of our people? Does it mean anything to our vast society? Is IT going to be of relevance to most of our people? Or; how do we make IT (IT revolution) of any relevance to those masses? How can we influence the common man? - are the questions we need to find or at least try to find answers to.

### OUTREACH, INFORMATION AND SPACE

A. Arthur Clarke's concept of geo-stationary satellite realized in 1964 through "Early Bird" was a breakthrough in mass communication. With three geo-stationary satellites separated 120° apart, you could in principle, communicate from point to point, instantly and reliably. Today, we have a few hundred geo-stationary spacecraft

operating in these orbits, six of our own and many more to come. We are ourselves co-locating two satellites and planning to co-locate three at one slot in the near future. The INSAT series of satellites with re-diffusion through local station have a coverage of 86% of the Indian population and cable operators, through a dish antenna, reach 100% of the population. The geo-stationary systems have reached maturity, providing a large number of services, most common and appreciated is the TV, including Direct To Home (DTH). Recently, you would see Digital Audio Broadcasting revolution, directly from satellite and receiving the CD quality stereo music while on move. We have provided Mobile Satellite Service (MSS) on INSAT-2C/2D satellite for Indian coverage in S-band and the receivers have now been developed. INSAT-3B will carry a MSS transponder, soon to be launched. The V-SATS using extended C-band have provided large capability (about 6000 V-SATS exist) and will see tremendous growth once 12 extended C-band transponders are available from INSAT-3B. The concept of Information Super high Way, providing 2GHz bandwidth in Ka band is emerging, Multimedia and Internet applications are now on an explosive growth path. Personal communication based on GEO is going to be a reality and will be integrated with cellular and other terrestrial systems. The LEOCOM concept, emerging through Iridium, Global Star and ICO is promising to provide direct outreach through a hand held receiver, from anywhere to anywhere. At what cost, 4-5 to 10 US \$ per minute, and what it means to our masses in India, is another issue. In spite of commercial failure of Iridium and ICO (both have filed for bankruptcy), the technical concepts are very innovative, sound and challenging. The concepts were probably a bit earlier than the world was ready and LEO in some form or other is going to play a very important role. Teledesic and sky bridge, again meant for large information flow with high band width will be available soon. The satellite communication, in spite of the presence of fiber optics based ground links, is going to play a key role, particularly for low density, mobile and remote locations. The outreach of space to every nook and corner, urban or rural is ultimate.

Information is of many types - personal, that you need to have about your family/friends; professional - about products, processes or skills is what you deal with everyday. These are important and you need to manage. Natural resource information which can be sensed remotely from space itself is very diverse in nature and is of utmost importance, so that these resources can be managed, on a sustainable basis, so that we may have a "sustainable society" on this earth. It is in this segment of information that space comes in. Through remote sensing satellites, optical and microwave, it is now possible to monitor natural resources, nationwide or worldwide, agriculture forestry, water/land use, disasters like flood, drought, landslides and perhaps, earthquakes, precision

cartography etc. Once we have the information, it has now been demonstrated that at least on a sample basis, it is possible to manage the system such that a transformation is brought about. In Ananthapur district in Andhra Pradesh, one taluk has seen such a transformation. Life can be made worth living for those millions of people who do not have drawing rooms to take advantage of the IT revolution. There are many more applications that can be exploited, like navigation, satellite positioning system, where you can locate yourself with an accuracy of ~ 100 meters, anytime anywhere in the world.

Space is a potential source of information on a wide scale, global level. Space has the outreach to disseminate or collect the information at a global level and what is needed is the "synergy" with IT, to make it happen and be useful to people at large. The concept of "GRAMSAT" discussed long back and articulated is essentially this. Making this resource information interpreted in the usable form, with its local specific dimension and then providing solutions to the individual that are specific to his needs. In the context of a farmer, it could be advice on the crop he should cultivate in his field (maximizing returns based on soil, rain/water etc) when to sow, when to water, when and what kind of pesticides to use, early detection of any crop disease and remedial action, type and time of fertilizers etc. This space segment needs to be supplemented by a large amount of IT segments and being in the social sector, I do not know this can be organized. DOS has funded one such experiment in Jhabua in MP and the experiment itself is under evaluation.

There can be numerous applications which can commercially succeed, resulting in enormous savings at national levels, if industry orients itself towards exploiting capabilities of Space. Recently, I saw in Vancouver, Canada, each taxi having special kit with a GPS receiver with the local map in memory. The taxi driver types the destination and complete route details are given on screen, with all details on turning points etc. Obviously, someone from the IT industry has done a good job and made money. I am told that satellite imagery based accurate Delhi map is now available. There are efforts in some cities to put the whole city on GIS, each house identified through satellite imagery and all details of importance like tax, in the database. An effort like this can perhaps increase tax collection by 10 times and eliminate/reduce the scope of malpractices.

The "Synergy" between information and outreach from space and the IT is there, waiting to be exploited.

#### **THE INDIAN SPACE PROGRAM (SUMMARY)**

As we enter the next century or new millennium in a few months, ISRO has built and launched 25 satellites, starting from Aryabhata on April 19, 1975, about 25 years ago, to IRS-P4, on May 26, 1999. The Aryabhata was

followed by two Bhaskara satellite (in 1979 & 1981) inventing a method of doing remote sensing from a spinning satellites. We supported launch vehicle SL V-3 and ASLV (7 launches between 1979 to 1994) through remote sensing and scientific missions. The last one, PROSS-C2 is still providing useful data. We supported three development flights of PSLV with IRS class of satellites, with IRS P2 and P3 being very useful scientific and technology missions, and the operational, state-of-the-art IRS series of satellite IRS-1A to 1D and IRS-P4, experimental communication satellite, APPLE in 1981 and then operational multimission INSAT-2 satellites (2A to 2E). This has established ISRO as a mature satellite design and development agency, for all the 3 types of satellites - communication geo-stationary, remote sensing polar sun-synchronous and scientific satellites. The IRS 1C/1D are the best remote sensing satellites in the world in the civilian domain with optical data with spatial resolution of 23 meter multispectral and 5.8 meter panchromatic. In IRS-P4, we have the best Ocean Colour Monitor with 12-bit radiometric and 350 meter spatial resolution. The Multispectral Scanning Microwave Radiometer (MSMR) with 4 orthogonal frequencies is the state-of-the-art, all weather sensor for sea state and atmospheric data. The INSAT-2E is a state-of-the-art 2.5 ton class of satellite with bulk transponders leased out to INTELSAT and the demanding customer is all praise for the satellite. We are building INSAT-3B as a fast track satellite to overcome acute shortage of capacity in some bands due to early loss of INSAT-2D. Having decided in December 1997 and finalized the payload in April 1998, the satellite is now undergoing final checks and will soon be ready for shipment. We are awaiting the launch schedule from the launch vehicle, Arianespace which is expected in January/February 2000. It is a very fast turn over even from Western standards.

The INSAT-3 series, starting from the INSAT-3A, is a 2.5 to 3 ton series with 3 to 4 KW power capability. The first satellite will be launched in the second half of next year, 2000, followed by the INSAT-3C, six months later. A state-of-the-art weather satellite, the INSAT-3D, will have a 6 channel imager with one visible and five infrared bands and an IR sounder with 18 infrared channels and a visible channel. The complex payloads are not available for sale at any cost and by 2002, India will be the second nation to have developed these. The INSAT-3E is designated to be a high power 8 to 10KW satellite to be developed for DTH like applications at a later date. In addition, we are developing an optimized 2000 kg class satellite (I-2000) for GSLV launches which will serve as a workhorse to meet the country's ever-growing communication needs.

On the remote sensing side, the thrust is on high-resolution stereo mapping for cartography Digital

Elevation Modelling. It is also important to have high resolution imaging capability for spot scenes. This needs development of a highly agile spacecraft bus with low weight and inertia. Radar Imaging is another emerging area in which serious studies have been initiated. Local augmentation of the GPS system using GEO overlay is another important area to move towards supporting commercial aviation up to category-1 level and further, up to category-3 level, to enable the regular airliners to land and take off in total conditions of poor or no visibility. This needs to be further studied through local augmentation and by using additional support coming in from space segments.

A dedicated scientific satellite is currently under definition with UV and X-ray astronomy payloads (ASTROSAT). Such missions can be further supported by exiting proposals. Microgravity, processing in space, are some of the key areas attracting attention. Recently, a study on mission to the Moon is organized to address the issues relating to unmanned flight journey and to conduct scientific studies.

The issues in front of us are many and challenging. The need to produce large number of satellites, which is too large a load on an R&D set up and not viable as a purely production set up in conventional sense. To sustain technology development, retain the edge, act as an agent for change in the country towards bringing in confidence, that high technology can be done in this country, against all odds, and finally to enable space application from each of those satellites to emerge and reach the user, spread across the country in rural areas - are the goals set for the very immediate future. Self sufficiency, excellence and innovation that act as a technology driver in the country, are the key themes around which the canvas of ISRO's programs will spread.

In conclusion, the basic technology to realize a space segment with any specific application exists, even though upgradation is needed on each and everyday for this fast moving world and to remain competitive is a continuous process. Newer applications like navigation or sustainable development need larger participation of the country on a wider scale. The IT industry has an equally large role to play in services to be provided from Space and their synergy has great promises to the society. It will perhaps make the very existence of IT and Space more meaningful as a concept and activity. I hope, society will be at the centre of our thought process, when we talk of IT and Space, separately or together. By 2010, IT and Space should influence *the life of each and every individual* in this country, helping him or her to achieve basic needs (*roti, kapada, aur makan*). I started with IT, Space and the Society, I end with IT and Space for the Society.

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# Electronic Warfare — A Perspective

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**M**ODERN battlefield is dominated by high technology systems, criteria being denial of battle space to enemy forces. This is achieved by using remotely controlled vehicles, precision guided weapons to achieve 'kill' superiority and by occupying the 'entire electromagnetic spectrum'. The latter manifests itself in the form of equipment which neutralize the use of EM spectrum by the enemy (offensive) for communication and other sensor systems while protecting our own electronic (communication and sensor) systems (defensive). The other main aspect of modern battlefield scenario is aimed at acquiring intelligence about enemy's 'Electronic Order of Battle'. This 'force multiplier' is driven by the latest communication and digital computer technologies. In a war campaign, ability to maintain battle dominance is linked to the ability to gain and maintain 'information superiority'. This need for information superiority is driving 'Electronic Warfare Technology'. The battle space encompasses the land, sea, air, space environments and also the electromagnetic spectrum. The dominance of battle space being the doctrine, the aim and intention of EW is to provide the dominance. For offensive or defensive EW actions, it is strategic to gather signal intelligence (SIGINT) for hostile sources. Electronic support measure systems (ESM) fingerprints the EM sources with the help of sensitive receivers and direction finding (DF) systems. Countermeasure actions are initiated to neutralize enemy threats and deny specific usage of EM spectrum by the enemy. Various ECM techniques, both active and passive, are in use. Electronic counter-countermeasure (ECCM) techniques are designed in our friendly systems to make enemy's ECM ineffective. The paper highlights briefly the EW concepts and provides an overview of some of the developments taking place in the country.

The EM spectrum encompasses the whole range – from low radio frequency to millimetric wave band and the visible (light) – ultra-violet and infrared bands of frequencies. In this paper we consider the EW scenario covering only the low radio frequency to mm wave band.

## EW TERMINOLOGY

Several classical definitions of EW systems are in order:

**Electronic Support Measure (ESM):** This involves

actions taken to search for, intercept, locate, record and analyze radiated EM energy, for the purpose of exploiting such radiation to support military operations.

**Electronic Counter Measure (ECM):** Countermeasure actions are taken to prevent or reduce enemy's effective use of EM spectrum.

**Electronic Counter-countermeasure (ECCM):** Counter-countermeasure actions are taken to ensure friendly use of the EM spectrum despite enemy's use of ECM.

**Signal Intelligence (SIGINT):** Gathering and collection of intelligence from EM data radiated by potentially hostile sources are the functional requirements of SIGINT systems. This includes communication intelligence (COMINT) and Electronic Intelligence (ELINT). COMINT refers to radiation from communication sources, whereas, ELINT refers to non-communications (radar etc) EM radiation from hostile sources.

COMINT and ELINT are basically strategic and are used also during peacetime to gather information regarding prospective enemy plans. In the modern context, EW systems classifications are shown in Fig 1.

## Electronic Support Measure

ESM involves actions to search, intercept, locate, record and analyse radiated EM energy for the purpose of exploiting such radiation to support offensive as well as defensive military actions. ESM includes all the sensors like Radar Warning Receivers (RWR). Communication Intelligence Acquisition Systems (COMINT), Electronic

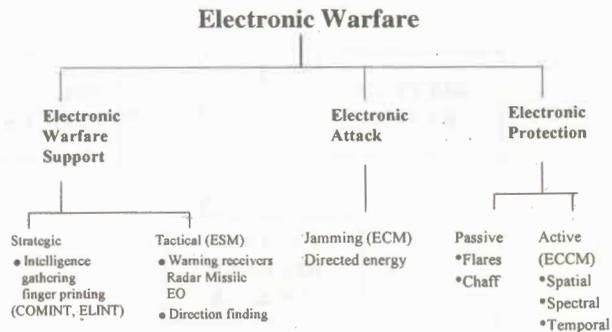


Fig 1 EW terminology

Intelligence Systems (ELINT) for the non-communication signals like Radar, Weapon guidance and control etc. Obviously electronic signature measurements call for a wide band receiving system. As for example, for a radar signature, it is required to cover a wide spectrum from UHF to Ka (400 MHz to 40GHz) band and above. Parameters typically scanned for radar signature are carrier frequency, pulse width, pulse repetition frequency, pulse amplitude, exoticity in modulation, antenna scan type and scan frequency etc. In addition, angular direction of arrival finding is essential to deploy suitable counter measure. Probability of intercept and response time-to-identify are the two important criteria of any ESM system. A well-laid EW system call for an elaborate data base for all friendly and unfriendly emissions for easy classification.

ESM receivers fall under broadly following categories:

- (a) Crystal video
- (b) Instantaneous frequency measurement (IFM)
- (c) Swept super-heterodyne
- (d) Bragg cell Acousto-optic
- (e) Channelised
- (f) Micro-scan
- (g) Digital

Crystal video receivers have low sensitivity ( $\sim -35\text{dBm}$ ), low dynamic range, wide frequency coverage and these are used for 'specific threat warning. IFM receivers have better sensitivity ( $\sim -60\text{dBm}$ ), very good dynamic range, good accuracy (2-8 MHz) and broad band capability. These are suitable typically for reaction oriented

systems. Swept superhet receivers provides very high sensitivity ( $\sim -70$  to  $-80\text{ dBm}$  typical), good dynamic range and excellent accuracy ( $\sim 200\text{ kHz}$ ). These are especially suitable for ELINT applications. Figure 2 shows a generic ESM receiver system.

Direction finding (DF) is an essential element of ESM. DF receivers are designed to measure the direction of arrival (DOA) of emissions. Among the various schemes, rotary DF, amplitude comparison DF, Phase comparison DF are important. Normal DF accuracy provided by these systems is of the order of  $5^\circ$  to  $6^\circ$  RMS. Phase comparison DF measurement technique employs either base line interferometer (BLI) technique or digital bearing discriminator (DBD) based on Butler Matrix receiver. Such systems provide DF accuracy of the order of  $2^\circ$  to  $3^\circ$  RMS. For pulsed signals, about  $1^\circ$  RMS accuracy can be obtained by time difference of arrival (TDOA) technique.

Other DF methods include rotary DF (narrow beam rotating antenna) and pseudo doppler methods. DOA measurements from multiple geographical locations can fix the location of the emitter.

Exotic emitters (like frequency chirp, agility, spread-spectrum etc) require complex processing capabilities in the above. In addition, emitter identification and classification help in deploying appropriate counter measure techniques to nullify the threat. Real time processing to accomplish all the above require complex algorithm development, special architectures and technologies. Shared aperture antennas, MMICs, ASICs, DSP techniques and special software based solutions are exploited in realizing various configuration of ESM systems.

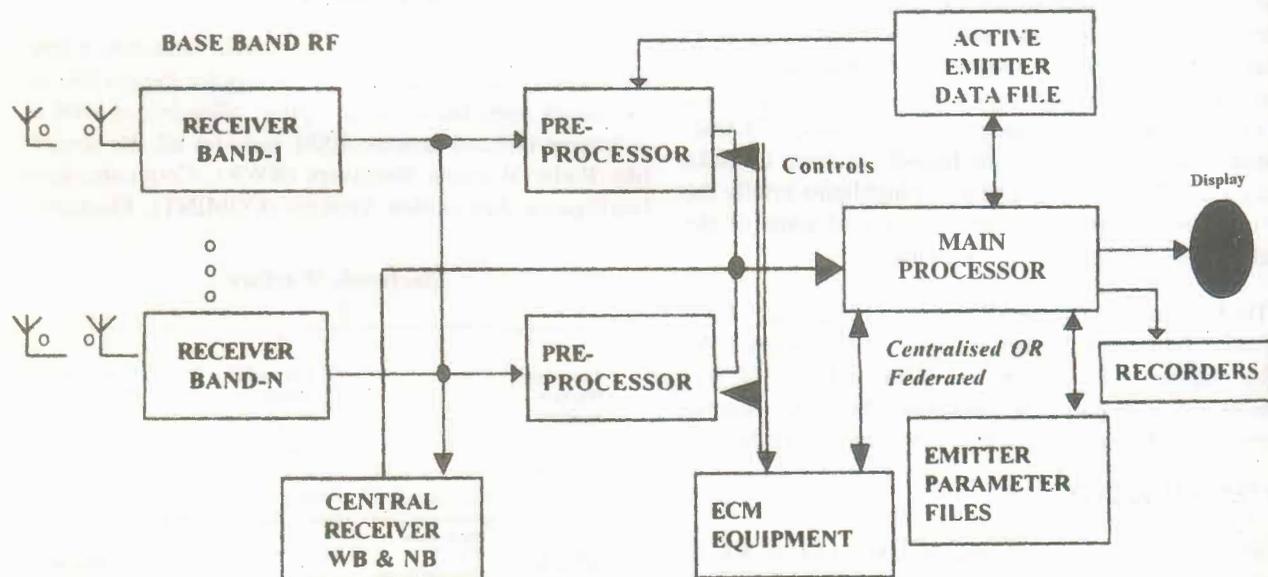


Fig 2 Generic ESM receiver system

**ECM Techniques**

Countermeasure actions are initiated to neutralize enemy threats and deny specific usage of the EM spectrum by the enemy. Countermeasure can be in the form of active jamming or passive (decoys). Various types of active jammers in use are spot jammers (requires apriori knowledge of exact frequency of enemy radar), barrage jammer, sweep jammer, deception jammer and so on (Fig 3). In passive jamming no EM radiation is employed but false targets are simulated to confuse the enemy. 'Chaff is one such technique. Deception jamming introduces false signal (say equivalent to RCS target return) into the victim system in order to deceive the system.

Digital radio frequency memory (DRFM) is widely used in pulse repeater jammers. This is a radar pulse waveform storage device in digital form. A schematic of DRFM is shown in Fig 4. DRFM applications include deception jamming of frequency agile, phase coded and pulse doppler radar. As the system digitally stores the complete radar pulse, it is effectively used for multiple false target generation, large delays for range gate pull off, range gate pull in, velocity gate pull off and velocity gate pull in. All most all state-of-art electronic warfare systems use DRFM.

As the names themselves imply, the self-protection jammers enable protection of the carrying platform against airborne and ground based threats. Such payloads are generally compact and are optimized for the mission role. Escort and Standoff jammers are high power systems and can simultaneously handle a multi-threat scenario over much longer ranges. Electrically steerable multi beam jammers with multi threat handling capability on diverse frequencies simultaneously is an essential features in these types of jammers.

**ECM Technique**

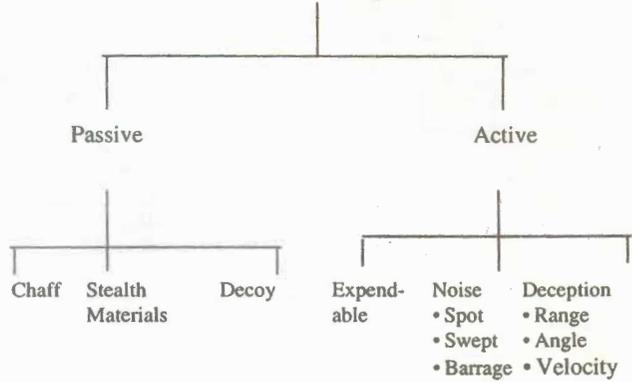


Fig 3 Countermeasure techniques

Towed decoys are off-board counter measures. These are essentially used to counter missile threats like anti radiation missiles (ARMs). With proper orientation of the decoy's antennas and adopting proper maneuver tactics, angular separation occurs between the aircraft and the decoy towed by the aircraft. This deceives the missile seeker and as a result the missile swerves off the aircraft.

**Electronic Counter-countermeasure**

*ECCM make enemy's ECM ineffective against our friendly systems.*

Electronic attack (EA) function also includes non-conventional weapons like Directed Energy Weapons (high energy LASER, high power microwave weapons etc) and so on, but these will not be covered here.

**ECCM Techniques**

To counter the possible ECM threat, present day

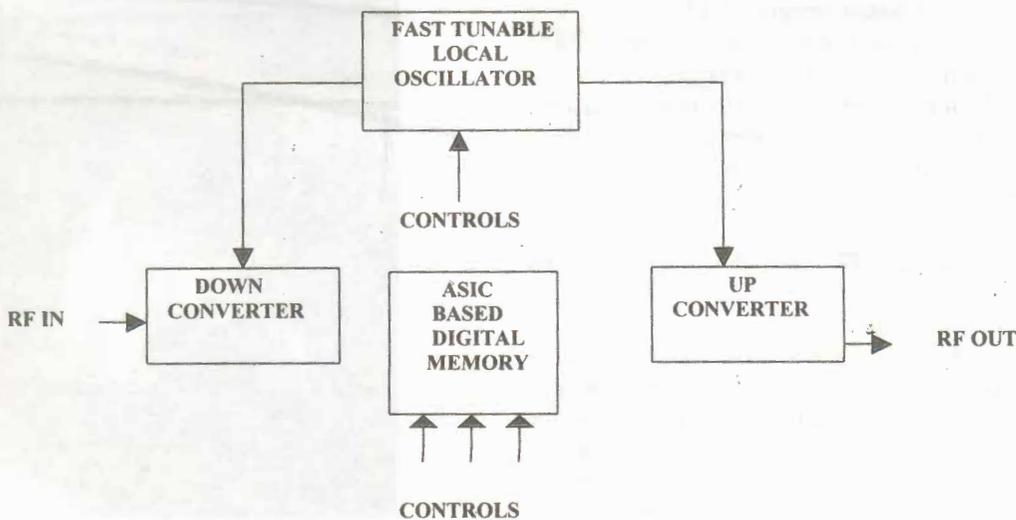


Fig 4 Digital RF memory

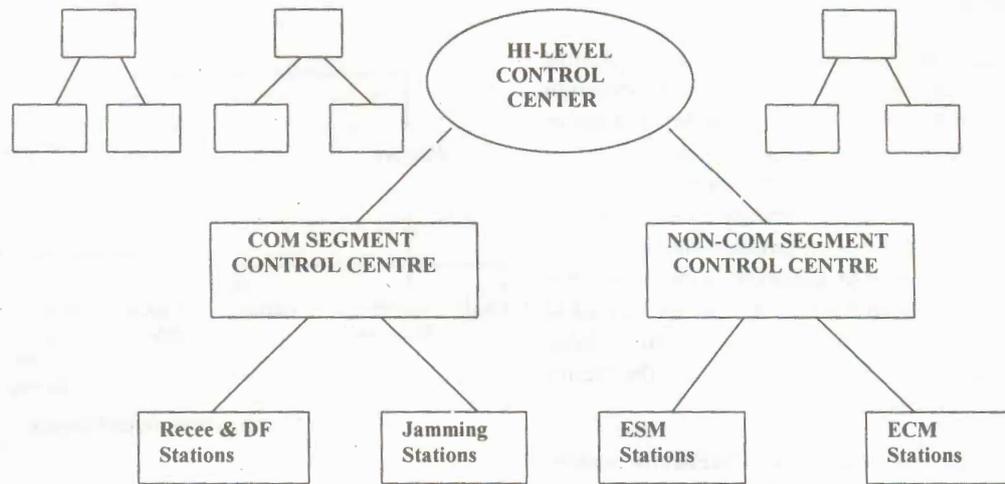


Fig 5 Typical ground base EW system

defence radars and communication systems are designed with ECCM features. This involves pulse compression, PRF agility, coherent transmitter and receiver, frequency hopping, direct sequence modulation (spread spectrum techniques), low side lobe antenna, adaptive array processing, adaptive nulling etc and many other electronic processing techniques. It is in fact a fierce competition between ECM and ECCM techniques that is making defence communication systems and active sensors more complex day by day. ECCM features are designed in the system. For a transmitter, frequency agility and PRF agility protects it from noise jamming. For an antenna system, low side lobe design and side lobe blanking eliminates side lobe jamming. A phased array antenna also can have multiple side lobe cancellers. Similarly the receivers also utilize complex hardware and software processing techniques to avoid front-end saturation, false target detection etc.

### Typical Systems

A typical ground based integrated EW system will consist of communication and non-communication ESM receivers and jammers deployed over a large geographical area (typically 100km x 100km area). For tactical reasons, these entities are mobile and interfaced with intra-communication facilities. A block diagram of such a deployable EW system is shown in Fig 5.

A typical recee and DF ground station is shown in Fig 6.

Typically such ground based EW systems cover a frequency range of 1.5 MHz to 40 GHz. This incorporates high sensitivity, narrow band and wide band receivers for estimating DOA and other com and non-com emitter parameters. The system also consists of high power jammers. The system is controlled by the control centres.

For a naval system, the complete EW functions are to be realized from systems mounted on a ship or a submarine. There are also airborne ESM systems mounted on helicopters and aircraft, which assist the naval system.

There are EW systems which assist in the protection of aircraft. The countermeasure assets include Self Protection Jammer, Escort Jammer, Standoff Jammer and Towed Decoys beside passive countermeasure like Chaff and Flairs. Such systems consists of radar warning receivers, missile-warning receivers, laser warning receivers etc to warn and initiate appropriate counter measures.

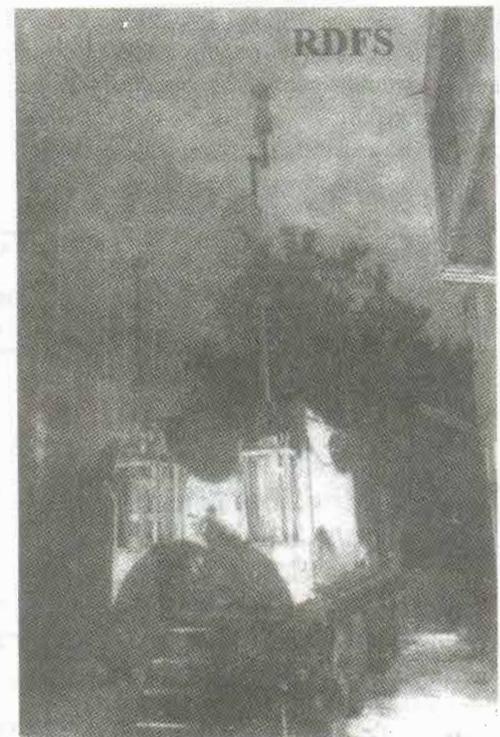


Fig 6 Recce and DF ground station

## Engineering Aspects

There are several engineering aspects that are required to be tackled, while designing and fielding such elaborate and complex EW systems. Some of them are concerned with physical aspects (size, weight, volume and packaging), environmental considerations, electromagnetic compatibility with friendly systems and so on.

Generally land based systems are mounted on mobile platforms and the entities are housed inside electromagnetically protected shelters. Quick deployment requirement necessitates special mast design for ESM and ECM antennae and platform stability. Beside these, there are other engineering issues that need to be addressed - high 'g' design, cooling, maintainability etc.

## Future

EW systems are technology driven. Future EW systems are going to be influenced by the developments in very high speed devices, ASICs, microwave super components, high power microwave tubes etc. For future EW, many more complex areas of stealth, IR, LASER, multi-sensor data fusion, artificial intelligence based decision support system are to be addressed. Future communication systems and networks are also to have ECCM features inherently in-built in the design of the system. New developments in ECCM techniques are going to dictate new developments in ESM and ECM. Achieving excellence in these fields result in having the competitive edge in the true military sense.

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1919 – 1971

*DR VIKRAM AMBALAL SARABHAI was a well-known scientist, educationist and a perfect gentleman. It was unfortunate for our country and the community of scientists that this genius was suddenly snatched away in December 1971 at an young age of 52.*

*Dr Sarabhai initiated and established Physical Research Laboratory (PRL), Ahmedabad where he was Professor and the Director. He also established the Indian Space Research Organization with Centres at Thumba (near Trivandrum), Ahmedabad, Shriharikota (north of Madras) and Arvi (near Bombay). Dr Sarabhai was awarded Shanti Swarup Bhatnagar award for Physics in 1962. In 1966 he was conferred Padma Bhushan by Government of India and in the same year he was appointed Chairman of the Atomic Energy Commission. The Government conferred on him the award of Padma Vibhushan posthumously in 1972.*

*Dr Sarabhai's involvement with Science and Technology was so intense that most of the organizations connected him and those who were with him considered his death as their personal loss. The Council of The Institution of Electronics and Telecommunication Engineers decided to institute a lecture series which will be held every year during Mid Term Symposium to perpetuate the memory of this great scientist.*



# The Place of Basic Sciences in an Atomic Energy Programme

RAJA RAMANNA

Bhabha Atomic Research Center, Bombay, India.

I deem it a great honour to be asked to deliver the Second Vikram Sarabhai Memorial Lecture under the auspices of the Institution of Electronics and Telecommunication Engineers. Dr Vikram Sarabhai was an eminent scientist whose contributions to basic sciences are well known. He was able to carry out his programme of original research in spite of the many burdens that he had to carry. This itself shows the calibre of the scientist. His early death was a great loss to the community of scientists involved in the basic sciences for he was ever ready to support basic research and give these scientists the pride of place due to them.

It is for this reason I have chosen to speak on the place of basic science in an atomic energy programme. Because of the great strides India has made in technology in recent years, unfortunately a lot based on foreign technology, there is a tendency to belittle the importance of basic research. I wish to show that without the component of basic science, we have in Trombay, we would never have been able to reach the status we have. India has a good tradition of basic science, but the uneven quality of it, as exists in the country today has contributed to the devaluing of its importance. Good quality basic research of a size to enable it to make an impact is essential for any technological programme.

In many of our Public and Private Sectors – even the very large ones – no concern seems to be felt about the danger due to the import of technology indiscriminately. Even assuming that these sectors make profits in the beginning, the eventual loss to the country both in obsolescence and confidence is irreparable. Beside, even to absorb foreign technology the R & D with a strong basic component is necessary.

Except in a few cases, the industrial sectors at best have a subcritical approach to research and development and this only to satisfy a general demand. Its work is not effectively utilized and the persons concerned ever sincerely encouraged. It seems as though the group exists more as a protective charm against public criticism. Under these conditions, the R & D unit can hardly make any worthwhile contribution and deteriorates to producing mediocre work and claim exaggerated achievements. To add to this, a good Research Director can hardly be

expected to work in such an atmosphere. Once the laboratory falls into incapable hands, the deterioration is complete, bringing R & D into greater disrepute. In this vicious circle, R & D utilization and imported know-how the only person who benefits is some salesman shark external to the organisation. The approach of buying R & D has taken such a deep root in India that people consider a person wanting to develop his own R & D as somebody slightly off his wits. I believe that every laboratory either in the university or elsewhere must be associated with an industry and every industry, agency, or workshop must adopt one or more appropriate laboratories in the country to both feed it with problems of mutual interest and assist it in its own basic work.

The Department of Atomic Energy has not hesitated to import technology when conditions have required it. The Tarapur Power Station is a clear example. Even in this project, the fabrication of the electronics control systems was sub-contracted to BARC and recently we have stopped importing the completed fuel and is now fabricated at the Nuclear Fuel Complex using the imported enriched  $UF_6$  gas.

In BARC and its sister organisations, we have several methods by which technology is transferred or encouraged in the country. They are as follows :

- (1) By public sector units beings created within the DAE family to exploit the technological developments of BARC. Examples of these are: Electronics Corporation of India Limited at Hyderabad, the Uranium Corporation of India Limited at Jaduguda and the Nuclear Fuel Complex at Hyderabad.
- (2) By transfer of technology to public and private sectors on a contractual basis. The best example of this is the vacuum equipment production which used to be carried out in Trombay and has now been transferred to Indo-Burma Petroleum Company Ltd. I believe the company is already making profits. I do not propose to list the know-how transfers of several other instruments developed at Trombay to industry.
- (3) Starting of special nuclear projects, one of whose main aims is to improve and introduce new technology. An example of this is the Variable Energy Cyclotron Project at Calcutta. Of this, I have more to say later.

- (4) Internal transfer of know-how evolved from basic research within BARC to its applied aspects, in BARC itself; a typical example of this being the construction of the fast reactor, PURNIMA and finally
- (5) Contracting out of basic components required for a reactor programme to a number of private and public sector undertakings as is done in the case of our reactor programmes at RAPP, MAPP etc. During the process, know-how is transferred from us on techniques such as welding, plasma cutting etc.

In the first category, one would like to mention specially the uranium oxide production at the Uranium Corporation of India, Jaduguda and the Heavy Water Plant at Kota which use the processes developed at BARC. The case of the Nuclear Fuel Complex is even a better example of close relations between a research center and an industrial corporation. Nuclear fuel and other materials play a vital role in nuclear power production. The production has to be constantly kept under check by experts in the field to predict and analyse failures. They will also have to keep in touch with the latest developments in fuel fabrication. Because of the possibility of direct transfer of know-how from our Metallurgy Division, several other projects have been started at the Nuclear Fuel Complex, Hyderabad for the preparation of pure materials of a wide variety of materials and in reasonably large quantities. These operations require a strong base in physical metallurgy, solid state physics and chemistry. The transfer of know-how can be effectively operated only if there exists a constant exchange of scientists and equipment between the research centre and the factory.

The construction of the 60 MeV Variable Energy Cyclotron at Calcutta is a very interesting example of how a machine required for use in pure basic physics has provided a strong incentive to the development of new technologies in the country. I mention particularly magnet design, high precision machining of heavy objects, coil winding of a precision nature and the development of very high vacuum in large volumes. These new technologies have now been developed in Bharat Heavy Electricals Limited, Bhopal and Heavy Engineering Corporation at Ranchi and of course in BARC. Though the cyclotron was originally conceived as a tool for basic nuclear physics in which considerable work has been done at Trombay particularly in nuclear reactions, nuclear spectroscopy and fission physics, it has turned out that the cyclotron will be an exceedingly useful tool in the study of radiation damage produced in fast reactors. You will recall that our future reactor programme is geared towards fast reactor development. As a fall out from our nuclear physics studies, considerable amount of nuclear data has been obtained from the 5.5 MeV Van de Graaff at Trombay which has had direct relevance to reactor design and other neutron multiplying devices. Even the pure theoretical

work on nuclear reactions particularly on fission has been of value in our technological activities.

The construction of the PURNIMA reactor is another interesting case of how a group of basic scientists were involved in the construction of a fast reactor for which no designs were available to us. Though several of the Divisions at Trombay took part in the fabrication of Purnima, it was essentially the interest and the expertise available in the pure physics divisions which resulted in the construction of this new important type of reactor. In the process, we were able to develop new technologies in plutonium fuel fabrication, control systems for fast neutron multiplying systems, safety devices etc. I believe, the reactor would not have come up in the short time that it actually did nor would we have been able to enter the field of fast reactor technology at such an early date, but for the enthusiasm shown by the basic scientists.

I can list several such examples, where the basic sciences have played a direct role in solving reactor and other technological problems both in BARC and elsewhere, but the purpose of my lecture is to show how a centre like BARC with a strong component of basic research and having a quality of research output comparable to anywhere in the world can show promise of immediate impact on technology generally. I have chosen three fields to illustrate the possibilities. They are (1) on the use of neutron radiation in the study of the solid state, (2) on some chemical effects of radiation, and (3) on some aspect of biological effects of radiation.

There are various research reactors at Trombay. The one used for Solid State investigations is the Cirus reactor. The neutrons emerging from the beam holes have an energy spectrum which follows Maxwell's law, just like the molecules enclosed in a vessel. The detailed shape of this Maxwellian depends on the type of the reactor. Different regions of this Maxwellian are used for various physics experiments. For most solid state measurements one has to define the energy of the neutrons and therefore choose a thin slice from the distribution. The thermal neutrons chosen in such a way have wavelengths in the range  $1-5\text{\AA}$  ( $\text{\AA}=10^{-8}\text{ cm}$ ), which are of the order of inter-atomic spacing in most solids. It is obvious, therefore, that thermal neutrons can be used in determining the arrangement of atoms in solids just like X-rays. But neutrons have an edge over X-rays in many ways.

Now the atoms in a solid are not always stationary but vibrate about their equilibrium position. These vibrations propagate as waves which have well defined energies and wave vectors (reciprocal of wavelength). These energies (which are of the order of  $10^{-13}$ - $10^{-14}$  erg) and wave vectors ( $10^8\text{ cm}^{-1}$ ) are of the same order as the energy and wave vector of thermal neutrons. Thermal neutrons, therefore, provide a tool for studying the dynamical behaviour of atoms in condensed system.

The principle underlying the determination of structure is through the well-known Bragg's law. If one shines a monochromatic beam of neutrons on a solid and makes an angular distribution of the neutrons scattered from the sample, one will observe Bragg peaks corresponding to various nuclear and/or spin arrangements in the solid. The positions and intensities of these Bragg peaks reveal crystal and/or magnetic structures. The studies involving nuclear displacements (phonons) and atomic spin rearrangements (magnons) require the measurement of energy and wave vector of the scattered neutrons from the solid. At Trombay, we have developed many spectrometers used for solid and liquid state investigations. Since the reactor works round the clock, the instruments are provided with control systems for automatic collection of data.

Reactor neutrons are also being used in neutron radiography, a spin-off from basic research. Because of the basic properties of neutrons, neutron radiography shows much better contrast compared to X-ray radiography. Neutron radiography has many direct applications in non-destructive testing of materials, e.g. nuclear fuel and testing of explosive shells.

I will now make some reference to some areas of research as a part of our Chemistry programme. They are :

1. Chemical dynamics and equilibrium
2. Energetics in chemistry
3. Nuclear and chemical properties of actinide elements
4. Materials science
5. Studies in trace analysis.

The major effort in the field of chemical dynamics and equilibrium has been on understanding the chemical and physical changes caused by the passage of nuclear radiation through materials.

Limitations in the techniques now available in Trombay restrict dynamic study of transient intermediates produced in such radiation interaction to 20  $\mu$ sec and above. However, the lifetimes of such transients can be prolonged if thermal diffusion is minimised as is done in low temperature studies known as matrix isolation method. Such studies using electron spin resonance, and optical absorption and emission spectroscopy have in some cases clearly defined the intermediates, their formation and their subsequent reactions. Fundamental studies of this nature will eventually pave the way for radiation protection for man and materials and for processes in high radiation fields as in plutonium extraction from spent nuclear fuel.

It is possible to use radiation as catalyst for the production of newer chemicals and for modification of properties of materials, one example being Radiation induced polymerisation of Trioxance to produce an industrially important plastic.

Laser stimulated chemical reactions is one of the newer and potentially very powerful new approaches to achieve difficult chemical synthetic routes. The reaction rate between two molecules if unfavourable under normal conditions can be enhanced, even 100 times, by vibrational excitation of particular energy levels by laser induced transition in molecules. Work in this field has been recently initiated in BARC.

The understanding of any chemical phenomenon begins with the knowledge of energy changes involved. The best way to obtain this information is by analysis of appropriate thermodynamic parameters. Much of the interest in thermo-chemistry in BARC is focused on high temperature reactions of transition metals and their compounds with special emphasis on titanium, zirconium, rare earths, uranium, thorium and plutonium. Two examples of such studies : (i) development of a continuous oxygen sensor in inert gases, and (ii) development of ultra-pure titanium and zirconium sponge.

A major effort on the chemical and nuclear properties of actinide elements (Ac, Ti, Pa, U, Np, Pu, Am, and Cm) have been under way in BARC. All the actinides are radioactive and most of them are man made. They are of great technological interest being fissile and fertile as is apparent from the elements thorium, uranium and plutonium.

Study of actinide chemistry has helped in understanding the behaviour of these multivalent ions in solution, which in turn is necessary for developing separation methods in the extraction of fissile Pu and  $^{233}\text{U}$  from reactor irradiated Uranium and Thorium respectively.

Materials science is the investigation of the properties of materials with a view to relate these properties to the ultimate molecular structure. The use of materials is central to all technology whether it is chemical engineering, metallurgy, electronic engineering or reactor technology. Ultimately the solution of any technological endeavour can be reduced to putting the right materials in the right place. New materials generate new technological possibilities and advancing technologies demand development of new materials. For instance  $\text{LaCrO}_3$  is being studied as a possible electrode material in magneto hydrodynamics wherein temperatures of the order of 2000°K are encountered and where a delicate balance of electrical conductivity, thermal conductivity and thermal shock resistance are desired.

Diffusion of one element in another under various environmental conditions is being studied to understand the behaviour of cladding materials and their failure under reactor irradiation conditions. Environmental influence on the thermal and compositional stability of materials is being studied with special reference to  $\text{UO}_2$  which is used as a nuclear fuel in power reactors.

The pace of technological progress demands continuing development of newer methods of separation and estimation of trace level concentrations of impurity atoms in various materials of interest. Particular emphasis is being made in BARC on enhancing selectivity, sensitivity and improving the quality of analytical data.

In many cases parts per billion level impurities have to be estimated in complex matrices and the range of investigations cover spectrographic, mass spectrometric and nuclear methods. A few examples are given below :-

- (i) Trace level rare earth impurities in nuclear grade U and Th.
- (ii) ppb range of impurities in semiconductor grade silicon.
- (iii) ppb levels of mercury in marine products-prawna and tuna.
- (iv) Trace element distribution in human hair-eleven elements ranging in concentration from 1 to 3000 ppm.

The biological effects of radiations can be classified into three different sections : (1) Physiological, (2) Genetic, and (3) Lethal. In contradiction to the general belief that radiations are harmful, I shall bring to your notice some of its useful applications.

As a result of physiological effect, radiation can stimulate growth in plants.

As different from physiological effects, genetic effects are caused by radiations altering the structure of the DNA molecule itself. This can lead to mutations by which new

varieties of food and crop plants can be produced. A new cotton variety having naked seeds has been thus produced. This variety, I believe, is of great value for easy ginning. Similarly an old variety of rice SR26B has been irradiated to form DWARF types IR-5 and IR-8 which are then mated to produce four new varieties. This led to improvement in quality of rice. It is clear that in view of the success of these experiments, one has to actually study the nature of the DNA damage itself to enlarge the field of these activities. This requires considerable amount of fundamental work. Another important aspect of radiation biology is to understand the repair mechanisms in cells. This is of great value in the study of how radiation effect on man can be treated.

Lastly, the Lethal effects are also an important study in the fundamental aspects of radiation biology. These lethal effects are brought about by damage to certain critical targets in cells. They can be either the DNA molecule or the Membrane. The damage in one is usually repaired by the other and the efficiency of this repair process decides the extent of lethality and can be altered by blocking the repair of any one of the targets. These studies have great application in the preservation of fish and killing of grain pests by maximising the lethal effect on bacteria and insects and yet keeping the radiation dose to minimum.

The purpose of bringing to your attention the various effects of radiation is to show how studies in the basic sciences can lead to direct application for the benefit of mankind. There is, in principle, no need to start a basic problem straightway with a need for its application, but when once success has been achieved in understanding the basic processes, it is only a very short distance to find important applications.

## The Computer in the Indian Context

P V INDIRESAN, DFIETE

Center for Applied Research in Electronics, Indian Institute of Technology, New Delhi 110 016, India.

**W**E have gathered here today with two main objectives; firstly, to recall, to our memory the great contributions made by Dr Vikram Sarabhai to the growth of electronics and telecommunications in our country and secondly, to discuss the strides made by us and others in the field of computers. There is no doubt that Dr Sarabhai, if he were alive today, would have been pleased that the Institution of Electronics and Telecommunication Engineers has organized this conference on the study of computers. This is so because he was one, who had devoted an entire life to bring our country up-to-date in scientific development and because these days there can be no scientific development without computers. In fact, it is now generally accepted that we are living in an age which can only be described as the computer age. These days, no society worth the name can tackle any problem—be it that of peace or of war; be it that of technology or of the soft sciences; be it that of acquiring new knowledge or disseminating old knowledge, except with the help of a computer. It is a great privilege to be associated with those who are leaders in this exciting new field and I am truly grateful to the IETE for giving me this opportunity to participate in this conference and for honouring me by inviting me to deliver the Vikram Sarabhai Memorial Lecture.

### RATE OF PROGRESS IN COMPUTERS

Currently, it is the accepted practice to measure the rate of progress in any field of scientific endeavour by what is called the half-life of knowledge. The half-life of knowledge in electronics and computers is currently assumed to be around five years, that is, half the techniques available today are likely to be obsolete within another five years and half the techniques known today were undiscovered just five years ago. If we were to consider certain aspects of the computer field, such as micro-processors, the half-life is even shorter—just two or three years at the most! It is no great wonder that in such a rapidly growing area, we, in our country, are several generations behind the world leaders. Nevertheless, we have currently a vigorous industry for the assembly of calculators and even fairly sophisticated indigenously developed microcomputers; we have made substantial progress in the design and development of computing systems to meet our defence needs and we have also

started the manufacture of computer-controlled telephone exchanges. All this is some progress, but, it has to be admitted that we are not only not keeping pace with the advanced countries of the world, but, are actually falling behind. Apparently, even China is racing ahead of us. Professor Quisser, Director of the prestigious Max Planck Institute of Stuttgart, Western Germany, has been so impressed with the progress made by the Chinese that he expects them, during the next few years, to surpass not only the Soviet Union but Western Germany as well. He has reported "that using only indigenous materials, the Chinese have mastered the techniques of crystal growth, diffusion and implantation of ions as well as of photolithography. They already have continuous emission semiconductor lasers with a working life exceeding 5000 hours, super-conducting alloys, intermetallic semiconductors and artificial diamonds. Computers are still relatively thin on the ground, although process calculators and numerically controlled machine tools are in full production". Against this background, we have to note that in our country, computers have been officially allotted a low priority. It was barely fifteen years ago that we suffered a humiliating defeat in the hands of the Chinese because, of all things we did not have proper rifles and one shudders at the thought of what can happen if we have to encounter them again.

### THE PROBLEM OF ACCEPTABILITY OF NOVEL TECHNOLOGY

In view of the decision to accord computers a low priority, *all the profound and esoteric discussions we are going to have in this conference will be of purely academic importance, unless we can convince the leaders of our society, that computers are an essential ingredient for our future progress and economic prosperity. Unfortunately, computers are still a novelty and it is not in human nature to accept novelty easily. The comment made by the New Scientist is worthy of quote. It says:*

"The appearance of an actual new invention spreads a quiet horror among the administrative staff. It threatens them with novelty, change, worrying problems with no administrative precedent and everybody breathes a secret sigh of relief when the evaluation committee decides, that after all, it is not practicable".

This, alas, is only too true. It is still as difficult to convince our bosses about the value of modern techniques like computers, as it was for Galileo to convince his contemporaries that the earth goes round the sun. However, we should not criticize others, for this is a basic human problem. Max Planck, the renowned founder of quantum mechanics and one of the greatest physicists of this century has said:

“A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.”

If this is how scientists, who by profession and training are expected to be purely objective and rational, behave what better can we expect of others? Hence, the task before us is not merely to catch up with the advanced countries of the world, but even more to educate the people here at home about the utility of modern technology. In many instances, the real obstacle to progress is not lack of scientific skill but lack of political will. If the Americans did not put the first man into space or the Russians on the moon, it was not because of lack of scientific talent or of resources, but due to a lack of political will. If today we lag behind, in electronics and computers, even such countries as Bulgaria and Taiwan, it is once again due to a lack of direction or more accurately, our inability to convince the powers that decide.

### THE CASE AGAINST COMPUTERS

Taking specifically the case of computer development, the popular objections may be summarized as follows:

- (a) Computers lead to unemployment.
- (b) Computers are a luxury and conventional techniques are as good, if not better than computer techniques.

These criticism and fears should not be brushed aside as figment of an uninformed imagination. It is a fact that computers do cause unemployment of certain categories of employees; it is also a fact that they create many more avenues of employment. This requires retraining and for the individual who has to retrain himself to a new job, it could be a nightmare. At the same time, it is an attitude of reaction to consider that it is improper to expect individuals to retrain. Training cannot stop at school or with the initial period of on-the-job training. In our own professions, with a half-life of knowledge of a mere five years, we will be obsolete in no time at all if we do not keep up with new knowledge. For instance, practically nothing that is taught in the undergraduate course at IIT Delhi was known ten years ago, let alone twenty-five years ago. If teachers and scientists are expected to be up-to-date why not the rest of the community?

But this is not a new problem. A hundred years ago,

when, the railway line was first laid between Calcutta and Patna, there was a furore raised by the “dandiwallahs”, whose entire livelihood, it was feared, would be ruined. One wonders, what our present fate would have been if these dandiwallahs had had their way. Unfortunately even today, in what is supposed to be a more enlightened age, the opponents of progress still think and act in a similar manner.

### NEED FOR COMPUTERS FOR INDIA'S PROGRESS

The second charge against computers is that they are not necessary—at least for a poor country like ours; or that there are other methods which are equally good. This is based on the feeling that computers are complex, that they can be used only for very specialized and sophisticated applications. On the other hand, of late, microprocessor-based computer games have been introduced into our country. It is a matter for debate whether this is the best way we can use the hard-to-get microprocessors. Nevertheless, if these toys make more people understand the versatility of computers, they may still serve a useful purpose. In actual fact, most of the computer applications are for comparatively simple process. What they provide, which nothing else can, is speed, precision and a virtually infallible memory.

Let me elaborate from a personal experience. One of my responsibilities at IIT Delhi has been the management of the academic programme of around 1200 undergraduate students. Three years ago, we introduced a fairly elaborate computer data processing system. This enabled me to keep track of individual students, to check who were poor and what is more who were getting weaker and who were improving in their performance; it also enabled me to tailor the courses to meet individual needs, likes and dislikes. As a result, at the end of three years, no two students in a class of about 250 students have had the same set of courses and each student has been able to get his own specific mix of courses! All this has been done without any clash of time table for students, class rooms or for teachers! What is more, in spite of all this complexity, the results are declared and grades sent out within a week of the examinations. Before computerization, all this took some six weeks and that too for a simple rigid teaching schedule where there was next to no choice. Also, no attempt could be made to analyse the students' performance. What is more, the myriad variety of class groups are formed at a few hours' notice so that the classes start from the first minute of the first day of each semester. Only a university administrator can appreciate how difficult these problems are. At times I wonder, whether our universities will run better if our Vice-Chancellors are replaced by computers!

The above is just one small instance of the power and utility of computers. There are many others and to quote them all will fill volumes. For example, our Government is

thinking of establishing a nationwide marketing system for items of mass consumption. This is likely to be a flop unless backed up by a computer-based management system. We want to export more engineering goods, but, without computers, the prospects are quite gloomy. Take for instance, the exports of such simple items as sewing machines. We have deservedly a fine reputation for the quality of the machines we produce. But how long can we maintain our market, when one can now get a microprocessor-controlled sewing machine which can produce twenty-four different stitches at the touch of a button? Similarly, microprocessor-controlled automobile engines are already under production; if we can have same, the savings in our oil bill will be of the order of hundred crores! We also know that a ten per cent increase in the efficiency of the railways will mean a saving over rupees two hundred crore a year, and, this can be done quite easily by more precise scheduling-by computers. These are typical examples of civilian applications; in military applications the computer can make all the difference between resounding success and total disaster.

#### COMPUTERS : AN EXTENSION OF THE MIND

The question is, cannot we do all the above without resorting to computers? Unfortunately, there are many amongst us who have a passionate faith in natural processes—but, no amount of yoga can make the eye see as well as a microscope, or as far as a telescope. Just as the microscope and the telescope extend the power of one's eye, the computer extends the power of the human mind, whether it be that of a scientist, an administrator, a planner or even that of politician. Just as nothing that we can speak can be a substitute for the written word, let alone a graphic sketch, nothing that the mind can think can be a substitute to the memory and computational ability of a computer. It would be folly to deny ourselves the use of such a useful and powerful tool.

#### NEED FOR INDIGENOUS HARDWARE DEVELOPMENT

There is an opinion that we ought to concentrate on software only, because hardware development is too fast for us to keep up pace with others. As mentioned earlier, we are passing through an evolutionary epoch in the development of computers. It was just two years ago that the 8080 was hailed as the ultimate in microprocessors and today it has already been superseded by the 8085. At the other extreme, gigahertz logic is round the corner with speeds over a 100 MHz already commercially available. The minicomputer which has shrunk to a board is now virtually available on a chip. Stack machines are introducing a major novelty in a

computer architecture—a case of the little ones teaching the giants. In this situation, where every new invention is virtually a one day's wonder, it can be argued that we should step aside and wait till the pace comes down to a manageable level. Or, one can say that with software costs increasing exponentially and hardware costs tumbling down, there is force in the argument that we should concentrate on software only. But, it must be noted that, although per unit hardware cost are coming down, the total hardware output is still increasing dramatically. Hence, it would appear inappropriate to neglect hardware; also, we cannot excel in software without hardware to work with. In this connection, we have to overcome the exorbitant costs we have to bear for indigenously produced hardware. With all due respect, this is still a technological problem, which we have to solve on our own.

#### STATUS OF RESEARCH ENGINEERS IN THE COUNTRY

The last time I spoke in public in Hyderabad was the day the emergency was declared. I started my talk with the traditional prayer, and may I repeat it again?

स्वस्ति: प्रजाभ्यः परिपालयन्तां न्याय्येन मार्गेण महीं महीषां ।  
गोब्राह्मणेभ्यः शुभमस्तु नित्यं लोकाः समस्था सुखिनो भवन्तु ॥

May the people be cared for by the rulers of the land treading the path of justice! May honour be with the brahmins and the cows always! May the entire world be prosperous!

Before I am accused of casteism and obscurantism, I should hasten to add that in days of long ago, the brahmins were the scientists advising the cultivator and the warrior, in the then profound sciences of astrological meteorology and archery. Also, in that era of the hunter, the cow was the highest product known to technology. In these terms, this prayer is still valid and the prosperity of the world still depends on the prestige accorded to the scientist and to technology. Part of our current national tragedy is because our society does not accord much respect for the scientist and much respect for technology. If you do not agree, let me ask you a question: If you are looking for a son-in-law, whom would you prefer, a Senior Scientific Officer at the Electronics Research Laboratory or the Sales Manager for Charminar Beedies?

Let me close with a note of optimism and express the hope that our deliberations in this seminar will take us higher in the esteem of our people and that the spirit of Vikram Sarabhai will lead us to such contributions that even our rulers will sit up and take notice.

Faint, illegible text, possibly bleed-through from the reverse side of the page. The text is arranged in several paragraphs and appears to be a formal document or report. Some words are difficult to discern but seem to include terms like "The following", "It is noted", and "The results".

## A New Testament for Electronics in India

S SAMPATH, DFIETE

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### TRIBUTE TO A GREAT SCIENTIST

**T**HE Vikram Sarabhai Memorial Lecture organized each year by the Institution of Electronics and Telecommunication Engineers is an act of homage to the memory of the work of an eminent Indian scientist. It is fittingly an occasion for introspection providing the motive-power for re-dedication on the part of the members of this professional Society to action in tune with the ideals and objectives which he cherished and for which he laboured selflessly throughout his life.

A fellow-student of Sarabhai's Cambridge days paid him this simple tribute on the sad day of his demise in December 1971:

"Sarabhai had a deep love of the subjects that he studied. He was of a sweet and sober temperament. When he returned to India, the nation gave him an opportunity to make the fullest use of his creative abilities. His earnest efforts, motivated by his deep interest in science, enabled him to reach a height of surpassing eminence in the national scene".

We saw him carve out for himself a niche in the hall of fame by the superb quality of the work that he did in putting the instruments of science and technology to use in raising the level of our national well being in several significant areas of application. He was a technocrat par excellence who harmonized his scientific outlook with compassion for the common man and, through his colourful career, led the scientific community in India with naturalness and grace.

Vikram Sarabhai not only maintained the continuity of the line of approach pursued by Homi Bhabha in the development of nuclear science and technology but also brought to bear upon it modern techniques of management and the rational utilization of the products of research made possible by the facilities built up by the Atomic Energy Commission. He pioneered the country's space research programme. He watched over the performance and growth of the Thumba Rocket Launching Station like a zealous parent over the child. In the choice of a site at Sriharikota for space technology activities, he demonstrated the kind of gift that he possessed, like Bhabha before him, for the selection of sites for sophisticated technological pursuits.

He saw merit in diversifying the work of the Bhabha Atomic Research Center. He set in motion several activities in the domain of radio-isotopes with emphasis on their use in the field of medicine for diagnosis and therapy. A notable event during his stewardship is the starting of the Electronics Corporation of India at Hyderabad—as a nucleating center for the development of expertise and capability in indigenously producing high-grade electronic components, device and systems.

Sarabhai was never deterred by the specious plea that the country did not have the wherewithal for highly capital-intensive projects. He stood for totality in modernization and urged that, in order to gain confidence, we should boldly experiment with our resources even at the risk of failure. It is in this spirit that he conceived of and laid the foundation for the fast-breeder reactor research center at Kalpakkam near Madras. In the months preceding his premature death, he was actively engaged in preparing a feasibility report for a pilot desalination-plant to be set up in Saurashtra. He was simultaneously engrossed in the task of selecting a site for a new atomic power station in the northern region of the country. He never missed an opportunity to plead with the Government for facilities to build agro-industrial complexes in the wake of the atomic power plants being established in different parts of India.

He was not a visionary but a hard realist given to contemplating ahead of others what the country's needs were likely to be 20 years later in fields that seemed to him to be very important. In the document entitled, 'The Profile of Atomic Energy and Space Research for the Decade 1970-80 presented to the Indian Parliament in July 1970, he had said:

"We have to rise from an in-built culture within which a major departure from an existing well-proven system and anything which is innovative in character are automatically regarded with suspicion. Ten to twenty years from now, when the population of the country would be between 750 and 1000 million, it can hardly be controversial that we would need a strong base of science and technology, of industry, of agriculture, not only, for our economic well-being but for our national integration and for ensuring our security in the world. The profile of development, during the present decade, of atomic energy and space research, carrying with it advances in fields such as metallurgy,

electronics and instrumentation as well as computer science, has been fashioned to provide a viable future. Advances in science and technology are accompanied by the rapid obsolescence of existing systems. Recognizing that we do not wish to acquire black boxes from abroad but to grow a national capability we should note that our plans have to be continually updated and even the strategy may have to be altered as we proceed."

Sarabhai was greatly fascinated by the prospects of the realization of a domestic communication Satellite and he worked tirelessly for it. He planned India's SITE experiment for 1973, using NASA's ATS-F Satellite but retaining full responsibility for the ground segment—in order to take our own instructional television programmes to villages and cities in several parts of the country. He had envisaged a national domestic Satellite (INSAT) to be ready for operation by 1974-75. For him, the pot of gold at the end of the rainbow of space technology was national communication coverage of all of rural India with the potential to generate a strong industrial base in electronics providing employment to well over 100,000 qualified scientists, engineers, technicians, managers and other communication personnel. To this, he said, we should add the benefits accruing from a large-scale collection of meteorological data and the information possibilities unveiled by remote sensing of the country's natural resources.

In a convocation address delivered by him in 1968, Sarabhai spoke of his vision of the country's future:

"Twenty years after independence, we find ourselves with a broad infrastructure of plants and facilities in the engineering industries which are largely under-utilized. We also find a number of well-established laboratories, without clear-cut development tasks that are meaningful in terms of our national priorities. What is needed now is a major investment in design and development effort directed at indigenous capability for carefully chosen tasks which are important to us. We can identify sub-systems under each of these major tasks and we can create design and development teams which can operate with a wide measure of autonomy. These will require major thrust to produce innovative results. All this is not a pipe-dream. I do hope we have the good fortune to realize these programmes before divergent functions in our society blow asunder all that we cherish."

The dreamer is no more in our midst, but he has left behind shining mementos of his bold thinking, the inspiration of his work the hall-mark of which was that he practised what he preached and several blue-prints for forward movement in crucial areas of national development. Progress in electronics occupied an important place in all his plans. As we remember him and honour him to-day, it should be our endeavour, now as well as in the future, to be worthy of the trust that he put in

his countrymen.

## ELECTRONICS IN INDIA -THE OLD TESTAMENT

In 1947, our national electronics estate was in a rudimentary state, consisting of about 300,000 domestic radio receivers with an annual production-capacity of 4,000 sets, a small number of low and medium-power broadcast transmitters and a telecommunication system catering to less than 100,000 telephone users. In the years following a number of public sector undertaking and R and D laboratories came into existence. Yet, even as late as 1962, the base of the electronics industry was quite small, with a capital investment of the order of Rs. 10 crores and an annual output of about Rs. 8 crores worth of consumer electronics equipment and Rs 4 crores worth of professional equipment. The total number of people employed was around 15,000 including those engaged in sales and servicing functions.

Against this dismal background of low achievement in an industry that intrinsically had a high potential for growth and applications, the Government of India appointed a Committee under the Chairmanship of Dr Homi Bhabha to look into the problem that effected the country's progress in electronics. A blue-print for the development of electronics in India during the decade 1965-75, bearing the hall-marks of the discernment and daring of Dr Bhabha, became available early in 1966 but poignantly a little after he died in an air-crash on his journey to Europe. The Report of the Bhabha Committee, presented by his colleagues to the Government of India, proposed that the country should set itself the task of raising the annual production capacity in electronics which was about Rs. 26 crores in 1964 to a figure of Rs. 365 crores by 1975. It put forward a strategy for making a capital investment of Rs. 170 crores over a ten-year period, capable of producing on the way Rs.1650 crores worth of electronic equipment, components and related accessories. This Report is undoubtedly an important landmark in our country's efforts to modernize itself and become a viable member of the scientific and technological world of to-day.

Attempts to implement the development projects envisioned in the Report, using the traditional organizational structures that were available and following time-honoured methodologies threw into relief many inadequacies and bottle-necks that impeded quick movement. A National Conference on Electronics was convened in Bombay, in March 1970, to review the progress made in terms of the earlier projections and to identify new guide-lines and strategies to deal with the current demands and to face the new demands that were likely to arise. Dr Sarabhai was the key-figure at this conference. The main thrust of get-to-gether of 500 scientists and technologists from all parts of the country who had a stake in the progress of electronics was the

articulation of the need to impress on the highest-level planners in Government the priority that should be accorded to electronics in all of our development programmes and to persuade them to see that electronics is not a commodity that could be dealt with in isolation—like jute, cement, sugar or edible oil but that it is an elemental force that makes an impact on all our societal functions. The conference strove to disseminate the idea that a national commitment to the development of electronics is the *sine qua non* for our progress in all spheres.

During the closing minutes of the Conference, as Dr Sarabhai concluded his valedictory address and asked if any one wished to make a last minute point, a member from the audience rose and said words to this effect:

"This Conference has been a useful exercise. We have paid our homage to the Bhabha Committee Report which is pre-eminently the Bible for our Electronics. But do we realize that this Report is only the old testament? The new testament is yet to be written and this task is best left to the younger people."

Dr Sarabhai beamed his approval. But an unkind fate intervened and he did not live long enough to preside over the writing of the new testament for Electronics. He was young enough in spirit to have undertaken and accomplished this task.

The National Conference gave birth to the new structure in Delhi that we know by the names of the Department of Electronics and the Electronics Commission. In the absence of Dr Sarabhai, the mantle fell on the shoulders of Prof MGK Menon. The shaping of these twin-organizations in their formative years bears the unmistakable imprint of this scientist's intellectual acumen and scholarly response to the demands for the creation of the requisite infrastructure for the development activities in electronics at the national level. As he has now moved over to look after the larger canvas of the country's science and technology activities and industrial research, the responsibility has been entrusted to Prof B Nag to keep the wheels of electronics moving for the good of the country.

It is legitimate at this point to enquire if the newly created institutional structures have helped to produce a new testament or have been content to live off the old one. They were constituted to bring into being a central agency to assess, on a continuing basis, the project-requirements of electronic equipment and systems of various types of users in the country, defining appropriate technological and industrial strategies and estimating the required investments, in term of finance and manpower, to achieve the targets in view; and conduct import-reviews to facilitate the adaption of judicious promotional steps to gear up indigenous capacity for production in areas of critical importance.

In the process of discharging these functions, a number

of innovative steps have been taken, notably, the setting up of the Information Planning and Analysis Group (IPAG) to collect, collate, process and disseminate information on the development of electronics; the constitution of the Technology Development Council (TDC) and the National Radar Council (NRC) whose main objectives are to identify gaps in the development programmes and to suggest viable, time-targeted R and D projects to reduce or eliminate these gaps, with emphasis on user-oriented projects characterized by relatively short gestation periods which, on completion, will make a meaningful contribution to import substitution and strategic self-reliance, the establishment of a Standardization, Testing and Quality Control (STQC) Group in the Department for planning and promoting the related activities; and the building up of the infrastructure embodied in the Electronics Trade and Technology Development Corporation (ETTDC) for promoting exports from the private sector and in particular the small-scale units.

The Department of Electronics has given an impetus to the creation of a number of State Electronics Development Corporations as lead-agencies for the promotion of electronics in several regions of the country. In the computer area, it has sponsored the concept and functioning of Regional Computer Centers; has set up the Computer Maintenance Corporation; and, with UNDP assistance, is laying the foundation for the National Informatics Center (NIC) that will provide a computer network system to facilitate the development of interactive, computerized data-bases for the various Ministries/Departments of the Government of India to aid them in decision-making in the areas of economic and social development planning and programme implementation. A semi-conductor complex, for the design and production of LSI-based electronic components and modules, is taking shape in Chandigarh. The Department has played and continues to play a coordinated role in a number of projects of national importance—for instance, the TITAN Project for the Oil and Natural Gas Commission in communication, telemetry and telecontrol; the MONEX Project for the India Meteorological Department; the ADGES and AREN Plans for the Defence Service. It supports and monitors viable projects in the fields of industrial electronics and medical electronics; and funds pioneering schemes for the introduction of the techniques of electronics in fields such as agriculture, fisheries and mining. In its own right, it carries out R and D work in strategic areas e.g. computer controlled systems in specific defence applications.

Two planning exercise have been carried out: one, a perspective plan for the development of Electronics during the decade 1975-85, the central feature of the projection being a policy of constant acceleration of growth taking into account the rising felt needs of the domestic market and expansion trends in the domain of exports; and, two, a

medium-term evaluation, at the behest of the Planning Commission, of the tasks that should be undertaken at the national level in the field of electronics during the plan-period 1978-83. This latter exercise has yielded a document that contains a review of the present status of the industry and a suggested policy-framework for future growth based on estimated production-targets, scale of possible investments, foreign exchange requirements and employment-generation potentials.

In quantitative terms; in the field of electronics, the country achieved in 1975 a total production of goods worth Rs 365 crores—fulfilling almost exactly the targets laid down in the Bhabha Committee Report. The production figures during the succeeding years, namely Rs 410 crores in 1976, Rs 509 crores in 1977 and Rs 590 crores in 1978, have all surpassed the targeted figures for these respective years. The increase in over-all production, in monetary terms, from the year 1977 to the year 1978, is estimated to be of the order of 16%—a satisfactory figure, in the Indian context. It may be noted that there has been a 22% increase in items described as consumer-electronics; 29% in electronic components (though a substantial part of the rise should be attributed to price increases); 16% in the area of computers, control and instrumentation systems, 13% in aerospace and defence-oriented equipment; and less than 1/2% in professional communication equipment. Exports touched an all-time high of Rs 40 crores worth of equipment, mainly radar and related items, and Rs 3 crores worth of computer software.

In the projection for the period 1978-83, the Department of Electronics estimates that the production will increase from Rs 509 crores in 1977-78 to Rs 1190 crores in 1982-83. The total production for the five-year period is set at Rs 4368 crores, inclusive of Rs 1137 crores of consumer-electronic items. The Central and State Sectors are expected to invest about Rs 450 crores, the private sector making a contribution of Rs 70 crores. Of this Rs 40 crores are expected to be invested on special materials and components and Rs 200 crores on telecommunication equipment. The foreign exchange component is estimated to touch a figure of Rs 750 crores inclusive of a large chunk of nearly Rs 350 crores for communication equipment. It is anticipated that about 300,000 direct employment opportunities will be generated.

There are a number of luminous signs on the Indian sky. The Central Electronics Engineering Research Institute (CEERI) at Pilani, just having completed 25 years of technology development, is poised to take on newer challenges. Products and processes developed at this Institute have been taken over by as many as 70 industries in the country. The total industrial production based on know-how provided by it has crossed the figure of Rs 32 crores. The development work done over the years covers consumer-electronics products such as television-

receivers and audio-systems, semi-conductor devices and integrated circuits, power-tubes, microwave tubes and magnetrons, control-systems for electric locomotives and instrumentation systems for dedicated purposes. As many as 200 diesel-locomotives of the Indian Railways carry the excitation-control system designed at CEERI and produced by ECIL, Hyderabad. Several other sponsored projects are on the anvil : the Scanning Electron Microscope—in collaboration with CSIO, NPU, BHU and CEL; a 150 KVA thyristor-converter for the Indian Railways—in association with CEL; a process-control system for the sugar industry, in collaboration with the National Sugar Institute; control units for mining locomotives—in collaboration with BHEL; and Silicon Solar Cells to meet the requirements projected by the Department of Science and Technology. The success achieved by this Institute should inspire confidence in us that, in several areas, we could adopt a strategy by which the technology practised in advanced countries may be emulated and reproduced by us indigenously and in a self-reliant way.

In several other laboratories and institutions in the country, in the field of equipment design and fabrication to meet our specific needs, several breakthroughs either have occurred or are on the horizon. An illustrative list will include the following : tropo-scatter communication systems; broad-band line-of-sight microwave relaying facilities; radar-units to serve a multiplicity of purposes such as the tracking of rockets, wind-finding, weather-mapping, air-route surveillance etc; radio-navigation aids like the v.h.f omnirange and the distance-measuring equipment; sonar devices and systems; earth stations for satellite communication tasks; mini-computer and micro-computer based systems for dedicated applications. Whereas the area of special materials, components and devices is far more complex and demanding due to rapid advances in technology, the high cost of imported know-how and the critical sizes of the quantities needed to support economic production, commendable work is in progress notably in relation to items such as ferrites, ceramics, liquid crystals, special semi-conductor devices, hybrid micro-circuits etc. Advanced facilities for mask-making and computer-aided design and the extremely demanding infrastructure for work relating to the processing of micro-electronics products and their testing are now available at a number of centers in the country.

In the Bhabha Memorial Address delivered under the auspices of the Institution of Engineers (India), in Bombay, in December 1977, Dr Amarjit Singh a leading figure in our national electronics scene, has called upon his colleagues in the profession to pay increasing attention in the coming years to those tasks that will make a visible impact on our rural and underprivileged population, through such devices as low-cost radio-sets assembled on a cottage-industry basis, electronic instruments to assist in

agricultural practices, solar cells etc and endeavour to bring into agro-based industries like sugar and tea, for instance, striking benefits that will accrue from the clever use of electronics aids. To this should be added the transformation of rural India that can be brought about through the rational exploitation of modern telecommunication technology.

### THE WINTER OF DISCONTENT

There are sceptics amongst us who take the view that the picture is too rosily painted and that the progress claimed is illusory on account of the extremely backward state from which we started and the very meagre investments that we had made in the past. They raise questions such as these : what has come in the way of our scientists and technologists in the electronics sector designing and implementing a national telecommunication system that people are reasonably satisfied with or a broadcast service that the bulk of our population can benefit from at a cost that is bearable by them or a medical care and health delivery system that uses the tools of electronics effectively and begins to transform the quality of life of our people. We do have a number of fine institutions—the Tata Institute of Fundamental Research, the Solid State Physics Laboratory, the Central Electronics Engineering Research Institute, the Telecommunication Research Center, the Physical Research Laboratory, the Defence R & D Laboratories, the National Remote Sensing Agency, the Central Electronics Ltd., the Indian Institute of Science, the Institutes of Technology and various university centers and in-house research departments in our public and private sector undertakings, but is it not our common experience that these tend, by and large, to function as isolated centers of activity and that their coming together for a coordinated approach toward the attainment of a difficult or complex unified goal is an event of rare occurrence?

Nine years ago, two far-sighted administrators in the Ministry of Defence formulated an S & T plan, encompassing the Indian Institute of Science and the five Institutes of Technology, to build up national competence in Radar Technology and to develop, in five-year period, the basic ingredients of a system of strategic importance to the Air Force. The academic institutions were happy over the trust placed in them and the funds given to them to build the necessary infrastructure. They planned their work with enthusiasm. At sub-project level, work of remarkably good quality has been done at a few of the centers. The principal user-agency, the Air Force has however remained sceptical about the possible outcome of the project and has been halting in its approach. Despite their best efforts, the Institutes themselves could not pool their ideas adequately and present a united front before the funding agency. The coupling that was attempted between the academic institutions, whose work could be only exploratory and technique-oriented, and the defence R &

D establishments who naturally place great emphasis on equipment-design, engineering, reliability, user-trials etc has proved to be elusive. It will be worthwhile to carry out a case-study of this well-intentioned but inadequately executed research and training scheme to pinpoint the reasons for the failure of the over-all objectives of this project of national importance and to derive lessons for our future plans. It may be equally worthwhile to study the extent of the depth, cohesiveness, focus and direction that the Indian Space Research Organization has been able to achieve in the last few years in building up a nation-wide structure that links a networks of laboratories, workshops and launch-complexes, earth-stations and tracking centers manned by several thousand scientific and managerial personnel and interacts with a host of academic institutions, industries, R & D establishments and design engineering and application-centers.

The Chairman of the National Committee on Science and Technology, Dr Atma Ram has drawn our attention to what he considers as our major weaknesses in the field of electronics. The first is that our national R & D effort in electronics is weak and diffuse and not up to work standards. The second is that our major public sector undertakings function in the mode of individual closed-loop systems and that this runs counter to the policy of adopting an integrated approach in facing national problems and in matters relating to the choice of technology, the procurement of materials and the designing of efficient production-schedules. Possible remedies to overcome these maladies are : to find a central agency and invest it with direct executive responsibility; and to bring all the major public sector undertakings in the field of electronics under one umbrella *a la mode* the Steel Authority of India (SAIL). The Santa Cruz Electronics Export Promotion Project (SEEPZ) has not made the headway expected out of it, though similar free-trade processing zones set up in Taiwan, Korea, Phillipines, Malaysia, and Singapore have produced spectacular results. The reasons for our failure in the critical sector calls for a review of our policies and methodologies.

If there is one single issue on which there is unanimity of opinion throughout the country, it is the poor quality of service that one gets out of the present civilian telecommunication network. We all realize that our requirements are massive, our resources are limited and it is host of man-centered problems that prevent us from reaping the full benefits from the technical facilities that are created and established from time to time. Yet, a clearly enunciated long-term development policy in this field is conspicuous by its absence and our technological limitations continue to have their baneful influence. It is in response to a situation in which a big gap was found to exist between our telecommunication needs as citizens of a free and progressive country and the rate at which we were producing the required equipment that the Ministry of

Communications set up a Committee of Experts, in 1972, to size up the problems bedeviling this service and to identify and suggest strategies for growth in tune with our needs. This Committee pondered over the current shortcomings and put forward suggestions on action-programmes to overcome many of these. Till to-day, no one outside the Posts and Telegraph Department has an inkling on what the Government's response is to the recommendations made by the Committee. The people of the country have a right to know what is being planned to be done for them in this vital area of national well-being.

That self-reliance in the manufacture of telecommunications equipment to meet our national requirements still remains a distant goal comes clearly through a news-despatch which a leading Indian newspaper carried a couple of months ago:

"During the Plan-period 1978-83, the Communications Ministry proposes to import telecommunication equipment worth Rs 190 crores to provide for short-falls in the indigenous production of cross-bar local switching equipment, trunk automatic exchanges, electronic telex exchanges and VHF and broad-band microwave radio relay equipment. The P & T Department Plans to set up 35 earth-stations to work with the INSAT domestic Satellite to be launched in 1981. The equipment for the first seven of these, that will be used in proving trials with INTELSAT, will be imported; and for the remaining 28, part of the need will be met indigenously and the rest will have to be imported."

The Sub-group on 'Electronics for Communication Equipment' that worked recently on the formulation of the S & T Plan for 1978-83 has pin-pointed gaps in several areas of strategic importance: electronic exchanges; line-of-sight microwave systems; telemetry, telecommand and tele-control systems; data communication etc; and has emphasized the urgent need to mount a well-coordinated R & D effort in these areas.

The predicament in which we find ourselves was highlighted by our distinguished colleague, Shri C P Joshi, Past President of IETE in an address delivered by him two year ago:

"It has to be conceded that the citizens of a free country have every right to demand, from the powers that be, that communication in the country should be good according to modern standards. Not only the national communication system but captive systems in key-sectors like Defence, Police and Railways should function equally efficiently. This will never be possible unless the indigenously produced equipment is of modern design, based on state-of-the-art techniques and available at reasonable cost within a meaningful time-frame.

*It would appear that, with regard to indigenous production of high-grade communication equipment, there*

is lack of "national will". This will should be generated by the consumer pull but this does not happen in our country. The will that we see appears to be a confused thrust generated by the cumulative wisdom of various planning agencies, a multiplicity of regulatory bodies and a few large public-sector undertaking. Most of these agencies, though engaged in hectic activity, work in isolation and often neutralize collectively any important suggestion made by any one of them individually. Instead of playing their roles as beacon-lights at commanding heights, our public-sector undertakings are content to remain as devotional lamps".

A pioneer in the field of police telecommunication, Shri Joshi has spoken out of the heart-aches and impediments that he as experienced in attempting to turn into reality the modernization plans of the police wireless organization in the country. The strength and vitality of a nation, in the ultimate analysis, depend on how secure and confident the average citizen feels in the conduct of his daily life according to the norms of civilized conduct. An efficient and fast-acting Police force is the corner-stone of the edifice of society. Electronic technology, through its instrumentality in the fields of radio-communication, data-processing and scientific aids in crime investigation, has become the sheet-anchor of law enforcement procedures in advanced countries. We, in this country, have not been able to evolve the strategy by which the police forces will get, in adequate measure, the hardware that they need for efficient working. For years now, there has been an inconclusive debate between the Police Administration and the P & T authorities on the relative merits of the former being allowed to establish and operate their own, in-house multi-channel microwave trunk routes on a country-wide basis or constrained to depend on trunk routes which may be leased out to them from the national carrier network of the P & T. An early resolution of this conflict is an imperative in the best national interest.

It is well known that the ground-support electronic facilities in our airports are meagre to the point of being great hazards for all those who travel by air. A retired Senior Official of the Department of Civil Aviation describes the position in these words:

"When the Department was formed in 1946, it inherited some old equipment used by the P & T Communication Stations and some war-surplus items put aside by the military authorities. The Department has acquired, over the years, very little new electronic equipment, except for a few navigational aids. Most of the items are old and fit only for an electronics museum. They are so outmoded that they do not meet the international standards for tolerance and other important functional parameters."

Following the Boeing 737 crash near Palam airport in May 1973, the Government of India appointed a

Committee in July 1973, under the chairmanship of Shri J R D Tata, to review the organizational structure and functions of the Civil Aviation Department and recommend steps to reorganize it in the light of the rapidly growing requirements of modern aviation. This Committee is known to have submitted its Report in December 1975, highlighting the deficiencies that it noticed in respect of equipment, personnel and organization. It strongly recommended advance action in pursuance of a study conducted by the *Equipment Sub-working Group set up* by it. This Group had identified as many as 17 high priority projects which had to be taken up if we desired to put our civil aviation standards on par with those obtaining in our neighbouring countries like Bangla Desh, Burma and Sri Lanka. We are in the middle of the year 1979 and there is no sign yet of the commencement of the implementation of these projects.

In the field of entertainment electronics—one of the key-sectors that can give a boost to the industry, the low per capita income acts as a deterrent to the building up of a sufficiently large market potential. Serious thought has to be given to the steps that should be taken to bring about a wider diffusion of entertainment electronics. The prime need, in this area, is to organize the manufacture and sale of radio-receivers and television-sets at prices which the lower income groups can afford. The Radio Electronics and Television Manufacturers Association (RETMA), in a note submitted to the Planning Commission's Working Group on the Electronics Industry in November 1978, has proposed the following production-targets: radio-receivers to be stepped up from a figure of 3 million in 1976 to 6 million in 1981 and 10 million in 1986; television-sets from 150,000 in 1975 to 500,000 in 1981 and 1,300,000 in 1986. These figures have been suggested as a part of a plan that will help to reduce production-costs in a progressive manner. It has been proposed that we should aim at keeping the cost of a two-band or three-band radio-set, in the economy class, at Rs 120/- approximately 1% of the estimated house-hold income in the mid-eighties. While stepping up production quantities will help to reduce prices to some extent, concurrent steps will be needed to unburden the industry of the cumulative incidence of duties, excise and taxes which to-day add a staggering 60% to the basic cost of a radio-receiver or television-set.

Another significant step would be an attempt to achieve a deeper penetration of rural markets with newer and cheaper methods of distribution and adequate service and repair facilities in the newly emerging market areas. RETMA has warned that, if prices are not brought down, stagnation would set in at a figure of 5 million radio-receivers in 1980 and beyond. If however conditions are created in which the proposed projections are realized, an increase in employment and investment and an improvement in the economy of scale would follow. Components to the tune of 1000 million resistors, 1000

million capacitors, 200 million transistors and 10 million i.c.'s will have to be manufactured in the 1980's. Economically viable projects for the mass-production of electronic components will then take shape and become implemented. Increased production will provide a stimulus to the R & D effort needed to improve, machines, processes and products. Quality control will become a true article of faith and will be exercised to avoid large-scale losses and wastage. The emergence of export possibilities will provide a further urge to design better and achieve a *higher quality. Improved production technology* and tighter materials control will lead to a further reduction in cost. Outdated machinery can be economically replaced by newer and more sophisticated units. New materials and technologies will make their advent; and items such as ultra-pure silicon, piezo-ceramics, metallized polyester foil etc will begin to be made in our country in economically viable quantities. Our electronics industry will then have acquired the base that it ought to have in order to be able to supply the much-needed high-priority professional items for defence, industry and communication. In his address delivered at our institution's mid term symposium in Madras, in July 1978, Dr Atma Ram focused attention on this major area of concern with this exhortation:

"We cannot expect a good internal market at the level of prices prevailing at present and, without a sizeable internal market, the industry cannot be sustained. This is the crux of the problem and it is to this that an organization charged with promotional responsibility should address itself."

We pay lip-service to the importance of achieving self-reliance in production of strategic components and systems but the policies adopted are such as to strike at the very root of such efforts. Shri C R Subramanian, Chairman and Managing Director of Bharat Electronics Ltd has drawn attention to the circumstances that led to the jettisoning of the TTL-devices production in his factory:

"It was thought that the TTL-range may have a large market as these are standard devices used all over the world. There was also the hope that, in the event of these devices being locally made, their import would be banned by the Government. After considerable effort, Bharat Electronics Ltd produced these devices with the co-operation of the Tata Institute of Fundamental Research. After the initial success, BEL went ahead and developed a large series of TTL-devices. These were tested and found to conform to world standards.

The cost to produce the device at BEL ranges from Rs 10 to 12 whereas an imported piece, after a levy of 120% duty, is available at Rs 4. The expected import ban did not materialize. As our costs are higher when compared to international selling prices, we have been compelled to stop the production of these devices. Government

protection would have enabled us to continue production”.

It is likely that, unless we formulate a rational and well-thought-out policy in time, we will witness the same drama of wasted effort at Chandigarh where we are planning, somewhat belatedly, to make LSI-chips.

On import-tariffs, Shri. Subramanian who heads the country's biggest electronics industrial enterprise, offers these suggestions:

“There is a strong case for full rebate of customs-duties and excise-levies in respect of raw materials, consumables and components used by industry. There is also a case for total duty exemption in respect of capital goods imported by this industry. The procedures for the import of capital equipment continue to be very difficult and serious delays still persist. Import licensing procedures should be simplified and made speedier”.

On the incoherence of the national policy on computer hardware development, Shri Vijayakar, Managing Director, Electronics Corporation of India, Hyderabad expresses himself strongly in these words:

“When IBM was wound up in India, it was expected that, except for sophisticated Central Processing Units of large capacity, only Indian products will be permitted to be sold in the country. It now turns out the ICL has been given a letter of intent to manufacture 100 CPU's in the ICL-2900 series. ECIL has laboured hard for a decade to develop indigenously EDP systems. It is now thrown into unfair competition with an established multi-national. Would it not have been far simpler for ECIL to have decided, or to have been asked to decide, not to go into the electronic-data-processing field at all?”

The above describes a situation in which Indian industry was asked to develop a product and, just about the time that the development was completed, made to face the hazard of competition with a foreign giant. The Japanese technique of avoiding this type of pitfall is worth attention. To cite an example, the import of IBM equipment was stopped for 5 years and, during this period, Japanese industry, research laboratories and universities mounted a crash programme to develop computers equal to those produced by IBM. In this effort, IBM was not merely equally but was surpassed.

Shri Vijayakar also has a comment on an irrationality in our import policy. He says:

“The duty on imported components is 120% while that on a finished product is 40%. Users will find it cheaper to import equipment than to buy it from any Indian manufacturer. The prime requisite for developing electronics in India is the availability of international grade components and devices at international prices”.

We should take note of how this industrial enterprise,

ECIL proposes to respond to the compulsions of technological change. It has been built up, over the years, on the foundation of two cardinal principles: the flowering of projects around gifted individuals; and the renunciation of the use of all imported technology. The first choice has led to an escalation in the number of projects and to a state in which the annual production figures in respect of several of them do not give an economy of scale; and the second has slowed down development in key-areas, albeit the existence of a sound R & D base. ECIL has made the hard decision to tone down these guiding principles—first, by reducing drastically the number of products that will be manufactured and concentrating its efforts on a few selected areas, namely, instrumentation, computers and communication; and secondly, by importing technology where there is a felt need and reorienting all the development efforts to be in tune with the corporate goals of the organization. ECIL is, in its own way, setting the pace in the writing of New Testament. Dr Sarabhai would have welcomed this approach.

### THE INGREDIENTS OF A NEW TESTAMENT

Pondering over the problems that have prevented us from making headway in electronics, the Council of the IETE has crystallized its views and placed them before the Electronics Review Committee recently set up by the Prime Minister. Briefly stated, these are:

1. The generation of an adequate capacity to produce electronic equipment and components of quality is a matter of crucial importance to our national development. The Government should take energetic steps in this matter—inclusive of the provision of special incentives for investments in the industry, the lowering of customs-tariffs, the granting of subsidies and the removal of barriers, based on a critical appraisal of licensing and screening policies.
2. Electronic components form the base of the electronics industry. The quality, availability and the cost-price of components together determine the reliability and price of equipment. At the present time, the production of equipment of acceptable professional standard is hampered by difficulties in obtaining state-of-the-art components from foreign suppliers. The import of such components should be allowed on a liberalized basis wherever considered essential and conducive to the improvement of the quality of Indian-made equipment. Concurrently, encouragement should be given to the fostering of the components industry, relaxing irksome restriction on the scale of production as well as collaborative arrangements. In well-defined areas of fast-moving technology collaboration with foreign agencies who have made progress through their massive investments on R & D should be permitted to enable us to buy time and accelerate the pace of our modernization.

3. The Industrial Policy Resolution which prohibits the manufacture of professional communication equipment in any sector other than the public sector has stood in the way of our meeting the national demands adequately. Other competent and potentially competent agencies in the country have been pre-empted from entering into and playing useful role in this area. This restraint should be removed and conditions created in which we will witness a wider but coordinated participation by a number of establishments in the challenging tasks of meeting the country's overall needs of communication equipment.
4. Radio and Television carry a tremendous potential for mass communication and education. The wide-spread diffusion of the benefits of these two services is of critical importance in the context of the needs and aspirations of people in developing countries. While heavy investment have already been made, and doubtless will be made in the future also, at the transmission end, the impact of the services has been inconsiderable and disappointing due to policies which militate against any reduction in the price of radio and television sets. There is an urgent, moral need to take the benefit of good-quality broadcasting to all the corners of rural India. A clear-headed policy is needed to set things right here and ensure that these services serve the purposes for which they were established.
5. The fostering of electronics and telecommunication in India on a scale commensurate with our needs and our desire to transform the quality of life of our people should become an article of faith. There should therefore be a strong, promotional agency at the center-operating on the basis of a political will and commitment to regard the all-round development of electronics as a matter of high priority, with autonomy to evolve plans and schemes judged by it to be relevant to our progress, to identify centers of excellence and to fund R & D programmes at these centers, without demanding an item-by-item pay-off, and, above all, with the authority to take note of failures in performance, lop-sided priorities and ill-conceived goals and to evolve and enforce remedial action.
6. It is equally necessary to create a suitable mechanism to overcome the present cumbersome screening and licensing procedures. It should be possible to examine all aspects of clearance for a proposed project at a single location and communicate decisions expeditiously without making the applicants run from the pillar of one agency to the post of another.

The world of electronics in India awaits the recommendations of the Mantosh Sondhi Committee. The setting up of this Committee has raised high expectations. Several new policy-directives and outlines of new strategies for rapid development are likely to emerge from

the deliberations of the Committee with concerned agencies. When they do, we will need to mobilize a national consensus for pursuing a coordinated action programme on several fronts. Such a mobilization effort should cover administrators, scientists, academicians, industrialists in the public and private sectors, people in the service sector and in all walks of life.

On the question of how far we should venture on the path of modernization and sophistication, Prof M G K Menon has expressed some thoughts:

"In a field like electronic components, there is no question of India adopting what is referred to as intermediate technology. The computers that we have must be the most modern. This is not for hand-waving or for prestige but because it represents the best investment that we can make. And this would be true for most areas of electronics where progress has been so revolutionary that this country, whether for defence, communication, exports or otherwise, must adopt and accept nothing less than the most modern techniques.

One should optimize the paths that the nation should follow, after taking into account all the resources that are available to us and all of what is known in the world concerning science and technology. We have a set of initial conditions which can be fairly well defined and there is a set of final conditions, at a prescribed point of time, that we hope to attain. The pathway to be chosen from the initial condition to the final condition does not imply a wholesale use of every thing that is modern and is in vogue in the developed countries nor a wholesale effort to use methods and techniques that are relatively low grade and appear to be less expensive at first sight".

We should take serious note of the criticism that our R & D effort in electronics is diffuse and not up to international standards. We should do all that we can to ensure that the flowers of creative work bloom at least in a few of our institutions without insisting on getting quarterly progress-reports from our scientists. If we show our concern for and demonstrate our faith in high-quality basic work, done in the best traditions of knowledge-seeking, we will have a climate in which innovative, applied work will flourish. We should build bridges-bridges of understanding between our academic institutions, R & D laboratories and industrial establishments, and, where such bridges exist, remove the road-blocks that hinder the movement of people through them. We should grant a greater measure of freedom than we do now to our engineers in industry to visit university centers for appropriate periods of time to receive continuing education and to get their mental batteries recharged. We should provide meaningful incentives and institute dignified reward systems to induce university scientists to do work of industrial relevance.

Let us make the decade of the Eighties a Decade of

Progress for Electronics in India. I take this opportunity to make an earnest suggestion to Prof B Nag, Chairman of the Electronics Commission, who is present here to-day-to consider the feasibility of convening a National Conference on Electronics in March 1980—exactly a decade after the first one convened by Dr Sarabhai—in a renewed attempt to bring together a large number of thoughtful, dedicated people in the profession of electronics and telecommunication engineering to survey our past achievements as well as our failures and to make fresh plans together to face the challenges before us.

In the last ten years, we have covered good distances. But we were caught in a few quagmires from which we barely escaped; and now and then, we wandered into by-lanes. Let us use all this experience wisely to chart our path more firmly for the future. We shall then be acting true to the spirit of illustrious men who lived and laboured before us for worthy causes. A galaxy of such men is rare in one single generation—men like Jawaharlal Nehru, Homi Bhabha and Vikram Sarabhai. It is our privilege and a responsibility that we may not shirk—to renew and revitalize the legacy left by them, and make our contribution, however small in each individual case, to the sum-total of the progress of our nation.

## Space Communications

U R RAO

ISRO Satellite Center, Peenya, Bangalore 560 058, India.

I deem it a proud privilege and honour to be requested to deliver the Vikram Sarabhai Memorial Lecture of this year to this august audience. Dr Sarabhai was an outstanding scientist, a great administrator, a skillful organizer and builder, a great visionary, and above all, an intensely warm human being. It is indeed a fitting tribute to him that the subject of "Space Communications" has been chosen as the theme for this year's meeting, a subject which was close to his heart and for which he laid the firm foundations in this country.

To me and many of my colleagues at the Physical Research Laboratory (PRL), Ahmedabad, all of whom joined as his students and later matured as his colleagues, he was an intimate friend, guide and philosopher. Even though in his death all of us lost a part of ourselves, he left us with a rich legacy of ideals and dreams and taught us the basic concept of leadership thus preparing us for the tasks ahead. The concept of leadership, expressed in his own words, "*Leadership for the development of creative disciplined individuals, highly motivated to ask basic questions, is not leadership of the type we normally understand..... A leader, if one chooses to identify one, has to be a cultivator rather than manufacturer. He has to provide the soil and the overall climate and the environment in which the seed can grow... The leader has to set an example through his own creativity, love of nature and dedication to what one may call the scientific method.*"

Realizing the difficulty of all developing countries in bridging the technological gap existing between them and developed nations, which tends to widen with every new technological innovation, Dr Sarabhai was the first to recognize the need for the developing countries to avoid building up their technological level through a step by step process followed by the other nations, instead of taking a quantum jump in technology. In his presidential address at the United Nations Conference on the Exploration and Peaceful Uses of Outer Space in 1968, he summarized his views:

*"A positive approach out of the predicament seems to lie in finding solutions where the particular disadvantage of developing nations, which is that they have little to build on, is made an asset rather than a liability. It is necessary for them to develop competence in advanced technology and to employ this for the solution of their own particular*

*problems, not for prestige, but based on sound technical and economic evaluation involving commitment of real resources. They would most likely discover that the traditional approach of planning to provide things like telecommunication services for national infrastructure based on projections of growth from past experience, leads to a dead end, that synchronous satellites could be planned in the context of a programme to be simultaneously undertaken for direct broadcast television to the entire countryside. Indeed, they would discover that there is a totality about the process of development which involves not only advanced technology and hardware but imaginative planning of supply and consumption centers, of social organization and management, to leapfrog from a state of backwardness and poverty"*.

Today, some of his dreams have come true. INSAT, our first operational satellite will soon become operational. Consistent with his philosophy of building up self-reliance and not importing black-box technology from outside, the country has systematically built up expertise in rocket and satellite technology, the foundation for which were laid by him. The world's largest sociological experiment of using satellite technology for rural education, which was conceived by Dr Sarabhai, has been accomplished successfully. APPLE, our indigenous three-axis stabilized communication satellite has been successfully launched and is now being used to carry out communication experiments of relevance to the country. Experimental remote sensing from Bhaskara has paved the way to attempt operational, state-of-art, remote sensing satellites of the future. Thus ISRO programme has focused on application of space primarily for solving the real problems of the country in the areas of remote sensing, meteorology and communications, consistent, with the basic philosophy profounded by Vikram, "*We do not have the fantasy of competing with economically advanced nations in the explorations of the moon or the planets or manned space flight. To us, there is no ambiguity of purpose. We are convinced that if we are to play a meaningful role nationally and in the comity of nations, we must be second to none in the application of advanced technologies to the real problems of man and society*".

### COMMUNICATION AND HUMAN CIVILIZATION

Ever since the dawn of civilization, man has looked up

to starry skies and wondered at the magnificence of the Universe around him, the vastness of the space beyond him. It is the space adventure more than anything else, which made man fully realize that this spinning planet earth which he inhabits, is a relatively small and insignificant planet tied down to the planetary system of the sun, which itself is an average star.

Even though the evolutionary history of the Universe can be traced back to 16 billion years ago, when the entire Universe started its expansion from a very hot and dense ball of gas, the creation of the solar system is only about 4.7 billion years old. The emergence of man is only 3.5 million years old and the emergence of human civilization as we know started hardly 300,000 years ago, a small time compared to the cosmic time scales. **In fact the developments in the last quarter of the century alone, probably match in both quality and quantity, all the developments earlier.** For example, during the last quarter of century alone, we have increased our speed of travel by almost a factor of 100, our speed of communication by a factor of a million, our ability to handle, digest and disseminate new information by a factor of 100. The quantum of scientific information which took almost 10 years to gather in the beginning of this century now takes hardly 10 months. *The single factor which has been responsible for such a tremendous progress in human civilization and which differentiates it from other anthropological species is undoubtedly the quality of Extra-genetic transmission of experience.* It is this quality, which is at the root of human ability to make technological progress and utilize the experience of previous generations i.e. vectorialize the technological development and growth.

The two most important characteristics resulting from the extra-genetic transmission capability are (a) logical reasoning, and (b) aggressive curiosity. It is the ability of logical reasoning which essentially enables the human beings to establish cause and effect relationship in a rational way, plan the next move and take necessary steps to accomplish the same. In other words, here lies the genesis of scientific thought process which can vectorialize the activities along the right direction.

The second major factor which has been responsible for the growth of human intelligence is undoubtedly effective communication. The internal communication governing physical and mental process is mainly through thought processes and nerve impulses, which are conveyed as electric impulses resulting from bio-chemical reactions. The transfer speed of such reactions, even though limited, is still far greater than the velocity of sound. Communication between human beings, however, is primarily through sound. Whereas communication through thought processes is occasionally used, human beings have not been able to develop this technique to a high degree of efficiency. Even granting the limited speed

of information transfer from one human being to another through sound, this form of communication has been developed by human beings to a high degree of proficiency unlike in other biological species. It is this forging of effective communication which has played a major role in the development of man.

It is now generally accepted that neurons or nerve cells are the active elements in brain function. A human brain typically consists of  $10^{11}$  neurons, as much as the number of stars in our galaxy. The information is carried from one neuron to another through elaborate networks of neuron circuitry at specialized junction points of contact called synapses. Each neuron is wired to the rest of the neuron system through 1,000 to 10,000 such synapses. Assuming each synapses carries at least one bit of information, the human neurons memory is sufficient to store at least  $10^{13}$  bits of information. An average person receives approximately  $2 \times 10^6$  bits of information each day through communication, conversation and reading which essentially means that his EPROM memory bank in the brain gets filled up at a fast rate with up-to-date information. Since the total memory is limited, non-essential or obsolete information is erased and replaced by essential and current information as the case may be. It is through this process that effective information and technology transfer takes place from one to another. The ultimate limit of communication speed among humans, assuming our thought communication media is developed to its maximum efficiency, is obviously dictated by the speed of signal transmission from one neuron to another and the response time of neurons themselves. Depending on the type and nature of impulse, the minimal response time of synapses varies from a fraction of a millisecond to tens of milliseconds, which is slightly lower than that of a modern computer. Nevertheless, the above description clearly indicates that the speed of communication even for earthlings can be increased by almost two orders of magnitude.

A related question which arises out of the above discussion is the distinct possibility of finding highly evolved societies elsewhere in the universe, with much faster means of communication. Whereas the arguments presented above indicate that the earthlings have still a long way to go in their evolution, intelligent life elsewhere in the universe could contain much more advanced societies than our own. We will return back to this subject later after dealing with communication, which is one of the important factors that has been responsible for the growth of human civilization.

## SATELLITE COMMUNICATION

The world has come a long way from the early smoke signals and drum beats to the printing press, radio, television and now satellite communication. With the successful relay of TV signals across the Atlantic using

Telstar, the first active repeater communication satellite in 1962, communication is essentially based on the principle that a geo-stationary satellite placed at a height of about 36,000 km above the earth travels exactly with the same rate as the spin of the earth and thus remains practically stationary over the same spot on the earth. In principle, one such geo-stationary satellite can view almost a third of the earth and hence three such satellites can meet the communication needs of the entire globe.

Direct point-to-point communication between different countries of the world using INTELSAT and MOLLYNA network of satellites is now a practical reality for most of the countries. More than 100 nations including almost 60 developing nations are today taking full advantage of the satellite system for communications. Most of the developing countries who still do not have easy access to a communication satellite for TV and domestic broadcasting, have now built ground stations to establish direct point-to-point communication using the established networks of satellites. The bulk of the overseas communication from our own country today is through such a system using 90 foot parabolic antenna dishes located at Arvi near Poona and Dehra Dun.

For a large country like India with a population of over 650 million which has been, by tradition, largely agriculture based, the spread of education through the use of mass media can be a most powerful tool as an initiator of development. The potentialities of television broadcast for imparting education in health, hygiene, better agricultural practices and family planning are now widely accepted. National television programmes accessible even in remote areas through community receivers can be a very powerful tool in promoting national integration by permitting people belonging to all sections of population young and old, urban and rural, literate and illiterate, speaking different languages and following diverse cultures, to share a common audio-visual experience.

Realizing the potential benefits of this technology, the Indian Space Research Organization initiated a number of studies as early as 1962 and arrived at the conclusion that the most cost effective practical solution to our problems lies in the adoption of a hybrid system which combines rediffusion from ground stations for urban areas having large population density and direct satellite broadcast system for catering to the needs of remote rural areas. With the tremendous growth in technology and the phenomenal increase in reliability over the last few years, it is now possible to have multipurpose satellites for communication, TV broadcast and even for continuous monitoring of weather with a life time of 7 to 10 years. Detailed cost analysis of the proposed hybrid system using modern geo-stationary satellites shows that this is only one third as expensive as the conventional terrestrial systems with the added advantage of the possibility of practical realization of the system in a reasonable time scale.

The capability of the satellite system to transmit information instantaneously and reliably from one part to another without being affected by normal weather condition is a great asset both for communication and navigation purposes. Effective and instantaneous communication can save enormous number of lives and minimize damage to property during flood conditions by allowing us to take appropriate advance remedial measures. Considering that on an average basis the total damage due to floods is about Rs 200 crores annually, even partial saving through the use of this technology will produce significant gains to our national economy.

## SITE EXPERIMENT

The inauguration of the year-long Satellite Instructional Television Experiment (SITE) programme on August 1, 1975 marked a major milestone in harnessing satellite technology for taking audio-visual education to remote rural villages. The significance of this experiment arises from the fact that direct reception television, as a concept, was tested for the first time on such a large scale. Using the NASA geo-stationary satellite ATS-6, educational TV programmes were beamed everyday to 2,400 specially selected villages in six States. Extensive preparations were made to make this experiment a success. The greatest challenge was obviously in the preparation of software programmes, which had to be carefully prepared for making a significant cultural impact on our rural audience. Since the experience gained elsewhere in the world has no relevance to our own rural atmosphere, the entire planning of this experiment had to be done based on our experience and expertise. Profiles of SITE village audiences were prepared in terms of village dialects spoken, food eaten, clothes worn, games played and religions practiced. Experimental TV programmes were taken to village and pre-tested to evaluate audience reaction for their comprehension, utility and entertainment value. Resident observer-anthropologists in SITE villages conducted holistic studies to assess the impact of various programmes on the audience behaviour, vocabulary and cultural adjustment to the message delivered. Using the vast amount folklore, mythological backdrop and the rich cultural heritage in the form of dances and folk songs as background material, messages of social value were projected to the audience. Special efforts were made to produce science programmes to make children realize that science permeates their everyday activities.

The year-long programme which ended in August 1976, though conducted on a small scale, has provided us with very valuable inputs both on the hardware and on the software side. On the hardware side, the experiment was a great success with more than 90% of the TV sets working, after the initial teething troubles. On the software side, we have learnt the basic methodology of planning the programme production, pre-testing and post-evaluation. For the first time, hardware scientists and engineers and

software scientists like sociologists, psychologists, economists and even anthropologists have learnt to work together, complementing each other's efforts in making this unique experiment. The experiment has conclusively proved that the audio-visual medium can be a very powerful tool for changing the way of life of a community in the shortest possible time.

### FROM ARYABHATA TO APPLE

The real benefits of the SITE experience can only flow into the mainstream of our country when this technology is used on a nation-wide scale and we develop our own indigenous competence and not use imported technology as a black box. The successful launching of Aryabhata on April 19, 1975 was the most significant major step in our attempt to build indigenous competence and harness the space technology for national tasks.

The conduct of the STEP communication experiment for one year during 1977-79 using the Franco-German Satellite SYMPHONIE, likewise, signifies an important landmark in ISRO's attempt to demonstrate the potential of space communication for rural development. In the field of earth observations, the launch of Bhaskara-I in June 1979 represented the culmination of a number of remote sensing experiments, involving aerial flights, sensor development, setting up of data processing systems and evolving techniques for the interpretation of the remotely sensed data obtained from aerial flights and from satellites such as Landsats.

The successful launching and management of the complex three-axis stabilized geo-stationary communication satellite APPLE on 19th June 1981 is a major milestone in ISRO's programme. Unlike the earlier satellites Aryabhata, Rohini and Bhaskara which were all spin stabilized, APPLE, weighing 673 kg was designed for three axis stabilization with its own apogee boost motor for taking the spacecraft to a near synchronous orbit of 36,000 km and its own small rocket thrusters to manoeuvre and control the satellite. The flawless firing of the apogee boost motor within three days of the launch, deployment of solar panel, achieving three axis stabilization, a highly complicated manoeuvre which involves the acquisition of Sun, enabling the solar panel to continuously track the Sun, acquisition of earth to point the spacecraft antenna to the earth and then establishing the spacecraft in a three axis stabilized mode within the specified accuracies is feat which calls for a high degree of expertise. Since then, the APPLE spacecraft has been moved to its final destination point of 102° East longitude over the equator, its antenna pointed to the center of India over Nagpur and is maintained within  $\pm 0.1^\circ$  of its location, as required by international regulations. Having checked the spacecraft and its subsystems including the payloads, the APPLE spacecraft has begun its mission of carrying out of a large number of experiments in close

collaboration with P & T and Doordarshan over the next one year. These experiments include the establishment of computer net-works allowing any user located at one place to access a computer at other centers, radio-networking, rural education through television and sophisticated digital and communication experiments. This experience will provide direct input into the utilization of INSAT, our operational multi-purpose communication satellite to be launched in the first half of 1982. INSAT system with its capability to provide communication, television and meteorological services over the next 10 years will enable the entire nation to take advantage of space technology to establish an operational domestic communications system and provide better meteorological forecast.

The main thrust of the Indian space programme in 1980s will be operationalize these services and ensure that the benefits from space technology will flow to the entire mainstream of the nation. Operationalization of satellite remote sensing backed-up by aerial surveys and ground truth collection occupies an important place in ISRO's programme for the coming decade. The ISRO Satellite Center at Bangalore, charged with the responsibility of design, development, fabrication and overall management of satellites, has already begun work on IRS, the first semi-operational Indian Remote Sensing Satellite which can provide imageries in the visible and near infrared with a resolution of 40 m. IRS is scheduled for launching in 1986-87.

In the field of communication, with the launching of INSAT, operational communication satellite early next year, the Indian communication scene for the next decade achieve a new dimension. The replacement of communication, television and meteorological services on a routine operational basis in the 1990s with indigenously designed and built communication satellite systems requires serious planning to be undertaken now. The work on proto-INSAT has already begun and with the experience gained from APPLE, ISRO should be in a good position to fabricate future INSATs.

### FUTURE TRENDS IN SATELLITE TECHNOLOGY AND LIMITATIONS

In addition to voice and video, satellites provide a convenient medium for data transmission between widespread geographic area. The wide bandwidth, high quality of transmission and large capacity make satellite data transmission very attractive. Whereas technological advances are consistently reducing the cost, the inherent transmission delays (270 ms one way) has been a distinct disadvantage so far. In the recent past, new and ingenious method of transmission protocols have been developed which together with the large capacity helped in minimizing the impact of this delay and also increase the transmission efficiency to a considerable extent.

Today's state-of-art communication satellite, such as

INSAT can transmit almost one billion bits/second of data. Even at 20% efficiency, the technology capability is equivalent to providing a half hour of computer terminal usage per day for every adult in our country. In addition to improving the capacity with multiple transponders, increasing attention is being given to improve the efficiency of channel utilization by means of new multiple access protocols.

The early multiple access protocols have traditionally extended the basic communication concepts to channel oriented protocols such as FDMA, TDMA, CDMA, etc within each transponder. Whereas in FDMA each area has access to a dedicated portion of channels, at all times, based on frequency assignment, in TDMA each user is scheduled to transmit in short non-overlapping intervals. The next step in this direction has been to incorporate dynamic sharing of a channel using either fixed assignment or demand assignment techniques. Nevertheless for efficient data transmission, the predominately channel oriented system which eminently suited voice traffic needs considerable improvement. The original ALOHA protocol, which enabled users to access at random without waiting for each other thus leading, very often, to the inevitable clash and collision between different users due to lack of co-ordination, has undergone a number of modifications. Thus slotted ALOHA system where a satellite channel is slotted into segments whose duration is exactly equal to transmission time of a single packet with both explicit and implicit reservation schemes, demand based assignment techniques and a number of variations of these now have increased the efficiency of transmission from 18% to well above 40%. The technology of introducing intelligence into the satellite system has been made simpler by the revolution that has taken place in the field of electronics in the improvement in high speed and low power solid-state device technology, with speed power factors of the order of 0.5 pico Joules, availability of microprocessors, high density memory chips and finally CCD's. Thus with the introduction of intelligence onboard spacecrafts, it is possible to choose a variety of reservation protocols ranging from the simple "round robin" in which each earth station is interrogated sequentially to more complex preferential treatment depending on volume of data, urgency and user requirements.

The technological growth in the space segment and the increasing trend in the lowering of launch costs with space shuttle and its future variations including the development of re-usable heavy life launch vehicles are bound to foster another revolution in space communication through "complexity inversion". Multibeam technology, multiple large antenna deployment to cover different areas with spot beams, can all be incorporated into a spacecraft which is specifically put together in a low earth orbit (LEO) using pre-fabricated systems of modules and then raised to the geo-stationary orbit through possibly electric propulsion.

Such satellite systems together with the advances made in the fields of spread spectrum, modulation, data compression and digital speech interpolation are going to usher us into a new era in data communications. This coupled with the advances in the encryption techniques will make it possible to transfer large amounts of data not only in a cheap and efficient manner but also with an adequate amount of secrecy and security. The experimental systems of today such as home video newspaper, electronic mail, electronic banking and fund transfer, electronic marketing, pocket and wrist telephones, direct broadcast TV, electronic teleconferences and even electronic telecommuting will become practical operational systems tomorrow. Thus it is conceivable to have persons sitting at their homes and carrying out their official work through a small satellite office with a low cost terminal equipment instead of commuting everyday to their office to perform their duties. The utilization of complex multiple access protocol systems on an operational basis provides, for the first time, economic feasibility of adopting distributed data processing systems (DDP) with multiple data bases within the environment of which even highly interactive message oriented data processing hierarchy can be easily incorporated. The ability not only to repair faulty ones but also to add ON modules to the orbiting spacecraft allows further natural growth requirement. Adoption of optical communication techniques such as laser systems can further improve the data handling capability of such spacecrafts by almost two orders of magnitude.

## LIMITATIONS

The major limitation is undoubtedly the scarce resource of the geo-stationary orbital arc itself. It is the irony of this century that only advanced nations have the means to monopolize such a scarce resource. The presently operative geo-stationary orbit allocation based on "first come first served" basis has essentially assisted the advanced nations who were ready to utilize the bounty of space technology leaving the developing nations, who need such technologies most, in a state of helplessness. The technological options available to partially alleviate this problem namely polarization diversity schemes, antennas providing spot and shaped beams allowing for frequency reuse, utilization of higher frequencies to obtain better bandwidth all the way up to Ku band and beyond, are all options which drive the technology higher in the scale of sophistication making it essentially out of reach for many countries. More than 60 active communication satellites are already in existence and a minimal spacing of 3° in longitude required to avoid serious interference between systems, poses a major limitation to the realization of aspirations of a large cross section of world society. Whereas WARC, ITU and United Nations are all active in trying to bring some rationale by which every country can benefit based on its practical requirements, terrain and level of development, the social system being

essentially slow and thermodynamic, the technological events are overtaking us leaving the developing nations in a state of uncertainty and helplessness.

### INTERSTELLAR COMMUNICATION

I would now like to revert back to the point where I started namely of interstellar communication. With the tremendous improvement in deep space communication techniques, facilities and the possibility of arranging large dishes to achieve 3 km or more diameter effective antenna apertures is well within the capability of present day technology. Thus by the year 2000 the present capability to penetrate distances of about 50-100 light years will be increased easily to 1000 light years. Such a system could easily produce detailed maps of Pluto as the ones we are now getting of Venus with more than 10 dB to spare. Considering that Radio Astronomy has been responsible for many developments such as large dishes, aperture synthesis, narrow bandwidth high resolution reception, in addition to the scientific interest in subject of interstellar communication, the technology input to a communication engineer is of sufficient virtue to briefly deal with this subject. And effective utilization of Tracking and Data Relay Systems Satellites (TDRSS) in space will further enhance data acquisition capability. Even deployment of large antennas in space—with clustered 2-MW klystrons and an Arecibo (300 m) dish or even higher ones (3000 m) deployed in space can easily provide an improvement of over 100 dB compared to the present capability.

Probabilistic calculations are based on various estimates such as the number of stars which can have planetary systems and the probability that life with intelligence has evolved in some of these planets. Our best guess is that there are at least a million civilizations in our galaxy at or beyond the earth's present level of technological development, the nearest civilization being probably at a distance of 300 light years away from us (1 light year =  $10^{15}$  km).

Out of the two possible approaches namely sending the interstellar probes to carry out search operations and "eaves dropping" using the terrestrial communication network of future space segment network, the latter admittedly is the more feasible one. The problem boils down to three simple basic issues namely (a) *Where* to look for (b) *How* to look for *i.e.* through which part of the electromagnetic spectrum and (c) *What* to look for *i.e.* the type of signals which one can expect—three basic questions which have always bothered scientists since the very advent of science. Regarding the first question the answer is relatively simple even though the solution is complicated *i.e.* anywhere and everywhere. The detector technology, background noise and signal to noise considerations clearly indicate the microwave part of the electromagnetic spectrum as the most promising to look for intelligent signals outside our terrestrial systems. Examination of the microwave

spectrum shows a broad minimum of background noise in 1 to 60 GHz range. However, the atmospheric attenuation which is predominant at higher frequencies narrows down this range to 1 to 10 GHz. It is here conjectures start and educated guesses coupled with divine ego begin. The presence of hydrogen line at 1.420 GHz and strong hydroxyl line at 1.667 GHz together with the minimum background noise and the fact that all life on earth as we know depends on Hydrogen and water makes this region of the electromagnetic spectrum between 1.4 and 1.7 GHz a divine "water hole" which could become the rendezvous with extraterrestrial intelligent life. Regarding the last question computer simulation of simple messages which could be coded have been put forward by many scientists and our ability to recognize messages from outside depends on our own intelligence.

Not all scientists agree on these conjectures and many new ideas are put forward including the possibility of extraterrestrial intelligence using neutrino communication. Isolated attempts have also been made to detect possible signals using the existing dishes such as the one in Arecibo. Advanced search techniques like Cyclops using 1500 antennae, each of 100 m diameter have been envisaged. I do hope systematic searches of this type will establish contact with extra-terrestrial intelligence before the end of this century making this discovery the crowning glory of science of communication physics and engineering.

### CONCLUSION

Space Technology is likely to completely revolutionize our outlook in the next two decades. It is quite possible that cheap source of solar energy could be economically tapped to meet large scale energy needs of man. Space manufacture will become quite routines by the year 2000. Space transportation will become cheaper by at least two orders of magnitude. Orbiting and geo-stationary satellites will not only provides effective means of communication but also will unearth new resources and provide a better handle for meteorological predictions, eventually leading to weather modification. The technological developments are likely to provide direct services such as resource information, communication in a decentralized distributed mode, with some of the services being made available in a personalized manner to individuals which can solve energy problem and also provide a fresh impetus to the urban citizens to move to rural areas. Space technology in the coming years will take the benefit of science right to the center of the individual houses and communities. Some of these predictions may look improbable. But let us not forget the lesson of history. Looking back, essentially 800 life spans can cover the growth of civilization of which more than 650 were spent under primitive conditions, only 70 of our forefathers had an effective means of communication, with one another, only the last 10 had really made use of the metal age, only

the last 4 have been seen the locomotive and the last 2 electronic monitors. Vast majority of scientific discoveries and technological breakthroughs which have been the cause of today's material wealth have been developed within our own life time. In this technological age, it is self evident that it is only technology which sets limit to man's activity and defines the state of his cultural and economic evolution. *It is important to recognize that it is no longer the resources which limit decisions but decisions which can create resources.*

For the first time in the history of man, technological

developments in space era seem to have opened up a vast spectrum of opportunities for the benefit of mankind. For a developing country, in particular, the exercising of right options based on sound technical and economic judgment is very important, if we are to ensure that the benefits of science and technology reach the very grass roots. *Space communication can be powerful catalyst in effecting both qualitative and quantitative transformation of our society.* To conclude, in the words of Dr Sarabhai "The question is not whether a developing country should adopt space technology. The question is whether a country can afford to ignore it".

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# The Information Age and the Digital Revolution

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## THE HOMAGE

It is indeed a great privilege and honour to be invited to deliver the tenth Sarabhai Memorial Lecture and I am deeply grateful to the President and the Council of IETE for the same. It is right and proper that we pay this tribute to Vikram Sarabhai, who had the vision that "Electronics and Space should play the role of a vital instrument of development in this country". In his opening remarks to the National Conference on Electronics, held in March 70, which many of us were privileged to attend, Sarabhai said: "Electronics is the one industry where this country can make a big break-through as Japan did, domestically and in export. Indeed we can do better, for we have a much bigger potential domestic market where we can regulate operations. India may have a low standard of living, but we are not a 'poor country'. While speaking on the INSAT programme, he visualized: "This is one major task which can provide, as the Apollo Project to the Moon did for the United States, a means of rallying engineers in a number of different directions to leap frog from our state of technological and economic backwardness. It not only gives a most valuable input for national development through a powerful communication system reaching the remotest village or isolated community, but introduces us to the latest technology in space and electronics, offering employment to tens of thousands of engineers". Speaking on "Television for development" at the Conference of the Society for International Development, held in New Delhi, 1969, the great humanist asked the question "should one concentrate on providing the benefits (of TV) first to urban communities and progressively go to rural areas?" He then answered in his characteristic way that: "For continued stability and national integration,.... there is need to bring together different units through a common mass medium of communication reaching all sections of the population... the literate and the illiterate, the privileged and the underprivileged. I would submit therefore that the answer to this question can be clearly stated. It is that we should consciously reach the most difficult and the least developed areas of the country and because they are in this state, we should reach them in a hurry." How far this has been achieved, ladies and gentleman, it is for you to judge.

Taking the cue from the prophetic words of Sarabhai, I would like to reiterate that the progress and survival of the

humanity depend now on a total information communication system and hence, I have chosen the topic of "Information Age and Digital Revolution" for my talk this evening.

## INTRODUCTION

Looking around us and looking at the technological development in electronics and telecommunications all over the world, one is inclined to agree with the futurologists that we have almost reached the Information age and the Information Revolution—a revolution much more significant than the Industrial Revolution of the last century. In the opinion of Dr John S Mayo, Executive V P of Bell Labs [1]: "The spectacular development in Solid-State electronics, computers, switching and transmission, have brought us to a new era, the Information Age, an age in which an abundance of sophisticated electronic machines will assist a major portion of the work force in getting, creation, processing, dissemination and use of information.... This is also creating enormous opportunities for entertainment and for relaxation, perhaps leading to an era beyond the Information Age.

Bulk of the information is generated in office, factories, Government, social centers and not the least, in homes. Information age technology has already moved into the business environment and the impact there is enormous. But the movement into the homes has been much slower, whereas more and more information will be generated in Homes (replacing classrooms, offices and work centers). These information centers must be highly interconnected with the outside world, and that requires significant *Digital Connectivity*.

Mayo further said that: "Information age is by no means the domain of just the telecommunications and data processing industries. It is a change in society more profound than the Industrial Revolution. Those industries who will respond to the needs of the change will survive and the others will have to perish in the process. The progress in the required technology will perhaps meet the challenges of the Information Age. But we need to do more in the way of optimizing the interactive functions which couple the hardware to people and the real world. When we overcome that challenge, we will have met most of the technology requirements of the Information Age".

Traditional information sources, e.g. Speech, TV, telemetry etc, have been mostly analog and of varying bandwidths, and as such, they have been processed and switched through distinct networks, mostly analog. It is only with the development of digital IC's, Electronics Switching Systems (ESS) and data communication networks, that the possibility of Integrated Telecommunication Networks has been seriously considered. Even in early 1970's, it was suggested that two groups of users, one for low frequency signals, such as speech and the other for wideband signals, e.g., TV should be processed in two separate switching centers and the overall processing for long distance connections should be done in super-switching centers [2]. An alternative proposal was an integrated system, where a set of unique networks are constructed for different signal types, and the overall control of these networks is given to the ESS. Thus a common signaling system is provided for the overall network, where network themselves remain somewhat individual. This however did provide for the total integration of the network and the problems of compatibility, interface and connectivity would restrict the universal use of the concept.

It was then quite evident that a totally integrated network can be achieved only if both switching and transmission of information are digital. Fortunately in 70's we saw a tremendous progress in digital ESS and digital short haul trunks, but the long-haul trunks still remained analog because of the economic reasons. It is only in 80's the digital transmission through digital radio (LOS), TDMA satellites and digital fiber optic media, has become economically competitive and hopefully, the progress towards the Digital Integrated Networks will be very rapid.

We wish to discuss in the following the new emerging services called for in the information age, the progress in digitalization, of switching and transmission and the overall impact of the Digital Revolution through 2000 A.D.

**WHY DIGITAL ?**

Consider the outline of a modern telecommunication network, as shown in Fig. 1, it is seen that the customer services are partly digital and partly analog. However with efficient A/D converters, all signals may be converted to

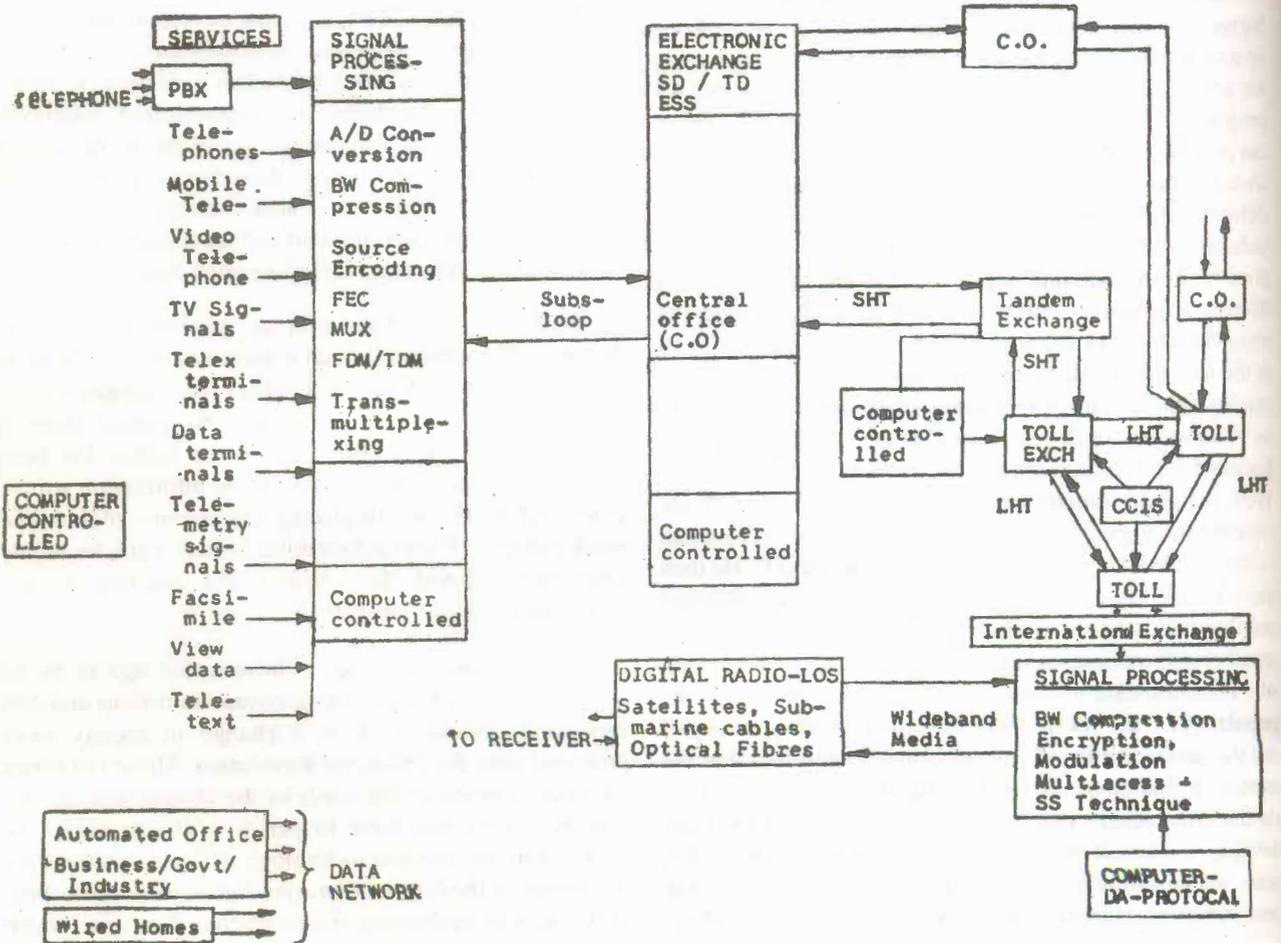


Fig 1 An outline of a modern communication network. Here: CO — Central Office, CCIS — Common Channel Interoffice Signalling, SHT — Shorthand Trunks (digital), LHT — Long Haul Trunks.

the digital form, and modern techniques of signal processing may be utilized for source encoding, bandwidth compression, error-correction, data formatting etc. As the information moves along, the data/messages are switched through local exchanges (ESS), short-haul/long-haul trunks, toll exchanges and ultimately to a broad band medium for intercontinental transmission. Since all signal processing and switching functions are now computer controlled, it is economical to have an all digital networks. Unfortunately, the long-haul trunks, till recently, have been cheaper for analog transmission and the progress towards all-digital network was slow. But with the recent development of digital carrier through Digital radio, TDMA-satellites and digital fiber-optic media, the integrated digital networks, where both switching and transmission will be all digital, will be established rapidly.

M Robert Aaron of Bell Labs has discussed the reasons for rapid progress towards all digital networks and briefly they are [3]:

- (a) Digital terminals are cheaper than analog and the network performance is mostly determined by the terminal characteristics (say, quantization noise).
- (b) Digital Mux is simpler and the media is interference limited due to efficient regeneration.
- (c) Digital signal processing, e.g., echo control, service circuits, bit rate reduction and encryption, is well matched to device technology.
- (d) Nonlinear optical and millimeter wave devices favour digital signals.
- (e) Improved performance over analog-circuits and simplified maintenance.
- (f) Promise of making new services viable.

Aaron has also given an analysis of the trends in digitalization of various telecommunication services in different countries. It is shown that the growth has been almost linear during 1968-78 period in almost all countries, and this has been mostly in short-haul digital trunks. USA has the maximum ckt-km of digital trunks installed ( $10^8$  km in 1976), followed by Japan ( $10^7$  km in 1976), where the present growth is faster. The continental countries are following the same patterns of growth.

The concern of scientists, technologists and telecommunication administrators, regarding the future of digital networks, their implementation, techniques and economics, is reflected in the programme of the international conference and communications, ICC-82, held in Philadelphia, during June 13-17, 1982. The theme of the conference was 'Digital Revolution' and the topics of the sessions clearly indicate the progress in the research and development in digital networks. Some of the more important topics discussed are [4]:

- Advances in Speech and Image processing
- VLSI in communication signal processing

- New Data-base oriented network capabilities
- Switched digital capability
- Integrated voice-data system
- Modern digital Satellite and Terrestrial Radio Systems
- Mobile communication satellites
- Spread spectrum techniques
- Transmission performance of digital network
- High capability fibre-optic systems
- Economic considerations in integrated communication systems.

Some of the new services, as discussed below also strongly indicate that the maturity of telecommunication lies in moving forward towards all digital systems.

### New Dimensions in Telecommunications [5]

The changing social needs and the development of new technology are bringing the evolution of new communication capabilities, e.g., videotex, electronic mail, teleconferencing and interactive CATV. These are also leading to *automated* offices and *wired* homes, where most of the future information will be generated, processed and utilized for running the industries, business and the government, and for education and recreation. Communication media are basically of two types (a) Record media e.g., books, magazines, newspapers, letters, etc. and (b) real time media e.g., telephone, radio, TV etc. Of the new media, Teletext and viewdata (jointly known as Videotex) may replace the record media and customers may now get the desired information on demand from a central databox which has all these information (books, newspapers etc) in its memory. Teleconferencing, electronic mail and interactive CATV will surely cater for all the needs of the real time information, characterized now by telephone, radio and TV.

Videotex is implemented in two ways, as viewdata and teletext. Viewdata is a two way, interactive system which was a combination of video display (often a TV receiver), local processing and a remote data base, accessible through the public telephone network. Pages of information are stored in the data base ready to be accessed through a tree-search protocol which allows the user to page the increasing levels of detail. Viewdata public service is now available in UK (Prestel), France (Teletel), Canada (Telidon), Japan (Captain), and other countries have installed limited test systems. An agricultural information system (Green Thumb) has been developed by USA. Teletext, on the other hand, is a oneway information system which employs unused lines in the broadcast TV signal to transport data to modified TV receivers without interfering with normal programme. In this, the details available in viewdata is not possible and the service is described as an electronic magazine. Teletext public service is again available in UK (Ceefax, Oracle), in

France (Antiope), and in several other countries. In UK and France where viewdata and teletext services are offered concurrently, the format and data encoding are made compatible so as to reduce the cost of signal processing at the display.

In electronic mail, text message, derived from letters and telegraph, can be exchanged between many persons using terminals communicating through a large common memory under the control of a modest computer. Messages addressed to a specific recipient (or Group of recipients) are stored until the recipients logs-on, identifies himself and requests for his messages. Most systems also provide answering, forwarding and filing functions, and some of them handle voice messages as well. Commercial electronic message systems are presently operating in USA. Postal automation on the other hand, aims at increasing the efficiency of the present system of delivering letters and telegrams to the addressees.

Teleconferencing, using videophone provides an interactive meeting space and substitutes telecommunications for travel (resulting in much of energy saving!). Its contents are derived from telephone, TV and data communications. The real time aspects of the medium facilitates unique executive discussions between several levels of management in several locations in an industry or government and proves the richness of the medium for any corporate discussion or conference. In USA, several major companies maintain facilities for teleconferencing, using leased and/or dial-up connections. Most major telecommunication organizations in the world now offer similar services on a limited basis.

Cable TV (CATV), although originally planned for TV programme transmission to rural subscribers, now provide a wideband, one-to-many, downstream connection together with limited bandwidth, one-to-one, upstream connections. It provides such services as Network and Premium TV, local access channels, opinion polling, alarm services, meter reading etc. CATV reflects the real time nature of its use and may partly serve as a Teleconferencing network. In USA, several systems provide security monitoring and a few afford the opportunity for answerback to the head end.

### **Automated Offices and Wired Homes**

Due to the availability of the above exotic technologies, the concept of automated offices is gaining ground and the application of advanced communication technology within the office as well as for inter-office purposes is going to have spectacular impact on the productivity of functions and products. The automated office will incorporate data processing services to achieve desk-to-desk transfer of text, data and image information, computer services to accomplish the design and drafting of complex products to control and support manufacturing, administrative program for coordinating all activities, and

communication services to provide electronic mail, information retrieval and conferencing. Through these applications, resources will be conserved, the reliability and consistency of the product improved and productivity will be increased.

As an extension of the concept of automated offices, the automated homes, or *wired household*, will incorporate microcomputer based entertainment and data processing functions, residential communication media, such as, Radio, Telephone & TV, and will provide an environment in which entertainment information and personal communications are readily available and administrative, security and conservation functions can be performed automatically. Teletext, viewdata and interactive CATV will be used in addition to the traditional communication media. Many of the application in wired homes, will require development of specialized infrastructure (data bases, networks, administrative centers etc.) which will have a social or commercial basis. Experimental systems, using cables or fibres, have been set up in Japan and Canada and surely other countries will follow them.

Thus the new communication technologies, as discussed above, will continue to evolve under the influence of consumer demands, supplier records and the opportunities presented by hardware and software developments. Whether the new media introduced in early 80's will achieve as widespread use and influence society as much as telephone, Radio, TV and data communication have done, will depend on the vigour of public demand and necessarily on the affluence of the respective societies in various countries. Media such as viewdata, electronic mail and teleconferencing, which will contribute to improved productivity, have the greatest chance of survival and growth, and they would play major roles in automated offices of the future. For home needs, interactive CATV, teletext and viewdata will surely be popular, at least, in the affluent society.

### **Current Developments in Switching and Data Networks**

In the context of the development of all digital switching and transmission systems, e.g., ITT system-12 and Bell system No. 5 ESS, T3 and T4 carriers, ITT proposed the Network 2000 as the concept of their telecommunication network for 2000 AD. The ITT system-12 is the first generation of digital exchanges developed with the concept of Network-2000, using distributed processing and fibre optics for transmission. In Japan similarly, digital switching systems, such as Hitachi HDX 10 and similar digital switching systems, are being installed using latest LSI technologies to achieve a compact, economical and fully electronic switching system. In UK, System-X, an integrated digital switching and transmission system, has placed the British telecommunications in the forefront of world technology [6].

Bell Labs, have developed their newer version of ESS, No. 5 ESS [7], where the stored program controlled digital time-division switching system will provide operational savings and ease in system growth for local offices. It has four major sub-systems:

(a) the central processor, (b) a message switch, (c) time-multiplex switch, (d) interface modules. The system uses fibre-optic links as trunks micro-processor controlled interface modules, and a time-space-time switching network. The SPC is distributed among the Central processor and interface module units. The ESS has a subscriber capacity of 12000 lines, uses PCM-format for incoming telephone lines and information rate of 32.768 Mb/s through fibre-optic links. It uses LSI circuitry including a digital signal processor on-a-chip, modular-hardware, e.g., Bell-Pac Packaged Systems and also high level programming languages. Given the switching system's flexible digital design, No. 5 ESS is expected to carry forward the evolution to an Integrated Service Digital Networks (ISDN) in the Bell system.

Concurrently, the computer architecture has gone through an evolution and today's distributed processing system has developed through point-oriented computers in 50's the family series in 60's, super computers in early 70's and then area-oriented horizontally distributed types in late 70's. This system is intended to carry out all possible processing at the site, where information is generated and used. Instead of a single ultra-large computer, this new system applies horizontal integration of several smaller computers to increase the system's capabilities. This results in better flexibility of operation and maintenance and in greater economy. Hardware wise, the single-chip processing power is approximately doubling each year. Bell Lab's BELLMAC-32 A, a recently completed single-chip, 32 bit micro-computer, has a computing power almost equal to some of the popular mini-computers. The trends in micro-computer development suggest that the micro-minis and maxi-computers, all three may be expected to process about  $2 \times 10^7$  instructions per second in the early 90's. Except for a few special purpose super-computers, the computer-on-a-chip will, by then, serve most of the processing requirements in our telecommunication networks. The optical disc, magnetic bubbles and semiconductor memories will meet the needs of large data bases at much lower costs.

The digital data system, as proposed by all Bell Systems and other, uses data multiplexers and concentrators, and the resulting high rate data (64 Kb/s or 1.54 Mb/s) is processed through the digital switches for onward transmission [2]. The digital hierarchy is developed by using higher order multiplexing of the primary MUX data streams of 1.5444/2.048 Mb/s, to generate the ultimate rate of 120/274/400/800 Mb/s. These are transmitted through coaxial cables/waveguides/radio

relay/optical fibres, using multi level DC-free codes. In satellite communication, 50/60 Mb/s is transmitted per transponder, giving 700/1000 speech channels. Newer TDMA systems are being developed for 100/350 Mb/s data rate in the 20/30 GHz band. Over and above the national common carrier system, independent high capacity networks are being developed in many countries, e.g., USA & Japan, using satellites and LOS links. Regarding the network protocol, the packet switching has been so far the most popular technique.

### Wideband Media

We have so far discussed the traditional and newer services required in the emerging information age, and also the requirements of the switching and data networks. For a totally integrated digital network, it is essential that the transmission network should match the characteristics of the switching network as well. Digital radio, Satellite TDMA and Fibre-optic media are the wideband transmission networks that are being used now and further developed for higher capacities. In general, the channel capacities achieved are: 200 Mb/s for digital radio, 60 Mb/s for satellites and 400/800 Mb/s for optical fibres. It is expected that with single-mode fibre cable, the data rate will go up to a few Gb/s.

### Digital Radio

In Digital radio (LOS), the progress has been rather slow because of the higher costs of long-haul digital trunks, as compared with the analog trunks circuits. But with the rapid decrease in the cost of terminal electronics, e.g., in digital channel banks and MUX equipment, the overall cost of the digital radio links is now competitive with the analog systems. The digital LOS systems are now widely used because of the added advantage of easy connectivity with the digital cable systems, better performance and the ease of implementation of digital signal processing, e.g., adaptive equalization, multiplexing, signal scrambling, and monitoring and control. The spectral efficiency of digital radio depends on the type of modulation used and its sensitivity to noise, interference and multipath. Extensive development activities in this direction have resulted into newer signaling techniques e.g., continuous-phase FSK, minimum-phase shift MSK, off set QPSK, Q-PRS, higher order APK and MA-MSK. Some of the important parameters of the systems are: Waveform signal set description, spectrum occupancy, eye-pattern and error-rate performance. An analysis of the channel capacity for various modulation schemes show that 16 QAM performs better than 16-PSK, both offering a spectrum efficiency of 4bits/s/Hz. Q-PRS and MSK techniques are also popular with system designers. With CW interference, however, the C/N requirement deteriorates, but even then the PSK systems offer considerable resistance to channel interference.

The parameters of some typical modern digital radio systems are [8]:

- (a) Long haul LOS System (Canada) using QPRS in the 8 GHz band, bit rate 91 Mb/s, RFBW 40 MHz, Spectral Eff: 2.25b/s/Hz,  $C/N < 17$  dB for  $P_e = 10^{-4}$ ,  $f_b/n_o \approx 1.7$  dB (less 2 dB coding gain),  $C/N$  degradation  $\geq 1$  dB for  $C/I \approx 6$  dB. Hardware complexity similar to QPSK, but less than  $8\phi - SK$  required for the given spectral efficiency. Amplitude and delay distortion similar to those of  $8\phi - SK$ . DFE used for connecting inter symbol interference (ISI).
- (b) Long-haul LOS system (Japan) using 16 QAM differential encoding in the 4/5 GHz band, bit rate :200 Mb/s, symbol rate 50 Mb/s, RF Ch spacing 40 MHz, Regeneration every repeater, spectral eff 5 b/s/Hz,  $\alpha = 0.5$ ,  $C/N = 20$  dB for  $P_e = 10^{-5}$ ,  $E_b/N_o \approx 13$  dB. 1.5 dB degradation in implementation. DFE used.
- (c) MSK modem for Satellite communication (experimental) Bit rate 100 Mb/s, Eff. BW = 50 MHz,  $WT = 0.5$ ,  $C/N_o = 9.5$  dB for  $P_e = 10^{-5}$ .

With further progress in DFE, adaptive multipath cancellers and modulation techniques, digital radio will be more wide spread in all national networks. This also has a special application for rural telecommunication networks being VHF/UHF bands.

### Satellite Communication

In the last 26 years, satellite technology has matured into a powerful communication medium with a large capacity, but having a nodal network topology which provides an enormous potential of control, flexibility, processing, switching and growth. Starting with the launching of Sputnik in 1957, a series of experimental satellites, e.g. Score (1958), Echo (1960), Courier (1960), Relay (1961), Telstar (1962), and Syncom (1963), proved the techniques of maintaining communication with earth stations. This resulted into the first International commercial communication satellite, Intelsat-I in 1965. Today the Intelsat-IV provides approximately 25,000 circuits at a reduced cost of 5,000 dollars per year per circuit, Intelsat-V will now provide the reuse of the spectrum by polarization diversity and will also use higher frequency assignments for same routes. With Intelsat-IV, satellite systems provided two thirds of the world's transoceanic telecommunications and consisted of 12 satellites and 300 earth stations in 125 different countries. Intelsat-V has approximately doubled the capacity of international telephone circuits.

Many countries, e.g., USA, Canada, Russia, Japan, Indonesia, India, etc., now operate domestic communication satellite systems. USA itself has four domestic satellite systems involving some ten satellites and more than 1000 earth stations. Almost all of these networks have ambitious plans for expansion and many

other nations are planning new domestic systems. Satellites for mobile communication now serve maritime and aeronautical users. MariSat, FleetSat and LeaSat provide mobile military communications. The civilian maritime mobile service will be supplied by Inmarsat using a new Marecs satellites series. For direct broadcasting of television and FM signals to home receivers, satellites need have effective radiated power of 200-500W per channel and this possibility was first demonstrated by ATS-6 at S-band. At present, Japanese Broadcast Satellites (JBS) and Canadian Technology Satellite (CTS) are giving direct broadcast demonstrations at K-Band.

In spite of the enormous growth in satellite communication technology, there are obvious limits to growth. They are:

- (a) The number of synchronous orbit assignments available is limited by interference between adjacent systems.
- (b) The frequency bandwidth available for satellite systems is limited by nature and the regulatory process.
- (c) The size of the satellite is limited by the current technology of launch vehicles, but this may be relaxed with the success of the Space Shuttle.

On the other hand, there are many promising techniques which promise long term growth within these limits. The important ones are:

- (a) Frequency reuse (being used in Intelsat-V) and cross-linking (of specialized frequency band) between satellites in space.
- (b) Multiple frequency band operation in a single large satellite.
- (c) Network control technology for centralized automated control of earth stations.
- (d) Solid-state amplifier technology.
- (e) Multiple-beam ground stations to access satellites from one station.
- (f) Multiple spot beams.
- (g) Digital signal processing for voice, data and video.
- (h) SS-techniques for small earth stations.

The problem of echo suppression in voice circuits (because of 0.6 sec delay in the path) has been solved by echo cancellers, now fabricated in a single VLSI chip at a lower cost. The effect of propagation delay in data transmission has been overcome by a satellite delay compensation unit, which permits much larger data block lengths (than in terrestrial circuits due to better error rates in satellite links) and increase the throughput efficiency by a factor of five. The video conferencing circuit has been

made cheaper and more attractive by using the frame differential band-compression technique. Even standard TV signals are now being transmitted at 32 Mb/s rate only.

The application of Delta modulation, FEC, ARQ, and M-ary QAM techniques improves the channel capacity manifolds and the band-expansion due to A/D conversion of analog signals is more than compensated, resulting into better signal quality and less error rates with minimum satellite power. In TDMA using 750  $\mu$ s frame time, the channel capacity of a transponder remains almost constant, even with large number of accesses and FEC improves the channel capacity by approximately 6 dB for low G/T earth stations. VLSI and  $\mu$ -processor techniques have greatly aided implementation of digital coding and data compression algorithms, and couple with the forthcoming VHSIC technology, complex signal processes operating at very large bandwidths is being realised in a small number of chips. The processing of signal on board the satellite leading to satellite-switched TDMA and regenerative repeaters are now possible using digital techniques and will lead to further improvement in overall efficiency.

The all-digital, fully integrated satellite systems, e.g., SBS of USA, FECS and RICS of Japan, use many of the digital processing techniques mentioned above. The satellite business system (SBS) has been designed to serve the full spectrum of communication needs of a large community of business and government organizations and others, and has the following characteristics:

Fully integrated digital-voice, data and image transmission capacity : RF-12/14 GHz; TDMA with DA, voice activity compression (VAC); 5.5 and 7.6 m antennas for earth stations on customer premises; data 2.4 Kb/s to 6.3 Mb/s, Direct access to a switchboard wideband communication network with reduced dependence on terrestrial access facilities. Equivalent useful capacity 13,900 voice ckts or 8000 data circuits each of 56 Kb/s ( $\approx$  500 Mb/s). The user of network services has available an assortment of advanced features, such as,

- (a) flexible voice and data conference arrangements
- (b) multipoint distribution of digital data, including document distribution
- (c) teleconferencing, including multipoint video conferences
- (d) hot line and other priority connections
- (e) network access control
- (f) electronic mail using page-a-second communicating copier.

Japan has been developing domestic satellite communication systems since their first experiments with ATS-1 during 1967-68. They have now developed a medium capacity domestic satellite communication system using the 30/20 GHz and 6/4 GHz bands. This includes

Fixed Earth Station Communication System (FECS) in 30/20 GHz band, Remote Island Communication System (RICS) in 6/4 GHz band and the Transportable Earth station Communication System (TECS) using both 30/20 and 6/4 GHz bands. Both for FECS and RICS, they are using TDMA, having 60 Mb/s and 100 Mb/s data rates. The 100 Mb/s system has the capability of transmitting and receiving two colour TV and 192 voice circuits, and has the following characteristics:

Bit rate 106.88 Mb/s, 2 CTV+192 voice ckts, No. of accesses 4; QPSK modulation with coherent detection; Network clock synchronization, FEC-Rate 7/8 convolutional codes and threshold decoding; 1.544 Mb/s voice and 32.064 Mb/s CTV signals. Data rates 6.4 Kb/s to 6.3 Mb/s.

Experiments are also being done with very small earth stations having one-to-three channel capacity and using SSMA techniques in 6/4 GHz band. Another system for an integrated digital satellite communication for transmission of diverse bit rates of data, facsimile and video between small earth stations has been developed. TDMA-DA is being used for accessing the system.

US defence department is developing a global positioning system, called Navstar, which will serve most of the needs of USA's global navigation and position determination. This will provide for the first time a common system for all classes of uses, maritime, aviation and space, and it may reverse the proliferation of special-purpose navigation and positioning systems. The system is all digital and the users determine their position by tracking long digital codes transmitted from four Navstar Satellites. This is one of the unique usages of SS codes and has range measurement accuracy of 10 to 20 meters. The US defence considers Navstar as the best way of keeping wide ranging forces (including Infantry) on target and potential civilian users are hopeful of getting this service as well.

The general trend towards larger space craft for satellite communication will lead to the support of large and complex antenna feed systems for multi-beam, multi-frequency use and the high power levels for multiple-transmit channels. Once large space craft of 2500 kg or more are built for any one mission, their use for multiple missions will become obvious. Thus, the concept of the geo-stationary platform being realized, the platforms will replace many separate small satellites that are now performing individual missions. In addition to economic benefits, platforms will be able to interconnect missions (e.g., international and maritime services) and thus conserve orbital arc and RF spectrum through the efficient use and reuse of several frequency bands. Initial studies show that a 5000 kg experimental geo platform could accommodate several advanced communication payloads, e.g., a 30/20 GHz system, a large aperture (12m)

multibeam 6/4 system, a satellite switched 14/11 GHz systems, and a 12 GHz broadcast satellite system. They would all be interconnected and could be used to accommodate a variety of user experiments and for commercial users, e.g. Intelsat, as well.

In the future, international service will continue to grow rapidly (at approx. 20% per year), and many new domestic systems will come into existence. New system topologies such as computer networking, broadcast and data collection, will be introduced, and new services such as video teleconferencing and electronic mail will become a part of satellite communications.

### OPTICAL FIBRE COMMUNICATION SYSTEMS

The pace of optical fibre communication system development and application has been rapid particularly in view of the radically different nature of this technology; from the first theoretical prediction of practicability in 1966, to the glimmer of the possible feasibility of the technology in 1970 to system experiments in 1976, and to practical economic system developments in 1980. Thus it is seen that in a short span of two decades only, a versatile, economic and very wideband communication medium is now available to the telecommunication planners and designers. It is predicted that at the turn of the century, the Satellite systems for fixed services will be replaced by guidedwave systems, specially fibre optics. Satellite, then, will be mainly used for mobile and deep space communications only.

In 1960's, the digital pair cable and analog coaxial systems were developed for inter-exchange trunks and in 1970's, large-capacity digital coaxial systems were developed. Large-capacity optical fibre systems will be used in the 80's and henceforth, as the main body of intra and intercity trunking. From the view point of voice transmission cost, digital coaxial systems were more expensive than analog systems in early 70's, but because of the remarkable advance in new digital devices, digital transmission systems using optical fibre technology will become less expensive than analog systems. The overall cost of the fibre optic systems will be one order less by 90's, as is shown in Table 1. From the loss/km point of view, recent reports indicate successful fabrication of 100 km single-mode fibre, whose losses are as low as 0.2 dB/km at 1.55  $\mu\text{m}$ . The present developments in fibre technology indicate a loss of 0.3 to 1 dB/km for the wavelength range of 1 to 1.8  $\mu\text{m}$ . However, the possible wavelengths presently used or available in the near future are 0.85, 1.3 and 1.55  $\mu\text{m}$ , this limitation being mainly due to the non-availability of laser diodes operating with other wavelengths. An estimate of the transmission bit rate and repeater spacing for long-haul circuits strongly depends upon the fibre type (step-index multimode and single-mode) and the wavelength (0.85, 1.3 and 1.55  $\mu\text{m}$ ). For 100-400 Mb/s, a single-mode fibre, with longer

TABLE 1: Trend of transmission cost reduction in cables

Year	Type of cable	Bit rates	Repeater Spacing	Relative Transmission cost
1960-70	Pair cable (digital)	64 Kb/s	1→2km	70→20
	Pair cable (analog)	-	1→2km	15→5
1970-80	Coaxial cable (digital)	274 Mb/s	1→2km	20→5
1980-90	Fibre cable (digital)	100-400 Mb/s	10→30km	10→5
1990-2000	Fibre cable (digital)	1000 Mb/s	50→100km	5→1

wavelengths (1.3  $\mu\text{m}$  presently and 1.55  $\mu\text{m}$  in future) gives a repeater spacing of 20-30 km. For long-haul systems, regenerative repeaters, using a laser diode and photodetector, are being built in hybrid IC forms and in future, will become more integrated in a few IC chips.

All major telephone laboratories, e.g., Bell Labs, GTE-Lenkurt in USA, Bell Northern in Canada, Nippon in Japan and European telephone administration labs, are working on single-mode long-wavelength fibre optic systems. However, at present the working systems are operating at 44.7 and 91 Mb/s using mostly first generation 0.8-0.85  $\mu\text{m}$  components. The Bell System is committed to a policy of converting all trunk lines and local loops into fibre optics, whenever this is economical. Bell Canada has already installed 3600 km of fibre cables (44000 km of fibres) for the Canadian telephone network. They have also the largest fibre-optic system, where a broad-band network links exchanges, which are from 100 to 200 km apart and require 3200 km of 12-fibre cable. It is expected that within five years, large-capacity optical fibre systems will be put into wide commercial use. In Japan a field trial of the long-haul system has been in progress. The system parameters are: Bit rate 400 Mb/s, Repeater spacing  $\approx$  20 km, total length = 2500 km, single-mode fibre cable having 0.7 dB/km loss, wavelength 1.3  $\mu\text{m}$  and overall error rate  $<10^{-8}$  for 2500 km.

Both in USA and Japan, development efforts are going on for a multifibre cable for undersea telephone transmission that will increase the repeater spacing to 35 km (from the present 9.4 km for coaxial cables) and have two-way voice channel capacity of 36000 (from the current 4200 channels in coaxial systems). Trans-Atlantic service is expected to start in 1988 with transmission of streams at 274 Mb/s on a single-mode cable operating at 1.3  $\mu\text{m}$ . The cable will be 6500 km long and reach ocean depths of 6.5 km. Nippon T&T in Japan is developing a

fibre optic system that is to be operational in 1985. This will transmit 5000 to 18000 voice channels at 400 Mb/s, using 1.3  $\mu\text{m}$  laser sources and receivers with repeater spacing of 25 km. With the development of 1.6  $\mu\text{m}$  system, the repeater spacing may be 100 km or more.

Although optical fibre technology has already proven its versatility as the next generation communication system, we may expect further improvement and drastic changes in the forthcoming era. Possible-realizable developments are: WDM (wavelength division multiplexing), bilateral transmission in a fibre, integration of repeater electronics, high speed repeater technology, optical IC's, optical amplification, coherent carrier transmission and fibre-optic transducers. Various WDM techniques are being investigated to transmit video, voice and data over fibre optic telephone systems for the home. A particular implementation of WDM is the subscriber loop trial (at a cost of \$ 6.3 million) now installed and operating in the rural town of Elie in Canada, where some customers (150 homes and businesses) receive their video, data and telephone services from an 0.83  $\mu\text{m}$  laser and transmit telephone, data and video switch control information upstream using an LED at 0.92  $\mu\text{m}$ . These two sources transmit bi-directionally on the same fibre, using WDM coupler. The researchers see a growing demand of WDM techniques in both local loop and trunk systems. The repeaters for fibre optic systems may use WDM techniques, where ten optical channels may be allocated in bilateral directions, similar to the technique used in guided-millimetre wave systems. It is believed that optical IC's will play an important role for the WDM technique and more than 50,000 telephone calls or 160 digitized colour TV channels could be handled by a single fibre. Use of the coherent detection of an optical carrier will increase the repeater spacing further, say to more than 100 km, and numerous cost and reliability savings will be obtained, specially for trans-oceanic transmission systems.

### Communication in 2000 AD

Looking into the future of telecommunication, it is perfectly evident that communication is getting more and more integrated with computers and data networks. Eventually in near future, we shall have a fairly integrated general purpose computer-communication (CDC) network, leading to the integrated service digital network (ISDN) as designated by CCITT. The factors which will contribute to the success of this Digital Revolution are (Refer Fig. 2):

- (a) Development of Digital IC's through LSI, VLSI and VVLSI (Computer on a chip).
- (b) Progress of the computer system architecture through multipurpose, centralised processing and distributed processing techniques, leading to horizontal integration of smaller computers and ultimate systematization of computers.

- (c) Development of switching techniques through space-division (SD) and time-division (TD) ESS incorporating distributed processing of calls and signals and a common switching network for both low-bit and high bit rate informations.
- (d) Diversification of communication services through Digital radio, TDMA-satellites and Digital fibre-optic media.
- (e) Diversification of communication services through Facsimile, Videotex, CATV, Electronic mail and Teleconferencing, leading to automated offices and wired homes.

Koji Kobayashi, Chairman of NEC, Japan has predicted that [11] due to the rapid-development of business communications and home electronics, the future C & C offices will be paper-less, but at the same time, will ensure accurate decision-making through the efficient use of the office equipment. The home-office, the reception room, the decision room and the Executive's office all will be interconnected through video terminals and data networks and customers and executives will mostly discuss matters through computer terminals.

He is of the view that: 'The spread of communication in this way is most significant in contributing to the enhancement of mutual understanding among people and will contribute to world peace..... However, C & C, systematic merging of computers and communications, is a key to responding to these requirement of future communications..... I wish to call your attention to the fact that communication systems may have a positive impact on the energy-saving problems and that every nation needs to work on communications development with the recognition that such development will save energy.'

However, to meet the challenge of the smooth change over to the new social order, resulting from the widespread ISDN and the acceptance of the Information age obligations, Dr Mayo has listed the following requirement [1]:

- (a) Better and 'friendly' interfaces between the electronic computer systems and the people that use them. Computers should not be viewed as dehumanizing.
- (b) Better understating of distributed computer and software systems. Better and cheaper software development techniques and automation of software maintenance.
- (c) Better display device 'friendlier' software, better human engineering and large data bases.
- (d) Low cost voice recognition and voice synthesis systems, more efficient signal coding, especially for world's analog signals.

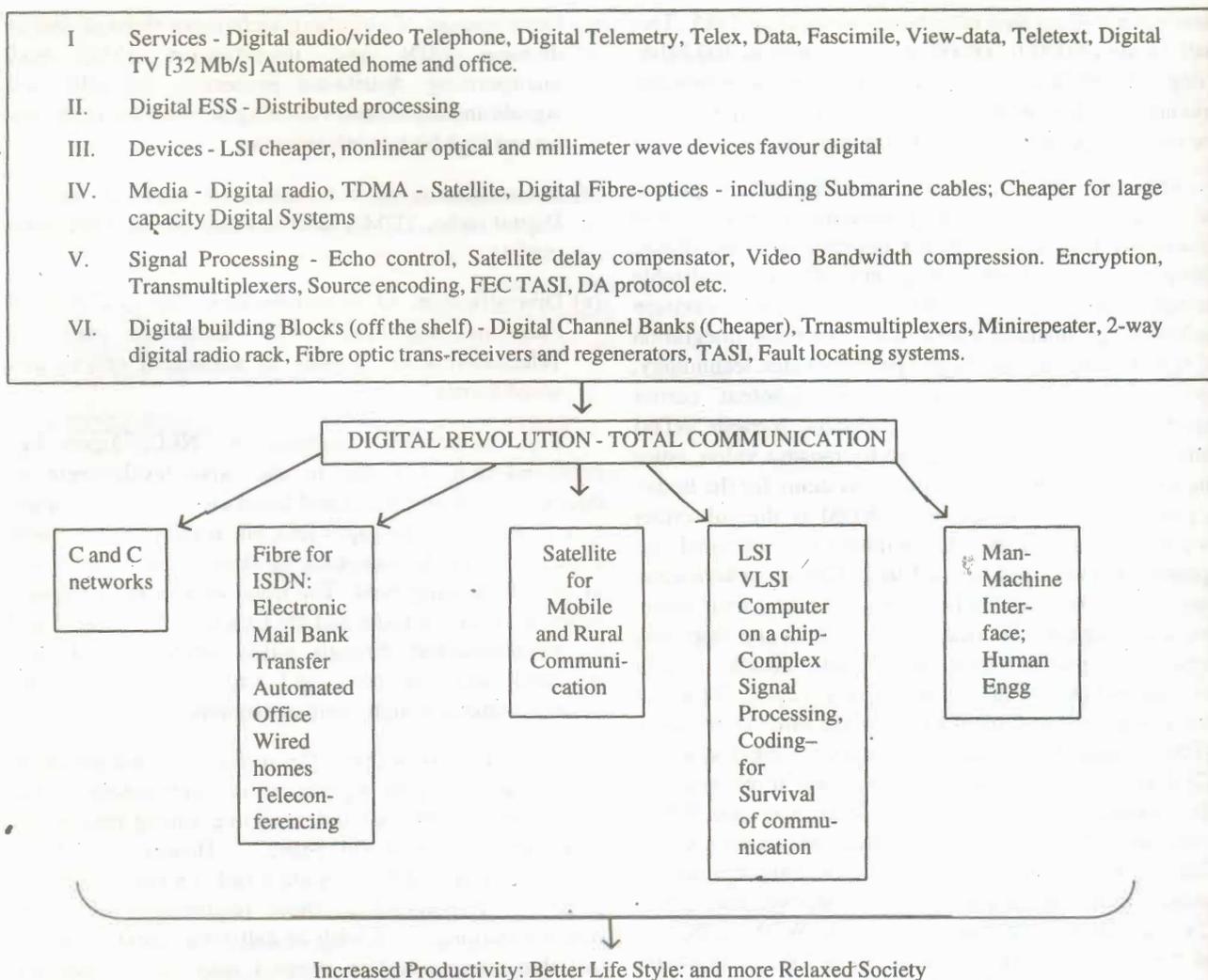


Fig 2 Digital revolution; input-output.

- (e) Significant enhancements in sensor and actuator systems for remote control.
- (f) Best way of interconnecting the numerous intelligent machines in homes and offices.
- (g) End-to-end switched 'digital connectivity'.
- (h) Simultaneous advancement of technology across a wide range of industries.

As a consequence of the above wide ranging developments in C & C networking, the academicians will have to develop a new unified theory for end-to-end Information systems involving Shannon's theory, theory of computational complexity and the theory of multi-user communication networks, including link reliability and cryptographic protection. Since man-machine interfaces will be an important element of future networks, it will be necessary to study model of humans as information processors. In the opinion of Prof E C Posner of J P L Caltech [12], 'the upshot of all this leads to the conclusion

that: we will need more information and communication theorists in 2000 AD than we need now. Not only that, but these theorists will be more broadly educated and trained in an even wider variety of disciplines and technologies than we are trained in now'.

In the ultimate analysis, 'the trends of developments in communication systems directly concern a nation's present situation and future vision, and its services and impacts should be perceived as a major national issue. It is, therefore, necessary for each nation to make the most suitable choice of communication systems based on its specific environment and objectives. 'Let us hope that, in the national scene our politicians, administrations, scientists and engineers will work together to bring in the desired social and economic revolution through the use of most challenging communication technologies and fulfill the wish of the great visionary Vikram Sarabhai, who in a similar context said: We do not have the fantasy of competing with economically advanced nations in the

exploration of the moon, the planets or manned space flight. To us, there is no ambiguity of purpose. We are convinced that if we are to play a meaningful role nationally and in the comity of nations, we must be second to none in the application of advanced technologies to the real problems of man and society.

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Faint, illegible text, possibly bleed-through from the reverse side of the page. The text is arranged in several lines and appears to be a list or a set of instructions, but the characters are too light and blurry to transcribe accurately.

# Materials and Components Technology

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**Materials and Components constitute the foundation of electronics and photonics which now need an integrated approach. The paper gives a critical review of its growth and development with all their possible future developments. The objective is to build a composite picture of the requirements of technology. The term, 'component', includes both the active and passive types. Materials are required with the highest levels of purity which could be a part in a million million and in some cases, in the form of 'artificially' structured films. It is now necessary to consider both electrical and optical properties and their variation with temperature etc. Miniaturisation is moving towards 'atomic dimensions' and the technology of micro-fabrication is fast becoming very important. The description gets restricted to a reference where detailed reviews are available.**

**Current Indian situation is indicated in general terms and its possible accelerated growth by all round systematic throwing up of opportunities for talent to display creativity and novelty is highlighted. Meticulous planning resorting to a description of all details by a few individuals and compelling investigators to mechanical action of a set and, perhaps, obsolete type, is most frustrating. It is not investment that matters but the display of 'vision' to give opportunities for known and unknown talent.**

I knew Vikram since 1935. We met frequently during 1942-45 when we were both working but on different aspects of cosmic rays at the Indian Institute of Science, and, during 1956-58 when I was Principal, LD College of Engineering, Ahmedabad. Vikram always thought of plans and projects in a big way. He could think quickly and take quick decisions. He placed the Country above himself. He could get the best out of men in the shortest possible time. He believed in excellence and NOT mediocrity in his search for man power. He took bold, calculated and reasonable risks in his execution of plans and projects. I think that this strange combination of qualities in one man was due to his parentage, his Cambridge training and, last but not the least, the influence of CV Raman in Bangalore. His building up the Department of Space so quickly showed how he could pick up the right men, nurse them and get the best out of them. His building the Arvi Earth Station showed how he could spot indigenous talent and sources from all over India and harness them in a cohesive way to reduce imports to the minimum. His use of satellite television for educating the masses showed his ability to harness an available resource for a very useful application. He got this project evaluated by NCERT which had the facilities and, since I was the Director of NCERT, I know how he cashed on all we had! His optimisation of the resources impressed me as having the precision of a computer!

Memories of such a Vikram Sarabhai compelled me to think before I made up my mind on the subject of today's talk. Normally, I should have lectured on 'Tropical

Lightning and Radio Noise', the subject of my life's research, a topic for which I am known the world over and one on which I had lectured the world over. But, I preferred another one, viz., 'Materials and Components Technology' because of its far reaching consequence to electronics and its growth in India in the years to come. It is a composite discipline sprouting out of 'Molecular Science and Molecular Engineering'. I said in 1960,

'While the engineer of the past proceeded to design on the basis of available materials and their macroscopic properties as revealed by experience, the engineer of the future will, in many cases, first design and then specify the building of the required material to order' [1].

Examining the problem on a world basis, that FUTURE has already arrived and will be now a part of 'Materials and Components Technology' as will be seen later. With a harmonious blending of science, technology and thumb rules deduced out of well planned trial and error experiments, we have already grown an intricate fabrication technology as Mead [2] rightly puts it,

'We are not limited by the constraints inherent in our fabrication technology; we are limited by the paucity of our understanding.'

This intricate fabrication technology is but a partial manifestation of 'Materials and Components Technology'.

In 1973, I said,

'The current challenge of science is the simulation of

the human nervous system through instrumentation. Electronics has already in its store the basic needs. Who will succeed first is the basic question' [3].

The race appears to be already on [2,4]. The only answer to a picosecond computer free from all-electromagnetic interference is the optical computer [5]. A proper memory for such a computer can only be realised through holography [4,6-8]. All these and many more exciting developments converge to the real composite discipline, Materials and Components Technology'.

After indicating the coverage of 'Materials and Components Technology', the historical approach will be adopted to formulate all that gets included in it as this is the only way to clinch issues. No attempt will be made to go into details but they are adequately described in the references cited in this paper and in the references of these papers. A point that has to be stressed is that the subtleties of this exciting subject cannot be packed up by visits to some laboratories or working there or by setting up plants through collaboration i.e., by purchasing the know-how. Only competent persons drawn from diverse disciplines working the hard way with a sense of commitment can hope to get at the right answers.

Materials get classified by their states into solids, liquids, gases and plasma. Solids particularly get further classified as crystalline structure commonly described as single crystals, a so called 'amorphous solid' but having randomly distributed crystalline lumps which is now becoming another state, glassy solids with no sharp melting points and liquid crystals which are all equally important. Bulk solids are distinguished by having distinct elastic constants (Young's modulus and Co-efficient of rigidity). Foils of metal can, at best, have Young's modulus but rigidly coefficient can never be furnished in repeatable values. Then there is the 'film'. This has no independent existence of its own and has always to be deposited on a substrate which has 'acceptable' electrical, thermal and elastic properties. What conforms to 'acceptable' is deduced by trial and error experiments. The most recent success in this area depositing GaAs films on silicon substrates. A film thickness can vary from a few hundred atoms to a few thousand atoms. The technology is rapidly moving to limit the thickness of films to less than five hundred atoms and there is optimism that films of about two hundred atoms thick could be the order of the day by 2000 AD. Even the cleanest surface of a solid, a foil or a film is uneven on the atomic scale. It is believed that the surface unevenness could be of the order of at least  $\pm 10$  atoms. The overall unevenness of the surface is important for doping the surface and this is the technique utilised for changing the recombination time of 'electrons and holes' or recovery time for refractive index of optical materials which are changed by changing the intensity of impinging radiation. Incidentally, this surface unevenness is important in the thinking of surface melting [9].

The term component is used here in the most modern sense which is expected to become standard within a decade. It includes both active and passive components. Thus, tubes, transistors, masers, laser, microstrips, resistors, capacitors, etc, are basically, components. Except in the area of power electronics including high power transmitters, the discrete components have been and will be rapidly phased out. However, the real needs of electronics instrumentation, particularly in probing natural pheno-mena, have been appreciated. To meet such research needs, it has been accepted in many countries of the world that some typical discretely should be manufactured and made available. The current approach is to get the data about a specific requirement, design an LSI and VLSI and get it on just one chip. Materials are being developed to meet the challenge of getting lasers operating on any specific frequency. Thereafter, laser fittings may get standardized and laser replacements may become similar to that of our ordinary fluorescent tubes of household use! These facts highlight the need for having ready the facilities needed for materials development and testing and for making the chips needed.

At this stage of discussion, it is appropriate to dwell on the reasons for talking about miniaturisation, micro-electronics, materials and components technology to meet such needs etc. Actual cost varies approximately as the square of the size. Performance varies approximately with size. Put in other words, reduction of size reduces cost and improves performance. Power needs get considerably reduced as the size is reduced. Miniaturisation is thus first class engineering conforming to its basic philosophy [10]: Micro-electronics will result from computer aided design, manufacture and testing (CADMAT) employing materials and components technology.

Engineering materials were thought of the conventional way even in the beginning of the present century. In 1908, Lee de Forrest successfully patented the 'audion', the three electrode vacuum tube and there followed rapid developments in tube technology. But, these developments were confined to tube manufacturers and their suppliers. The desire to eliminate occluded gases in tubes for extending their life and to get high efficiency cathodes/filaments forced the tube industry to look for better materials. After about 1930, researchers in the physics of the solid state, the successful growing of single crystals, metallurgical developments etc threw up the possibilities of utilising high purity materials, not necessarily metals. About 1940, radar development work at MIT, USA, pointed to the need of high conductivity oxygen free copper. The University of Purdue looked at the entire problem in a much wider perspective. This was also followed up by the MIT where the problem in the broadcast perspective got going under Von Hippel [11]. In 1945, Mott [12], in his Kelvin lecture, highlighted the characteristics of perfect crystals free from impurities.

About the same time, H Fletcher, J Fisk and M Kelly at the Bell Telephone Laboratories made a critical study of the available information on the solid state and concluded on the distinct possibilities of meaningful results to follow a critical study of the solid state [13]. Subsequent work of Shockley *et al* leading to the invention of the transistor in 1948 is well known. This marked the beginning for the systematic formulation of materials science as a discipline. Attempts to get materials with an impurity content of one part in a million with aims to get to impurities less than one part in a million million and so on became common. Subsequent development leading to a wide variety of transistors culminating in the successful production of digital IC's is well known. Simultaneously, the developments made Japan enter the picture with a missionary spirit committed to give Japan the leadership in the field [14]. Scientists chosen worked without expectation of individual rewards and succeeded. By 1956, Japan could make better transistors and IC's than the USA and sell them cheaper. The same period, 1948-56, saw spectacular developments in ferrites, dielectrics etc, also but that is being dropped for discussion here. By 1971, integrated circuits, particularly VLSI, became the aim and fabrication technology took a new turn with concentration of effort in standardise and explore all the needs of technology taking an integrated view of both materials and components. A variety of new techniques were developed for deposition etc. In 1976, optical bistability [15] was discovered leading to developments which led to a laboratory model of the optical computer in 1985 [5]. Optical properties of materials became important. In 1989, the composite picture of the needs and the available theoretical knowledge were utilized to think in general terms of the possible future expectations. These are described in what follows and the formulation of technological needs thereafter [16-18].

The conventional transistors had dimensions of the order of 1mm. But, even the present silicon devices are of the order of 100  $\mu\text{m}$ . The devices in integrated circuits of the sixties and early seventies were of the order of 10  $\mu\text{m}$ . The size of an atom is of the order of 0.1nm and we are now moving to these orders of magnitude (0.1 nm is  $1^{\circ}\text{A}$ ). Incidentally, the resolution of the eye is about 100  $\mu\text{m}$  and of the optical microscope about 0.2 or 0.3  $\mu\text{m}$ . We now have electron microscopes with a resolution of about 0.1 nm. Depth resolution of a currently available scanning tunneling microscope is about 0.06 or 0.07 nm. These rough orders of magnitude of resolution of available instruments are being stated to stress that we do have instruments to check the orders of magnitude we are concerned with in our present and future fabrication.

We are interested in (a) the electrical properties of materials and their variation with temperature with a significant attention to these properties at room temperature viz, mobilities of electrons and holes,

recombination time and their control artificially, effect of the substrates on the stability (mechanical) and the electrical characteristics of the film etc, (b) the optical properties of the materials, viz, refractive index and absorption coefficient, their variation with light intensity at different temperatures, the combination coefficient of electrons and holes at different temperatures etc, and (c) whether the inter-atomic distance in crystals can be changed leading to change of optical/electrical properties, artificial creation of quantum wells etc, by resorting to crystallisation under high pressures. Most generally speaking, we have to attempt well calculated 'guesses' or 'speculations' on properties to expected on the basis of available theories although none of them is far from perfect. We have to keep in mind that, ultimately, we may use the materials in the 'crystalline' state of solids, 'randomly distributed crystalline state' in solids, liquids or gases, and 'glassy solid', but 'plasma' may not enter the picture in the immediate future. It must be mentioned that the material may be used for VLSI's, discrete transistors, transphasers, magnetic recording heads, opto-electronic components, surface wave devices, lasers, etc.

VLSI's are basically semiconductor integrated circuits. We are now moving to have just on one chip hundreds of thousands gates. Ordinarily, we compute statistically what is the optimum number of such gates we must have to meet the widest practicable variety of applications and then fabricate that the resorting in mass production. Ordinarily, the design is through CAD and manufacture employs CAM. In such cases, testing has often to be resorted to in the very process of manufacture, CAT. Hence, VLSI's are best made by CADMAT. At present, the sizes are large and the current tendency is to move towards the theoretical limit in practice. Currently, VLSI's are fabricated with a line width of about 1.2  $\mu\text{m}$  and the thickness of the deposit could be large. Present developments are to move towards 0.5  $\mu\text{m}$  technology by 2000 AD. In thin film technology, it is useful to attempt a rough estimate of the limit we should be able to move towards on the basis of theoretical knowledge. In thin film technology, we should be able to move from about 2000 atoms thickness towards about 200 atoms thickness. Expectation for line widths cannot be smaller. These appear to the author to be the limits realisable through ultra-violet light, X-rays, electron and ion lithographies [10]. Going beyond is not practicable as it can create problems arising out of surface unevenness and inaccuracies in statistical deductions.

The discussion so far has clearly indicated that just producing or getting the material is not enough. It has to be obtained in a certain form viz, single crystals, single crystals grown under pressure, etc, and in a specified state of purity, or in a certain state like vapour etc, having regard to the need for a specific component. Often, it is not a single discrete component but one in many. Further, the production is not a single component but often a VLSI or

similar circuit mass produced under CADMAT. So, it is the unified need in terms of materials and components technology that has to be thought of and provided for. For proper, accelerated and orderly development, it is necessary to have the minimum basic needs under one roof. Those who have to acquire skills and grow it must have a composite knowledge of the characteristics, operation, maintenance and repair of all the equipment and the science of materials and statistics. Any industry looking ahead has to grow the personnel and plan to retain them to work with zest and, definitely without allowing frustration to set in. The previous discussion has made clear the type of technology needed and this is summarised in what follows

It appears that the overall base most useful is as follows:

- (a) a sound knowledge of electronics and photonics engineering and materials and materials sciences
- (b) production and measurement including maintenance of low pressure equipment
- (c) production, measurement and maintenance of low temperatures
- (d) production and measurement of high pressures
- (e) methods of growing crystals including that at high pressure [17]
- (f) obtaining pure material at the level of purity desired for an operation and getting it to a desired form or state
- (g) thin film fabrication processes including ultra-violet light, X-ray, electron and ion lithographics [10]
- (h) problems of surface treatment [9]
- (i) evolving procedures for CADMAT.

Laboratories are preferably best set up with basic equipment only. No attempt should be made to completely plan everything. Competent persons recruited should be given a free hand to add to equipment etc, and they should suggest planning special instruction etc, and fuse and build a team. Such a team, however competent, cannot avoid some wastage due to errors but this should be ignored. Everything possible should be done to retain the team.

Lastly, it becomes necessary to indicate the Indian scene. Since 1972, the importance of materials and components technology has been partially realized. A semiconductor complex was set up. Several committees have reported. A monumental effort to get towards silicon at the desired level of purity for further processing has been made [19]. A strong case has been made for hybrid IC's [20]. 'The growth of electronics and micro-electronics in India is limited by the inavailability of starting materials' [21]. Our Science Advisory Committee to the Prime Minister has produced a most valuable document on Advanced Materials-National priorities, where the needs for the subject discussed is indirectly

highlighted as one of our priorities [22]. Our public sector and private industries make equipment using IC's LSI and VLSI. In some cases, they are producing IC's starting with materials processed to a certain stage. Our production is rising significantly every year. We have also excelled in computer software where exports figure prominently. But, we have ignored the starting point, the basic materials and technology and we cannot predict moving to 'atomic dimensions'. Research and development is a must. Scientific approach to engineering research has already been elaborated [23]. But, in an extremely costly area like 'materials and components technology', it would be prudent to set up a facility for a consortium of industries producing different end products and the government must extend maximum support. The consortium must provide maximum opportunities for intellectual and technical growth of its personnel and prevent frustration setting in.

In education and training, a plan has already been furnished for incorporating 'materials and components technology' in regular curricula including specialisation and research [24]. What is stressed is the need to create a 'national awareness' of the technology. A great weakness of the country is a quick and authentic review of any recent development likely to take shape for production within about a decade and a typical paper has been made available [5].

Governments of all countries support heavily research and development in such areas as Materials and Components Technology. Concentrating all effort in one completely government controlled set up on the plea of limited funds is not the right policy. Government must provide the funds to a small body of scientists and leave it to them to make funds available to approved schemes, the schemes to be prepared independently by the institution/industry concerned.

A typical example of complacency leading to drift has already been described [25] and such a trend must be avoided.

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# Road Map of Evolution of NICNET towards Globalisation of Computer-Communication

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A view is advocated here that the application of computers and communication as an integrated technology, has more impact on social and economic development than computer technology alone or communication technology alone. As social and economic interaction cannot be localised artificially in a world moving towards a 'global village', globalisation of computer-communication networks will become the major enabling instrument for this evolution.

The evolution of NICNET, the computer communication network of the National Informatics Center, is so oriented that such an integration and globalisation is progressively implemented utilising the latest low cost technologies available in the international market. Tracing the evolution of NICNET from its genesis in 1985, the choice of the various technologies to date, and, the road map for NICNET till 2000 AD is projected in step with the forecasting of technological evolution towards integration and globalisation of computer and communication resources.

The choice of SSMA/CDMA based Very Small Aperture Terminal (VSAT) satellite earth station technology is discussed to support the contention that VSAT Technology enabled the first level of integration and globalisation between 1985 and 1992.

Discussing the inevitability of the Ku/Ka band choice for the next level of integration and globalisation, the potential of SCPC based 'hubless' VSATS with two-way as well as data broadcast capabilities and dedicated high speed external gateways is outlined as the second essential step in the integration and globalisation while at the same time, realising a NICNET Info-Highway during the period 1993 to 1997. On the ground segment, special technologies for effectively linking widely separated local area networks, network FAX and image server and multimedia communication services are proposed. Special features for accommodating a large number of close user groups and offering virtual private networks can increase the propensity for the spread of the IT culture as well as prod the growth of demand.

During the period from 1986 to 2001, certain concepts of future space data networks are forecast which can propel NICNET to the third level of integration and globalisation. Based on the concept of NICSAT earlier conceptualised, a series of very low cost microsats will be launched for an internally operable dedicated space data network with user end to end communication capability, built in features for promoting specialised value added services, built in access security and expert system based network management. Low cost on-board features, a versatile space link scenario and a low cost ground infrastructure scenario are suggested. The possibility of introducing BISDN via such a satellite cluster are examined.

Towards the end of the decade, NICNET will be incrementally converted for providing global intelligent network services over a strong skeleton of data super highway utilising the concept of application gateway in a global intelligent network, the inter-operability of the service management systems, service creation environment and operation systems as well as support the interaction of the intelligent network components for intra-network and inter-network cases. The intelligent network architecture proposed is explicitly designed to support personal communication services on a global basis.

SINCE 1985, a major transition in the world economy is taking place with the globalisation of an increasing set of products, capital markets and service markets. Competition, intra-national and international is becoming fiercer. The transition of the economy from the traditional distribution of labour force in agriculture, industry and services in the ratio of 60:25:15 is getting reversed into

15:25:60 on an average. The evolution of the industrial economies into information based economies, is bringing about an increasing dependence on the transfer, management and use of information, increasingly, in the electronic form. The demand for computer communication network based services is becoming critical to corporations and even national survival. To get a competitive edge in

the dominant globalised market, corporations and countries must adopt globalisation strategies-worldwide distribution of standardized products, world-wide access and delivery to services and consequently, world-wide network based delivery and access of information. Inter-country competition is forcing customs and tax policies, money market, industrial and trade policies to morphose in the direction of giving a competitive edge and hence introducing an element of globalisation even of national policies. It is for this reason that the information technology sector including telecommunications has attracted an unprecedented investment globally estimated at one trillion US dollars so far, including telecommunications carrier construction expenditure of US \$ 140 billion in 1991. Global spending on telecommunications products and services is estimated at US \$ 750 billion in 1993 and will exceed US \$ 1.5 trillion by 2000 AD. By this time, information technology will become the largest single sector of the global economy.

Cost effective and reliable networks giving value added services are increasingly in demand. In spite of diversity of business, commonality of technology and services are emerging through such frame-works like FDDI, ISDN, intelligent network management and global private virtual networking, SONET and SDH, among others in a global broad-band network infrastructure (Fig1). The international services gateway provide broad-band services including ATM, SONET and SDH between countries and between continents. These switches also support several advanced access services, in the evolution

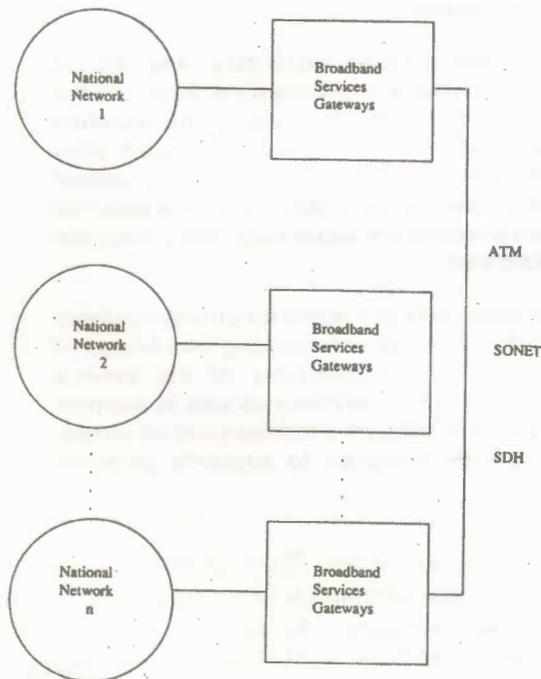


Fig 1 Global broadband network infrastructure

of global networking, an important enabling technology is 'international band-width on demand', followed by video on demand, multimedia workstations and high capacity high quality imaging systems. These will be supplemented by increasing memory and processing capabilities of computer platforms and higher band-width of communication platforms. Such capabilities are drawing up new application possibilities like cooperative CAD/CAM/CIM, storage and retrieval of multimedia objects including drawings, X-rays and photographs.

In India, there are a number of computer-communication projects which are evolving towards globalised systems. One of the extensive nation-wide networks, which is mainly dependent upon space communication, is NICNET, the computer-communication network of the National Informatics Centers (NIC). The evolution of NICNET is so oriented that the integration of computer and communication as well as globalisation of the network is progressively implemented utilising the low cost technologies available in the international market. As a case study of planning for globalisation, the road map of evolution of NICNET from its genesis in 1985 upto 2001 AD is projected in step with the forecasting of technological evolution towards integration and globalisation of computer and communication resources.

#### THE INITIAL DEMAND PUSH BEHIND NICNET

The Government administration in India has undergone successive administrative reforms to fulfill the needs of the public in the past for decades. Decision making on development activities of the nation call for efficient discharge of functions at all levels of the government administration - ministries in the central government, the secretariats of 32 state government / union territories and more than 500 district administrations.

With the implementation of NICNET, the National Informatics Center has become a bridge between the state government and the central government on the one hand and the state governments and their district administration on the other.

The need for reliable and timely information for decision making requires no emphasis. Already there exist information sources in sectors like agriculture, power, health, family welfare, industries, education, employment, labour, transport, communication, forest, roads, etc, at the district level. Information gets manually validated and consolidated progressively at the districts, state and the center. This manual process has inherent delays, apart from lack of completeness and accuracy of data. This problem can be overcome by capturing data at the source by establishing District Informatics Centers. Keeping this in view, NIC has launched its District Information System Programme (DISNIC). With the active cooperation of the

state governments, through their support to numerous pilot projects, NIC has developed DISNIC database templates for the following 26 sectors.

- |                          |                        |
|--------------------------|------------------------|
| 1. Agriculture           | 14. Rural Development  |
| 2. Animal Husbandry      | 15. SC/ST Development  |
| 3. Building and Works    | 16. Social Forestry    |
| 4. Civil Supplies        | 17. Labour             |
| 5. District collectorate | 18. Panchayat          |
| 6. Collegiate Education  | 19. Power              |
| 7. District Planning     | 20. Public Instruction |
| 8. Employment            | 21. Roads and Bridges  |
| 9. Fisheries             | 22. Social Welfare     |
| 10. Ground Water         | 23. Town Planning      |
| 11. Industry             | 24. Transport          |
| 12. Irrigation           | 25. Water Authority    |
| 13. Health               | 26. District Treasury  |

With setting up of NICNET, a stage has been set for developing a distributed Geographic Information System (GIS) on the network. The Distributed Database Management System (DDBMS) concept has been extended to GIS software package. This is paving the way for the setting up of GISNIC, a nation-wide GIS on NICNET accessible through a query system.

To equip the district level administration with a computer assisted cartographic tool, DISNIC has embarked on an ambitious project which aims to amalgamate spatial and non-spatial data with the help of the computer system installed at the district headquarters. The present effort is an experimental step in this direction. This minimal system is undergoing field trials in a number of districts. The following modules are being implemented progressively.

1. Interactive, feature based map editor
2. Choropleth mapping software
3. User defined symbols library
4. Programmable interface for thematic mapping
5. Merging adjacent map sheets (under NIC-UDMS)
6. Network based distributed operations
7. Distributed GIS query system on NICNET
8. Link Software between pre-GIS and structured GIS
9. Link software between space image formats and GIS
10. Link software between GIS and distributed DBMS

Beside development of a number of integrated on-line data bases and related applications, various planning models are being developed on NICNET. NICNET is fully equipped to cater to the needs of various planning agencies in the Government for building simple to complex

planning models as an aid to decision process. One of the important areas is the on-line progress monitoring of various central sector projects and schemes. NIC is providing turn-key service to the ministry of Programme Implementation for the monitoring of all central sector projects each costing more than Rs 100 crores. The computer based system is operational in the office of the ministry of Programme Implementation on the NEC system for generating various reports for indepth monitoring and control through the concerned administrative ministry in each sector.

However, it is now proposed to cover all the central sector projects costing even less than Rs 20 crores with respect to time and cost monitoring.

The success of any organisation, in particular of large corporations, depends mainly on how powerful is the system for project planning, monitoring and control. The project planning approach developed by NIC anticipates the various sequential steps needed to complete a project. At the micro-level this includes identification of tasks and their sequence, establishing a project schedule that includes mile-stones and deadlines as well as estimating the resources and raw materials that will be needed, when they will be needed, and at what cost. A project plan is prepared as a complete model that reflects project components and their logical and structural relationships.

Time and cost over-run status of various central sector projects costing over Rs 100 crores falling under 14 different economic sectors are being monitored by the Government on quarterly basis followed by detailed analysis of various projects. At present, time and cost over-runs account for an overall increase of 48.4% over the original project cost. NIC is developing a number of project monitoring (PM) software systems for various government departments and public sector undertakings. It has the following broad features.

- It can build and refine a project on the screen as a network (called a Roadmap) along with the critical path.
- It can translate time and cost of tasks into schedule bar charts and cost graphs respectively.
- By inputting resources, PM draws upon allocations and loading graphs to show how each resource is allocated and how much each resource is in use.
- It is thus, easier to minimise time and cost, and use resource efficiently.
- For large and complex projects, one can break it down into a number of sub-projects, and combine them into one sub-project. PM handles all the computations and automatically carries information from sub-projects to the next higher project level.
- It can print a variety of reports on projects and one can

transfer PM data to make databases and later on use it for preparing spreadsheet.

One hundred nodes on NICNET is planned for the infrastructure for such online project monitoring of as many projects representing a total plan investment of Rs 90,000 crores with the following approximate sectorial break-up.

Power sector	Rs. 30,000 crores
Fertilizer sector	Rs. 10,000 crores
Irrigation sector	Rs. 12,000 crores
Steel sector	Rs. 10,000 crores
Cement sector	Rs. 6,000 crores
Coal sector	Rs. 12,000 crores
Oil sector	Rs. 10,000 crores

Utilising NICNET, it is expected that such online project monitoring would reduce time over-runs and cost over-runs atleast by 10 per cent through timely identification of bottle-necks and getting them rectified. Monetarily, this would amount to a contribution of Rs 9000 crores upto the end of 8th Five Year Plan 1990-95 with a cumulative investment by NIC of Rs. 500 crores upto 1995.

### **STAGE I: INTEGRATION OF COMPUTER AND COMMUNICATION IN NICNET**

As the demand for customer services cannot be assessed accurately at this point in time, network cannot be planned merely on the basis of presently projected user services requirements. The long term approach is to design the network as a whole anticipating the user requirements for the next several years. The example of the design of NICNET will illustrate this point. NICNET has a computer and a satellite earth station in each of the 500 District headquarters, the 32 State/UT capitals and the national capital. Through this, a decision support information system for the Indian government is being evolved based on the design of a predominantly query based computer network with hierarchic distributed databases and random access communication. The district level NICNET was completed by 1991.

#### **The Basic Decision**

With interference to tolerance and random access as two guiding principles behind the choice, spread spectrum transmission and Code Division Multiple Access system of satellite communication was adopted. Each node of the network is a 32-bit computer which is capable of local bulk storage of upto three units of 300 megabytes each for purposes of query-accessible distributed databases. The design and implementation of such a distributed database has endowed the network with the capability to distribute the data related to such database over various nodes in the

network so as to be able to accept a query from any of the nodes. Each of the technology features of this network is mentioned below to show how technology forecasts and appropriate technology choice have been made so that the network will remain contemporary technologically for a decade.

#### **Features of the Network**

To achieve the data network, a number of features have been built into the communication system.

#### **Flexible Network Structure**

Terminals can be connected to the system directly or via telephone, telex or circuit switched network; remote terminals can be connected via packet multiplexer or PADS through satellite circuits.

#### **Board terminals Integration**

Packet terminals, non-packet terminals and host computers of different speeds can be integrated.

#### **Network access**

The system should facilitate access to the communication network, be it via leased or dedicated lines, switched telephone network or satellite circuits.

#### **Line utilization**

Each packet terminal can communicate with a number of other terminals over one physical line.

#### **Error-free transmission**

The system checks the data for errors step by step as it transmits.

Considering the above requirements and the need for a low duty cycle interactive network with a large number of stations, a satellite based system was selected to meet the requirements of NICNET. Adjacent satellite interference, as well as interference to and from the terrestrial system must be minimal for enabling free siting of the small aperture earth stations. In view of these considerations, a Spread Spectrum Code Division Multiple Access System was chosen for NICNET.

#### **Spread Spectrum**

Spread Spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information; the band based spread is accomplished by means of a code which is independent of the data and synchronized reception in which the code of the receiver is used for data despreading and subsequent data recovery. It is, in fact, based upon a principle which is a direct antithesis of reducing bandwidth, namely, deliberately employing a larger bandwidth.

A characteristic advantage of this approach is that it

minimizes interference from other satellites and terrestrial sources. Further, due to the fairly uniform power spread over the entire bandwidth, it offers a low interference potential to other satellite and terrestrial sources. As such, site clearance problems for interference even in congested area are substantially lower. While spread spectrum uses a larger spectrum, this is compensated for by the significant interference reduction capability inherent in its use. Consequently, it is possible that a number of users might share the same spectral band simultaneously.

### CDMA Technology

Code Division Multiple Access (CDMA) allows efficient multiple access in extremely large network of low duty cycle terminals. The fact that no satellite power is allocated except during actual transmission permits thousands of relatively infrequently transmitting earth stations to share the same 5 MHz transponder channel. CDMA takes advantage of the unique way in which spread spectrum technology allows transmission of signals without interference problems.

The information spectrum is spread by a direct pseudorandom noise (PN) sequence, where each data bit is encoded with binary (chip) sequence with 15 to 2047 binary (1 or 0 chips) per bit. The expansion is achieved by an exclusive - OR operation on the data and the chip sequence so that a "1" bit contains the chip sequence in inverted form. A "0" bit is a non inverted chip sequence. Although the encoding chip sequence is pseudo-random, it is perfectly replicable for decoding by the authorized receiver using the same chip sequence to recover the data and is operated by exclusive - OR with the chipped data (the inverse of the operation used to encode the data) to obtain the data.

The code sequence modulates the carrier using 180 deg biphasic shift keying (BPSK). Data are converted to 0 and 180 degree phase modulations of the carrier, where the carrier is transmitted with one phase when the encoded sequence chip (exclusive-OR operation with the data) is a "1" and the opposite phase when the encoded sequence is a "0". The chipped data is then transmitted as if they were the original data bits, producing the phase shifted signal corresponding to each chip.

CDMA has significant advantages over Time Division Multiple Access (TDMA) for sharing a satellite channel among a large number of transaction terminals. This is because the only constraint imposed by a CDMA system is that the total number of simultaneous transmissions are kept below a specific threshold to avoid the harmful effects of "code noise", or self-interference resulting from imperfect code orthogonality. This is a far easier constraint to satisfy than the constraints imposed by other access techniques. In most other techniques we must ensure that no more than one terminal is transmitting at any instant. As a result, very impressive throughput performance can be

obtained. For example, if the threshold of code noise occurs at 100 simultaneous messages, a throughput of 84% can easily be obtained, with only about a 1% chance that a message sent in the peak busy hour will suffer any excess delay. NICNET uses a CDMA access techniques of this type, combined with "throttling" to inhibit transmissions when the threshold would be exceeded by such messages. Even when such a CDMA system approaches overload, i.e., more than the allowed number of simultaneous transmissions, the consequence is not serious with a reservation TDMA system, where a retransmission is required after a 0.5 sec minimum delay. When a CDMA system approaches overload, 0.1 sec delays are inserted to throttle demand, rather than requiring retransmission.

NICNET consists of a master earth station located at New Delhi. This master earth station is connected to the host computer. Micro earth stations are located at all regional, state and district centers. These micro earth stations communicate through the master earth stations.

The components of this interactive network are described below.

- A network control center (NCC), which incorporates host computer interfaces to connect NEC S-1000, Cyber and other host systems.
- A number of micro earth stations and controllers which transmit to the satellite.

### The LAN-MAN-WAN Hierarchy

The National Informatics Center is the decentralized depository of information for various central and state Government departments. For this purpose, large databases are being developed in coordination with the user departments. In order to maintain these large databases on a national scale, NIC has already four very large mainframe computer system (S-1000 from NEC Japan) at Delhi, Pune, Bhubaneswar and Hyderabad. These are the four main nodes of NICNET. The Delhi system acts as the main host.

Local Area Network (LAN) and clusters of mini computers/super ATs are being installed in the secretariates of the state capitals and union territories. These systems are being primarily used by the state governments to consolidate the information coming from various districts/blocks as well as from within to meet their own requirements and to pass on the necessary consolidated macro level information to the center. The various LANS in different parts of a city are being connected by a Metropolitan-Area-Network (MAN).

As the districts are the basic administrative units under the State, the consolidation of the detailed information pertaining to the districts is done by various agencies at the

district level. In order to capture and consolidate this data, super ATs are being installed at the 440 districts in the country. As the block is the smallest development monitoring unit, especially for the plan scheme implementation, they are the generators of the basic data for this. In order to capture this basic data, PC based terminals are expected to be installed in the third phase of NIC at the block level, covering more than 5100 block. Here again, LANs and MANs will be installed in course of time. All these MANs will be connected into a Wide Area Network (WAN). The LAN-MAN-WAN hierarchy will be the logical network structure that will evolve over the next decade (Fig 2).

At the local level, things are developing into local area networks, where one can have the office automation followed by voice mail, facsimile, text mail and electronic files. Then, one can have computers connected to it with large data bases, either remote or local.

Through the wide area network connecting various cities with the micro earth station, even the districts get connected to a central computer, or a group of computers.

The above is a fleeting outline of the kind of scenario that is emerging.

**Distributed DMBS**

A software called UDMS has been developed as a Unified Database Management System to provide a Data Base Management System (DBMS).

UDMS act as a coordinating system for the DBMS packages mentioned above at different nodes in the network. It provides a single user interface to design a database distributed over different nodes in the network and provides SQL-like query language to retrieve information from databases distributed over various nodes. For a user working under UDMS environment the underlying DBMS packages on different nodes are kept transparent for the design as well as to process a partitioned query on a given node. From this of view, it is possible for a user to use that part of distributed database which is implemented on this node. However, as this segment of the database is a part of the overall database, it may not be possible to perform such functions in a stand alone mode which may affect the integrity of the global database. Distributed database environment as a C&C network is clearly the shape of things to come in the next ten years.

**Query Servicing vs File Transfer**

All queries are submitted to UDMS in a network environment. The system first refers to local directories and the query is first analysed with reference to it. The query is then sent to the central system for processing at other nodes based on availability of information at those nodes. Query is partitioned based on distributed pattern of the database. The partitioned queries are then translated into queries/DML programs of the local systems. The partitioned queries are filtered for those functions which

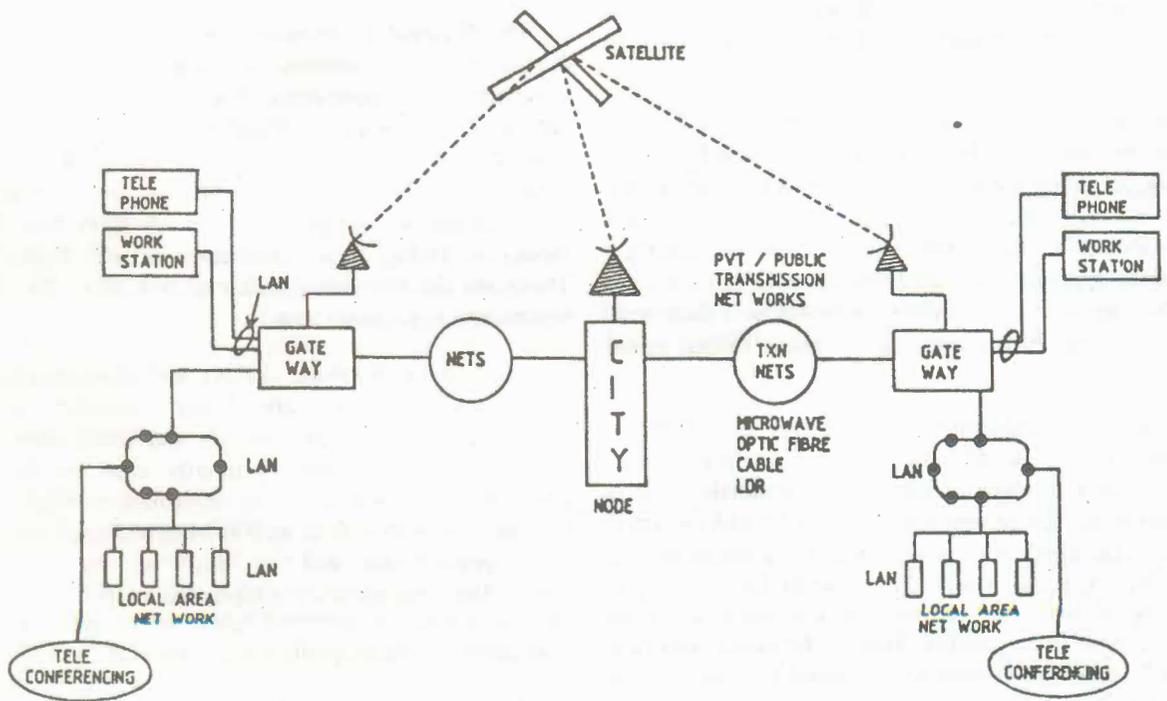


Fig 2 The LAN-MAN-WAN hierarchy

are not available on local systems. These partitioned queries are posted and executed at respective nodes. Additional processing with respect to global functions is performed at the central node. The results are then combined. The final response to the query is then sent to the originating node.

Where it is not necessary for all information to be centralised, the information storage can be decentralised in a computer communication network. With low cost computers, one can capture the information in magnetic form wherever it is collected and keep it ready for any query to access it. Therefore, one has to decentralise in a computer-communication network mode.

On NICNET, transmission of information files is minimised and transmission of queries and answers are maximised. Whoever has information is assisted to capture the information at his location in a standardised format in a manner which is compatible in terms of computer-communication, and allow the queries to go from one place to the other and the answers to go back. By doing this, the load on the total computer-communication network can be minimised.

### The Evolutionary Development of VANS

The entrenched predominance of the 'Plain Old Telephone Services (POTS) is slowly getting digitalised with the introduction of E 10B electronics exchanges and in the near future, the CDOT-ESS. Unlike in developed countries, the digitalisation transition is likely to take a decade for the entire Indian telecom network to become electronic. Whether during this transition in the 90s one more transition can be introduced by upgrading POTS by a growing range of Value Added Network Services (VANS) in a cost-effective manner is the subject of the following discussion.

VANS can be classified in several ways

- (i) 'Vertical' services which are designed for a specific sector, e.g., NICNET for the government sector, databases for travel agents, databases for tourism and hotels etc.
- (ii) 'Horizontal' services by contrast are designed for a diverse groups of users but offer a specific functional service, e.g., electronic mail, electronic fund transfer etc.

These classifications may be recast at follows

- (a) Application specific, like computerised yellow pages or electronic fund transfer at point of sale.
- (b) Customer specific, like SAILNET, Tour-net, Power-net, Irri-net, etc - principally for electronic data interchanges.
- (c) Facilities specific, such a electronic mail where the service is open to the public and the casual user.

The above clearly point to the need for open inter-connection as a requirement for success of the VANS. ISO/OSI should be the more a primary requirement for all the major providers of VANS. This will ensure that the users have easy access to several VANS, that there is wider choice of terminal equipment and competition is carefully groomed among VANS operators as well as terminals suppliers. This will enable the user to get the best for his money.

A particular illustration of standardisation will be felt when electronic mail services proliferate with subscribers in danger of being locked into the system they happened to have selected in the first place. Ideally, they should be able to communicate with any other user. In India, the adoption of X.400 standard of E-MAIL is likely to solve this problem and enable exchange of messages with members of other services.

The initial phase of evolution of VANS will be confined to non-speech services. Further, the monopoly position of DOT in voice telephony is likely to be protected until atleast 2000 AD. Voice related VANS will be secondary motivators for the development of VANS. The non-voice area of VANS can be classified as follows

- Managed Data Network Services (MDNS)
- Electronic Mail Services (EMAIL)
- Electronic Data Inter-change (EDI)
- Electronic Fund Transfer at the Point of Sale (EFTPOS)
- Online Database (OLDB)

The 70s saw liberalisation of American telecommunications, and the 80s that of European telecommunications. The 90s are likely to see liberalisation of Indian telecommunications. The formation of public sector corporations—Mahanagar Telephone Nigam Limited (MTNL) and Videsh Sanchar Nigam Limited (VSNL) spun off from the Department of Telecommunications, is likely to continue with the spinning off of several other public sector telecommunication corporations. This will help break the purchase monopoly in the telecommunication sector. With autonomous purchase power, the stage would be set for bringing in competition in the areas of telecom equipment manufacture and telecom services. Earlier when there was a purchase monopoly in the field, private manufactures were hesitating to enter the field. Now with an acute resource crunch during the eight Five Year Plan, it is inevitable that the telecom sector has to find resources through public bond issues and sizeable involvement of the private sector for not only manufacture, but also for providing services. VANS can provide the much needed impetus for such a commercial initiative, breaking through the stronghold of telecom regulations, government policies, monopolistic manufacture and monopolistic

services. Though USA has the most liberalised telecommunications regime, the UK closely follows this desirable development with strategies offering a number of lessons to the process of telecom liberalisation in India. It is argued here that the introduction of VANS in India as the cutting edge of telecom liberalisation would call for a launch pad for VANS and NICNET can act as a backbone for evolutions of VANS in the public domain. This would call for a number of government initiatives broadly along the following lines.

(i) A policy framework has to be designed to allow the telecommunication industry to be composed of both public sector and private sector, greater freedom to use the P&T inland network so as to quickly satisfy the growing demand for more sophisticated services. This will enable Indian business to exploit information technology in the formation of telecommunications network service more effectively.

(ii) VANS may be opened up to the private sector by issuing VANS general licence requiring companies to register their proposed services. For the magnitude and complexity of the Indian economy at the present stage several hundreds of services are possible by more than hundred companies. To discourage less serious entrepreneurs, the Government may impose a substantial licence fee. In order to break the monopoly of DOT, it is necessary to quicken the process of spinning off of numerous autonomous public sector corporations like MTNL, one for each major state, one for the entire North-East with the smaller states and union territories being served by one of the neighbouring public sector corporations. As a measure for the introduction of the private sector, the North-East Corporation as well as a number of limited services networks should be allowed for the private sector. This has to be done carefully so that the new competitive environment would not be such as to cause confusion, but would allow for a gradual restructuring to meet the demand for new telecom services. Such a protective mechanism may be in the form of DOT retaining certain exclusive rights for the public sector companies during the transition period.

(iii) After careful consideration, a Managed Data Network Service (MDNS) classification in the form of a value added network service licensed with certain transitional limitations, for example, basic voice telephony or basic telex, cable programme, land mobile radio services, etc are excluded from the licence. From the VANS licence, it is also desirable to exclude during the initial period of transition, the basic packet switched service, as also 'sample resale' which involves taking a packet

switch call conveyed over a leased line and then returning it to the public switch network.

- (iv) During the transitional period, it may also be stipulated that if the basic conveyance of live speech is provided as part of a total service, the rate charged must be at least equal to that for the equivalent public switch network.
- (v) It is desirable to ensure that VANS operations are not cross subsidised from elsewhere in the business.
- (vi) International Standard Organisation (ISO)/Open System Inter connection (OSI) protocols should be utilised as standards by the vendors as far as possible.
- (vii) Conglomerate organisations with large internal networks will be permitted to charge within their groups for the conveyance of basic voice and telex traffic. Spare capacity for business purposes would be subjected to the foregoing conditions.

#### **Managed Data Network Services (MDNS)**

In order to pre-empt the need for customers to rent and maintain a dedicated network of leased lines, the Managed Data Network Services (MDNS) is coming into being which is related to the network which is interposed between the two end points of the users' systems. In accordance with the VANS licence conditions, enhanced services - like speed/protocol conversion, system management, system security and packet assembly/disassembly services are provided by the MDNS supplied by the simultaneously sharing the network with the other clients. The major participants in the MDNS business are those with an existing and substantial network (Fig 3).

#### **Electronic Mail Services (E-MAIL)**

The E-MAIL services competes with telex. For popularising this service and realising its full potential, the interconnection between competing systems should be considerably enhanced. Teletex which is considered as the natural successor to telex in turn; is facing competition from facsimile service.

#### **Electronic Data Interchange (EDI)**

Electronic Data Interchange (EDI) is the electronic shuffling of commercial documentation such as purchase orders, delivery notes, receipts and invoice between trading partners. The design has to allow organisations equipped with incompatible computer systems and document formats to transfer such information across the network.

#### **Electronic Fund Transfer at Point of Sale (EFTPOS)**

This technology seeks to do for the retailers what the automatic teller machines have done for the banks. It

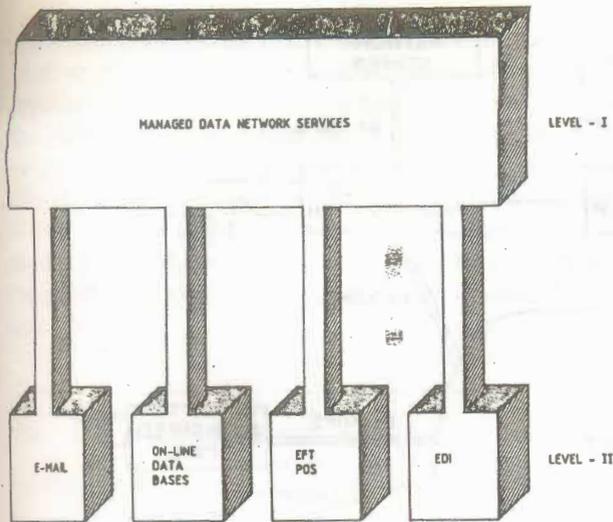


Fig 3 Data services under VANS

allows the customers automatic transaction at the point of sale by presenting a plastic card with magnetic strips (or micro chips) which authorize transfer of funds from the customers' account in the bank to the merchants' account in the form of an online transaction. Each terminal should be able to read any valid type of card credit/debit from any authorised issuer. The network should also be nation-wide.

#### Online Database (OLDB)

Online databases will become available in India through NICNET and other similar networks for subjects ranging from specialized database design for a particular vertical market sector to widely accessible generic services where the diversity of information represents the principal benefits. The system-based videotex standards and technology have a tendency to become pervasive and there is a need for DOT to allow private videotex system (PVS) VANS designed to give services specific to industries like the travel agents. Because of the user-friendly features, the videotex is also popular as a management information system tool and in retail stock management applications. A major factor which can make possible a sustained growth of videotex based VANS in India is proliferation of the off-the-shelf software packages designed to facilitate the adaptation of existing data processing host computers in order to provide access for videotex terminals which will encourage the closer interaction of videotex with main stream data processing.

#### NICNET as the backbone

The potential of satellite communication networks to serve as vehicles for various types of interactive services has long been recognised. Satellite services with dedicated channels and transponders for international value added data services is now steadily evolving. In a liberalised scenario, one could install a micro earth station dish

antenna on the roof of his building to receive and transmit signals directly via satellite bypassing the terrestrial cable network. Over NICNET, a large number of Closer User Groups (CUGs) are possible; each CUG representing SAIL-net, Oil-net, Coal-net, etc and the scale of investment and operation can be justified by such shared CUGs. Satellite VANS around networks like NICNET can become the cutting edge for introducing VANS in India which otherwise may take considerably more time to spread.

#### STAGE-II EVOLUTION OF NICNET HIGH SPEED INFO HIGHWAY

The next step in the evolution of NICNET planned during the Eighth Five Year Plan period between 1993 and 1997 is to establish a powerful NICNET Info Highway as an overlay network over the SSMA/CDMA network. During this period, as many as 150 economically important cities, towns and mega project locations will host the highway nodes.

The present SSMA/CDMA based NICNET has VSAT links operating at 1200 bps in most cases and 9600 bps in a few cases. This speed is so low that it has created bottleneck situations at the earth stations located at the state capitals thereby reducing the density of transaction applications at these state capitals. Further at 1200/9600 bps, large file transfers take considerable time. At peak hours, numerous users simultaneously generate a demand for network services thereby reducing the response time for E-mail, database querying and other applications.

#### The planted High Speed Network

It is well known that the traffic pattern plays a vital role in the design of an efficient network. The government structure is hierarchical. As a result the information flow in NICNET also flows this pattern, i.e., districts to states and states to center. The number of district vary from state to state. The information mainly flows from the districts of a particular state to its state capital. Information flow between interstate districts is not significant. Since the NICNET employs star configuration, the information originated from districts reaches state headquarters in two hops. Outband data rate is 153.6 kbps. Nearly 30 percent of the outband traffic is generated by districts and reaches its state headquarters. If all the state capitals are connected to the central station directly using high speed fixed assignments links, this 30 percent traffic can be rerouted removing congestion from outband channel. In view of this, a fixed assignment of high speed circuits each to the important cities and Delhi with good connectivity to the existing network will markedly improve the network performance. In this scenario, a high speed network connecting about 20 cities in the first instance with the hub center with due provision for expansion both in capacity for each city and possible addition of more centres offers itself as a solution.

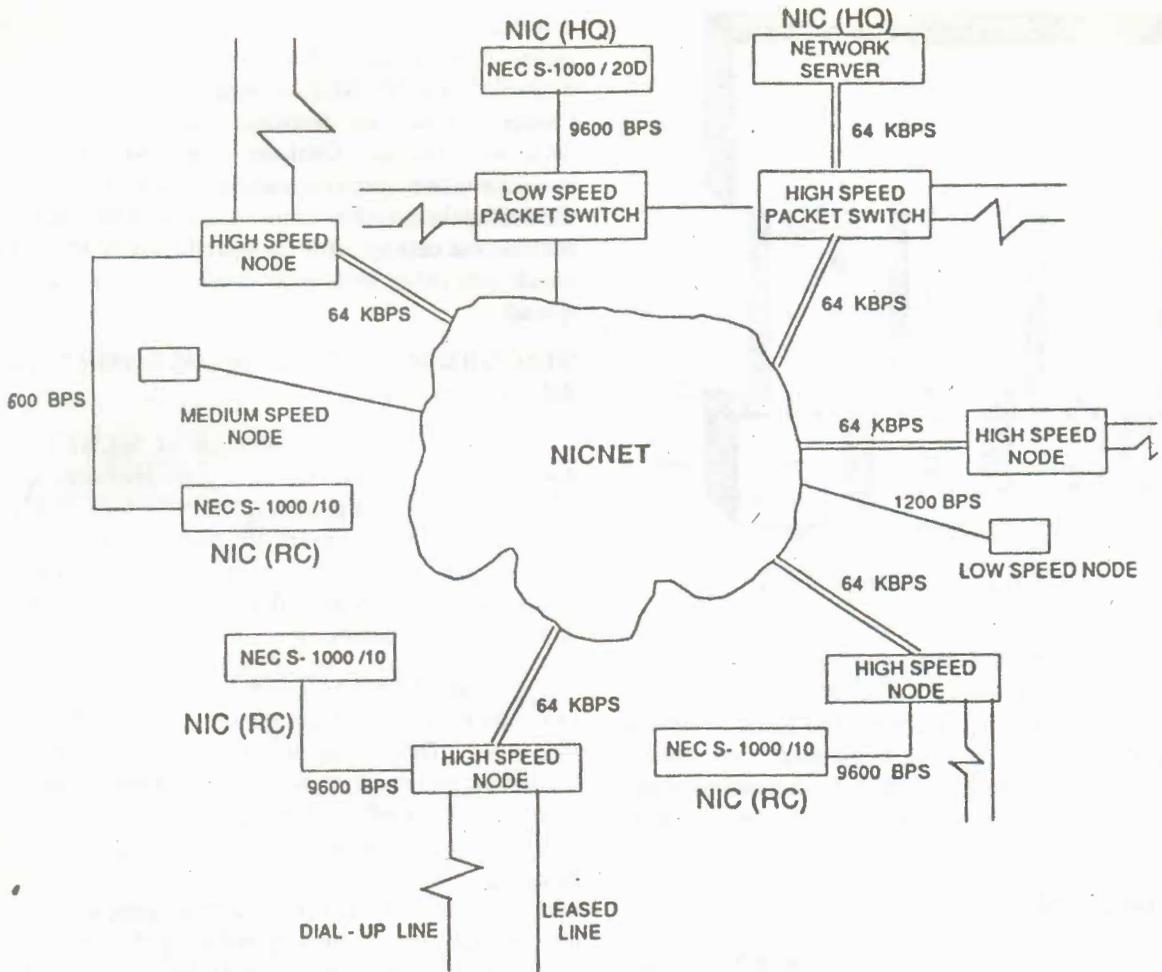


Fig 4 Future plan of NICNET

In view of the above, it is proposed to establish a high speed networking linking all state capitals and important centres. Each of these links will operate at 64 kbps or higher speed. They will have provision for PAD/switch to establish X.25 connectivity with NICNET users of that particular location. The hub centre at Delhi will have the required multiplexers/PAD/switch and interfaces for connectivity between the two networks. The hub will have integrated network management system to integrate the overlay network with the existing and proposed NICNET applications which are already mentioned.

**Reasons for the selection of Ku-band for NICNET Overlay**

The choices available for the high speed network are, C-band, extended C-band and Ku-band. For the extended C-band operation the VSATs are not commercially available and will have therefore to be custom built. This makes the VSATs cost prohibitive ruling out extended C-band operation.

The current trend in satellite communications is towards Ku-band though C-band operation is still in

vogue. Use of C-band transponder requires larger antennas which are more expensive and less attractive. Also, C-band is currently shared by satellite and terrestrial users and hence power radiated from C-band transponder is restricted to reduce interference. In addition, every C-band site location requires site clearance to be obtained leading to delays and inconvenience. Available transponder EIRP from Ku-band transponders are stronger than C-band transponders. The enhanced EIRP at Ku-band is however, neutralised by path losses when compared to C-band performance. The increased receive gain for a given size aperture at the earth station at Ku-band is available for system margin to combat weather related vagaries normally associated with Ku-band operation. The following table illustrates the comparative advantage of Ku-band system.

Band	Satellite Antenna ft	Tx gain deg	Tx Beamwidth degrees	Tx power watts	Max EIRP
C-band	4	32	4.3	6	39
Ku-band	4	41.5	1.4	6	48.5

We see that for a given size satellite antenna and transmitter the Ku-band offers 9.5 dB transmit EIRP at the expense of earth coverage which is acceptable to many applications. It should be noted that down path loss has also increased by a similar margin offsetting the gain. However for a given size earth station the increased receive gain at Ku-band over C-band is the real advantage. A part of this gain can be judiciously apportioned to combat Ku-band rain attenuation and the balance be traded for increased system performance. This is illustrated in the following table:

Req Band	Rx anten in ft.	Rx gain dB	System noise OK	Rx G/T in dB/k	Rain margin dB	Other losses MB/S	Outage hrs.	Traffic capacity
C	4	32	120	11.2	0	2	18	10(6×T1)
Ku	4	41.5	220	18.1	2	2	44	31(20×T1)

We see a three fold increase in traffic capacity is possible. The same advantage can be traded in other design parameters where the same level performance is expected.

### Multiple access

The multi access protocol is a set of rules by which a number of distributed remote stations communicate reliably over a shared channel. The key issues to be considered in selecting the channel sharing protocol are

- (i) The efficiency of channel sharing (throughput) - the fraction of time useful traffic is carried on multi access channel.
- (ii) Delay characteristics both in terms of average and peak.
- (iii) Stability properties—elimination of undesirable congestion modes.
- (iv) Robustness in the presence of channel errors and equipment failures.
- (v) Operational respects such as start up, recovery etc.
- (vi) Implementation cost and complexity.

There are three broad classification of channel sharing techniques (1) fixed assignment (2) contention (3) reservation.

The existing NICNET is of contention type which is more suitable to district level traffic. Whereas this is designed for district linkages which are bursty and short duration type it is unsuitable for linkages with state capitals where the traffic is steadier and of fixed type. In view of this, a fixed assignment option is more suitable for the high speed network. There are two candidates for fixed assignment type, the TDMA and FDMA/SCPC. Whereas both of them offer roughly the same capacity, delay and

stability, properties of the two differ in robustness cost, complexity and flexibility.

The overlay network will be a star SCPC system providing typically the 64 kbps dedicated satellite links to each of the remote earth stations. The network will have the expansion capability to increase to any number of earth stations and each link will be capable of operating at variety of speeds from 64 kbps to 2.2 mbps.

Each remote site on the SCPC network will have an earth station with a 1.8 meter antenna. The network will have multiple data channel capabilities combined upto an aggregate of 128 Kbps. The star hub will be in New Delhi with a 6 meter antenna and for each remote site a dedicated modem at the hub is provided. As each data link will have its own dedicated channel, blocking or congestion in satellite resources is avoided. The network is configured for modular expansion with not only modular addition sites, but also the data rates can be altered as required and multiple data circuits to any center can be added by installing a multiplexer.

The satellite system characteristics like coding tape and power levels can be modified to match the required link characteristics. The network control at Delhi will configure all aspects of the network utilising a Star Network Management System (SNMS). The SNMS is a monitoring and control system that will operate at the hub station so as to monitor the status of the hub and remote site. The SNMS typically runs on a 386 or 486 microprocessor operating under WINDOWS environment.

### Data Broadcast Network

The data broadcast network over NICNET overlay operating in the Ku-band will have a multiplexed hub which can be located to go with the SCPC hub in Delhi and controlled by an appropriate Network Management System. Initially, the data broadcast network will be uplinked from the Delhi hub, but later, it will be carried out also at a few other locations. Typically each data broadcast required will require 1.2 meter antenna, LNB and a data broadcast receiver. The network can either operate in a multiplexed or multichannel mode at aggregate speeds upto 256 kbps or in a clear channel mode without multiplexer at speeds upto 2 Mbps (Fig 5).

### Evolution of the INFO Highway

The NICNET INFO highway which is an advance stage of design will be a satellite based universal broad band network (UBN). Efforts are being made for UBN to have a uniform, universal and suitable standard for basic switching and transmission to encourage users who will be willing to invest in the facilities required for the network. The standard requirement is critical and some flexibility will be built in. The NICNET INFO Highway will have network hardware, basic control and software which will

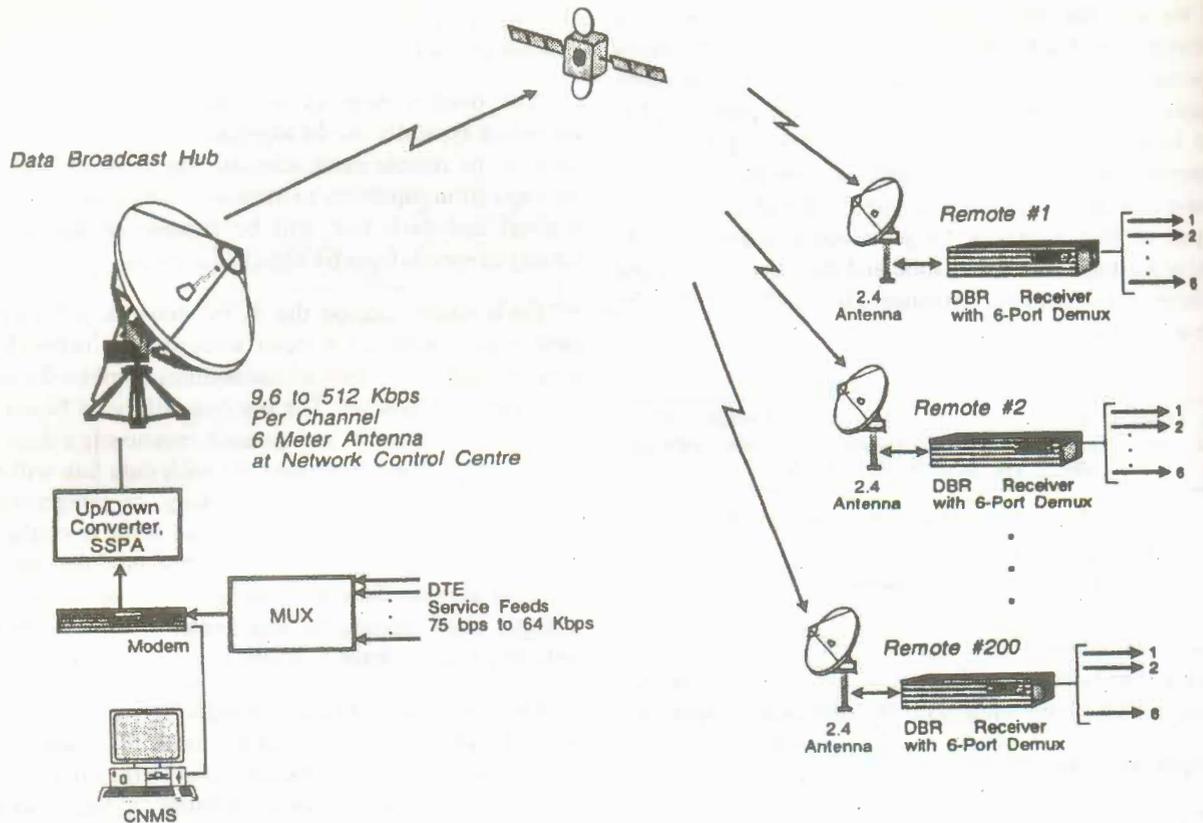


Fig 5 National informatics proposed data broadcast network

enable such standardisation so that any conceivable service application may travel on the highway. The least common denominator of digital encoding and signalling will allow for service integration without perceptible loss of transmission speed.

Plans are well under way for the setting up of the NICNET INFO Highway initially linking 30 cities by September 1993. Each node will have 2.2 Mbps rate of transmission per module. The variability will be adjusted between 16 Kbps and 2.2 Mbps. An intelligent network management system will adjust the rate at each node depending upon the forecast of the demand.

The star hub at Delhi should not be construed in the same sense as the hub of the SSMA/CDMA hub of NICNET. Though there is a network management control system used at the star hub, it is to be considered only as a cluster of point-to-point communication in which one of the points for each pair is located at the star hub.

Each node of the network can also be clustered as parallel pairs connected to the star hub in order to increase the overall transmission rate modularly in multiples of 2.2 Mbps. Thus, the INFO highway is being designed for modular expansion specially as well as capacity-wise.

On the ground segment, special low cost technologies

for effectively linking widely separated local area networks, network FAX & image servers and multimedia communication services are proposed. Special features for accommodating a large number of close user groups and offering virtual private networks are designed to increase the propensity for the spread of the IT culture as well as prod the growth of demand.

#### BISDN via NICNET INFO Highway

A widespread BISDN use is expected to take place in the near future. BISDN protocol and services can be effectively provided over satellite links. The fast cell switch technique of ATM can be used so that all services such as voice, video, image and data, can be provided using the ATM adaptation layer (AAL) and ATM protocol layers with 150 megabit per second access digital television and high definition television can be accommodated. With ATM, voice and video are broken up and packaged in 53 byte cells carried from the source across multiple nodes and perhaps multiple networks and finally, reconstructed as continuous stream at the destination. The network will not distinguish between voice, video or data cells.

Satellite based networks are flexible and can quickly be set up for meeting communication services to business and government customers from distributed locations

using small and medium ground terminals located at the customer premises. In the near future, ATM can be provided over satellite by introducing an ATM earth station interface line card. Such cards are already under development and pilot scale experimentation. Two major facilities proposed to be provided on the NICNET INFO Highway are the close user group facility and virtual private network facility.

#### **Close User Group facility**

A closer user group (CUG) facility is a shared network in which membership is limited by some a-priori specified restrictive criterion, e.g., corporate headquarters along with all its branch offices, a bank along with all its branches, a super market and its customers, a large central government offices, etc. This helps the users to pool their demand for a customised service or solution and thereby obtain the same advantage as a very large user. This facility helps in globalisation by external linkages to users with shared concerns, for example, when a number of Indian banks become member of the SWIFT, the international banking network, they become part of a CUG. As soon as NICNET Highway become available, hopefully, around September 1993, this would enable a very large number of banks and their main branches to be connected to SWIFT through NICNET INFO Highway. There are many other applications where CUG of NICNET can help the enterprises go globally.

#### **Virtual Private Network facility**

With NICNET INFO Highway acting as a computer communication carrier, virtual private network can be offered for using software control to carve out a portion of NICNET and place it at the virtually exclusive disposal of the user. Such virtual private network have several advantages. Users need not make large investment in network facilities. They would need a minimum skilled technical staff to operate their network. The amount of capacity of network can be altered and network can be reconfigured on demand. The users gain access to some of the network management systems of the public carriers. More importantly, users begin to share in network economies of scale and scope.

#### **External gateways to NICNET INFO Highway**

NICNET is connected to international networks through GPSS of VSNL located at Bombay. Through linkage X.25 networks worldwide are being accessed. For example, NICNET users access the National Medical Library at Bethesda through the MEDLARS as well as DIALOG databases. NICNET is also connected to UUNET for international E-mail services for its users. E-mail and NICMAIL are the electronic mail services available on NICNET. UUNET is a UUCP network connecting a number of UNIX hosts and acting as a gateway to many other networks. NIC is providing

UUNET connection to the users to send E-mail to various international sites which are also on UUNET or are accessible via UUNET. All mails generated on NICNET are routed through the gateway machine located at Delhi. NIC provides connection to GEMS-400, an X-400 posed E-mail service provided by VSNL. GEMS-400 is resident on a VAX system located at Bombay. To meet the needs of the NICNET users, NIC is shortly introducing EDI services. EDI, a value added service, based on OLTP system is being implemented in the first half of 1993. This value added system is being interconnected to international EDI networks through VSNL gateways for global transaction of NICNET users.

Two 64 Kbps external gateways are being connected to NICNET, one through the GPSS of VSNL and the other bypassing it. These will make use of the SPRINT transit network in USA to enable NICNET users to access more than 40 networks around the world. When the NICNET INFO Highway is established, the number of high speed external gateway links will be modularly increased depending upon the demand.

#### **STAGE-III: THE INTELLIGENT GLOBAL NETWORK**

During the period from 1998 to 2001 certain concepts of data networks have been forecast which is taken as the current basis for the design of NICNET at the third level of integration and globalisation. Based on the concept of NICSAT earlier conceptualised, a series of very low cost microsats are proposed to be launched for an internally operable dedicated space data networks, with user end to end communication capability, built in features for promoting specialised value added services, built in access security and expert system based network management. Low cost on-board features, a versatile space link scenario and low cost ground infrastructure are under consideration. The possibility of introducing BISDN via such a satellite cluster are also under examination.

Towards the end of the decade, it is proposed that NICNET will be incrementally converted for providing global intelligent network service over strong skeleton data super highway utilising the concept of application gateway. The intelligent network architecture is proposed to be explicitly provided for personal communication services with globalised access.

The basic approach to the evolution of the network is given in Table 1. Initially, the connectivity will be provided and the basic network infrastructure will be put in place over which virtual private network facility will be created. The next phase of the evolution will make the new services available on the basic international network infrastructure built on international intelligent networking.

In the third phase, full band width on demand will

TABLE 1 Approach to evolution of global networks

Connectivity	Services capacity	Broadband
Basic NW Infrastructure	Intelligent Networks	Bandwidth on demand
Virtual Private Network	PCN/Mobility	
ISDN Switches with Packet Handlers	SDH/SONET Switches with Advanced Access Services	Multifabric switches supporting ATM
1993	1997	2001

National Services - International Services

become available globally with the extension of Asynchronous Transfer Mode (ATM) from national networks to the global networks.

Almost any national intelligent network service will be a candidate for a global service. It is on this basis, that the globalisation of NICNET is being evolved. Initially, global network services will be relatively simple extension of national services as described under Stage-II. The intelligent network will enable service providers rapidly to provide new service tailored to their markets. The main thrust of introduction of intelligent network concept into NICNET INFO Highway is private virtual networking. As soon as global private virtual networking becomes a reality, the standardisation norms for NICNET will be fine tuned to become compatible with them.

A number of services can be included under the overall purview of global private virtual network, e.g., the customer definable global corporate dialling plan can be made operational.

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## Emerging Trends in Video Transmission Technology

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**D**R Vikram Sarabhai was incarnation of God in human form. He possessed all Godly qualities. He had very long foresight. He was a good planner. He had control of every situation he was in involved in. He protected people around him. He guided them. He took care of their personal needs no matter how small the person might be in stature, social position or academic status. I had the fortune of experiencing all these benevolent aspects of this unique, magnanimous, unparalleled personality and I am sure that all those who worked with him will bear me out in each and every of my statements. Once sitting in his house across the table I was tempted to pick up the groundnuts from the bowl which is a traditional item in Gujrathi household. Before I could pick up the courage, it was Dr Sarabhai who moved the bowl towards me and encouraged me to pick up what I wanted. Once I happened to be traveling in an AVRO aircraft between Trivandrum and Madras. Dr Sarabhai who was sitting in fifth row, spotted me and invited me to sit by his side. He was a internationally known Scientist and I was a fresh engineer who had just joined the then Space Science & Technology Center (now Vikram Sarabhai Space Center). I was more than thrilled and at the same time tremendously nervous. During next half an hour he guided me thorough the minutest detail of a new project he suggested I should take up. All this time I was floating in air inside the seroplane trying to absorb what he was relating. At Madurai, where the plane had a stopover Dr Sarabhai asked me to write down the gist of what we "discussed". Before the plane landed at Madras Dr Sarabhai went through my notes made a correction or two and then put his famous initials VAS at the end of it. It took quite a few days for me to realise that I had a Rs. 30 lakhs project approved by the God called VAS. This authorization was enough for Mr S R Thakore to release the funds without even a formal request in writing from me. I had been officially designated as a project leader by that time and had the freedom to spend the money. Can there be any such project sanction quicker than this process? Can there be any institution which provides such guidance, and such freedom of work to an engineer who is in the lowest scale of Scientist/Engineer in a small place in an obscure little village of Thumba. It has to be only the God's own doing. I recall another event. First time I met Dr Sarabhai, he asked me to come to PRL. Can you imagine the contents of this invitation! Air ticket, a car waiting to receive me at

Ahmedabad airport and accommodation at PRL Guest House, all as per the personal instruction of Dr Sarabhai. Dr Sarabhai was just waiting only for me in his chamber when I arrived. Even today it is beyond my perception how he could pay attention to each minute detail, in case of each such Kulkarnis who must be in thousands working for him and around him. Does it not require the Almighty's strength and capabilities to take care of each of the small fries in the universe?

Today I have been asked to give a Vikram Sarabhai Memorial Lecture. Such a great honour is bestowed upon me that I still feel that this must be a dream. It must be my fascination for this great visionary that I have started visualizing a dream about him. It must be his memories occupying my mind that make me feel that I am delivering a Vikram Sarabhai memorial lecture. I am sure that the God as he is will forgive me for this arrogance of mine. Let me therefore put forth before you a few thoughts and some pieces of information which I have gathered while commemorating the great Vikram Ambalal Sarabhai.

Video Transmission Technology is the topic assigned to me today. In layman's language TV and VCR provide video. In technology the very definitions of various technical terms are continuously assuming new dimensions due to the extremely fast developing technological frontiers. Anything very wideband could perhaps today be covered under the term of video technology. And all this technology which we are experiencing today is a very recent development. It has total life span extending to only 50 to 60 years of history. You may recall that regular TV broadcast started in Britain in 1936. Public utilization of TV transmission took roots in 1939 in USA. Another very powerful technology - the computer technology has been integrated with the communication technology in the recent past and the two together are shaping the modern life. And even this computer technology in its present form has celebrated only the 50th anniversary of the public announcement of Electronic Numeral Integrator and Computer ENIAC on 14th February 1996. So history is short but geography of this technology does not know any boundaries and has gone into entire universe. Today's society is known as information society thanks to this technology. A "Global Village" concept has given rise to a "Global College" concept and new words like Edutainment, video, on demand are

heralding the Global Information Society of the 21st century. The development of video technology owes its progress to communications, computers, display technology, and a new field - the so called software technology. The basis of all these is the semiconductor technology, one more 50 year young lad joining the fray. Transistor which replaced the tubes came in existence in 1946 and since then it has not looked back 5.5 million such transistors today cohabitate in a single chip and provide Giga (or is it tera?) FLOPS-floating point operations per second. This helps in generating, collating, organising and processing information that is the basic ingredient of information society. This so generated data is then transmitted at the rate of GBPS/TBPS. Terrestrial broadcasting, satellite transmission, cable distribution (CATV), Multipoint-multichannel distribution (MMDS), digital and analog optical fibre distribution and prerecorded distribution are various options available for transporting the video information. A "Glass Neckless" the Fibre Optic Link Around the Globe (FLAG) an ornament big enough to cover entire neck of queen earth is being contemplated to provide data transfer from any point to any point at the rate of 5.3 GBPS per optical fibre pair. A combination of all these media like satellite at global level, terrestrial for urban and rural, optical fibre to neighbourhood and coaxial cables to homes are being used for transportation purpose. (In urban areas 750MHz bandwidth systems carrying 110 conventional 6 MHz spaced TV Channels have now been implemented). The Third giant is in the field of software where Giga instruction per seconds are skillfully manipulated to provide the information in the desired form. The fourth G component appears in the form of Gigabytes of memory storage capacities offered by the technological like floppy discs, CDROMS, magneto optical and floptical device. 1 GB capacity CD ROMS are available today which is 1000 times improvement on the not so old floppies of 1 MB capacity. The achievements of all the technologies are finally made visible by the display technologies. Starting with cathode ray tubes we are now entering into flat panel displays. Picture enhancements by better resolution cameras, addition of enhanced signal to luminance at studio to compensate for lost details, adoptive emphasis, progressive scanning conversion, three dimensional chrominance/luminance separation filters and such techniques are being used to improve the resolution of displayed material.

Generate, Process, Communicate, Store and Display are therefore the panchsheel, the five sides of the information pentagon that have been developing at astonishing speed and it has become impossible to analysis the progress of the technology without looking at all of them. Video technology which demands maximum output from each of the five fields has also developed its own ingenious ways of synergically using the best of each one of them.

The main objective of video transmission is delivery of

clean, panoramic, high resolution, high definition video image which conveys information in pictorial graphic and text form. Initially all such systems were analog. Early fifties saw the emergence of standards like NTSC (National Television Systems Committee), PAL (Phase Alternation Line), Sequential counter arec memoire (SECAM) (Europe). Even today this is a dominant mode of transmission. Approximately 200 million analog TV sets and 100 million analog VCRs are in service today. India continues to produce about one million colour TV sets (and four million B & W sets) per annum. Japan is continuing and plans to continue its analog transmissions though in different improved formats.

However a need to develop newer technology came mainly from the requirement of the so called HDTV-High Definition Television. Here again first effort has gone into development of new methods for the existing analog technology. The reason was simple. A total replacement by digital technology would be very expensive and will render the existing technology unutilized. USA therefore decided that there will be simulcast approach. NTSC will coexist with HDTV (Eventually NTSC is expected to be withdrawn say by the year 2008.) In between Europe went for the so called Enhanced Definition TV (EDTV). They decided to go for double the PAL picture lines (1250) based on multiplexed analog components (HDMAC). This technique separates chroma & luma in time, rather than putting them on separate sub carriers. However HDMAC did not meet much success. Now the indications are Europe may go the American way. Japan came up with a hybrid solution. The effort was on both the fronts. Digital data compression and analogue transmission for total system improvements. Multiple subNyquist Sampling Encoding - MUSE techniques are being developed since 1990. The aim is 1125 lines resolution with 60 fields per second. Band width comprehension techniques are used for both analog & digital signals. Major improvement have been made on the receiving side. (a) Image enhancement, (b) noise resolution by DC shift equivalent to level of transmission noise, (3dB improvement) and (c) Improvement in C/N by 2dB using frequency selective non-linearity of magnetostatic surfacewave devices are some of the techniques used at receiver end. On transmitting side better resolution cameras have been used. Corrective signals to luminance have been added in studios. Adaptive emphasis techniques, progressive scanning methods, ghost cancellers and three dimensional chrominance luminance separation filters have been used. Aspect ration of 16:9 is maintained for HDTV. It has been made compatible with 4:3 aspect ration systems by a letter-box approach in which black bars appear across top and bottom. In the area of encoding various innovative approaches like Trellis Code modulation (TCM) which combines error protection and multilevel display modulation scheme, have been harnessed. However MUSE occupies double the standard 6 MHz band width.

Today Japan has introduced HDTV set using the hybrid approach. Sight seeing buses and some of the taxis in Japan are proudly displaying their TV sets. USA decided not to go for hybrid. Simulcast up to some point and compatibility with the existing TV receiver particularly to be maintained by cable operators was the FCC's decision.

Home delivery of a digitally clean, panoramic high definition image accompanied by digital surround, sound audio is based on

- MPEG-2 Video compression & transport protocol,
- Multiple transmission format
- Dolby AC-3 digital audio
- Vestigial side band digital modulation

HDTV aspect ratio of 16:9 (existing 4:3), 1125/60 Hz and 1250/50 Hz (double of NTSC/PAL) and two million pixels per picture (six times spatial resolution of NTSC) are some of the features of this schemes. Progressive scanning provides temporal resolution of 60 full frames per second (twice the NTSC.) It promises no ghosts, no show, no false or artificial colors. The signal is either perfect or zero. (A digital property even for the signal level.) Digital vestigial side band modulation enables a 6 MHz band width channel to deliver 20 MBPS data.

The effort is tremendous, the complexity is enormous. Hence ten giants have entered in the fray on a collective basis. AT&T and GI have undertaken development of video encoder, Philips is involved in video decoder, Sarnoff & Thompson are responsible for transport sub system, Zenith is doing modulation subsystem, Dolly lab (SF) supply digital sound system, ATTC, Cable labs, ATEC will carry out tests and MIT adds its own contribution. Integration will be done by Sarnoff. Herculean efforts have gone into arrive at HDTV standards. FCC has forced the warring groups to arrive at common standards and the latest information is that the standards have now been approved. Amongst the HDTV standards MPEG (Motion Picture Expert Group) is video/audio coding technique leading to high compression ratio. MPEG based TV Transmission can provide 4 to 5 standard definition TV signals through a single 36 MHz Satellite transponder. Normally a 3 MBPS compressed data provides acceptable quality. At this rate a two hour movie will occupy 2.7 GB of disc storage.

The cable can deliver the data rates of 7b/S/Hz. So a 6 MHz RF channel for a standard resolution picture at data rates of 3 MBPS can deliver up to 12 channels. Storage of digitally compressed data for transmission to different terminals is also being widely used. Video servers are becoming more popular. The input can be from either camera, or VCR or any other data generating device. The video processors convert the analog video/audio into

compressed digital format. Video servers of 1.35 terrabyte storage available in the market carries 500 titles of film material. It can support up to 100 concurrent stream. ATM, the asynchronous transfer mode is becoming effective way of handling such a situation ever over SONET (Synchronous Optical Network).

In India we seem to be in infancy in the area of video transmission as a whole. Its true that the color TV transmission (analog) is taking roots and being supplemented by data networks. Use of terrestrial and satellite transmission are being adopted both for video and data transmission by various Government departments like DoE, DOS, DOT, Doordarshan, NIC of Planning Commission and a host of private, mainly cable operators. Information highways VSAT terminals, Insat channel, NICNET covering around thirty major cities, connectivity to Inet, Internet, Ernet etc are becoming available to common man at faster rate. But so far very little has been done on HDTV or any digital video data compression system. It appears that our course will be piecemeal utilization of technology as becomes available and as is convenient and fit in our immediate needs. It is necessary that a national policy has to be worked out keeping the overall technological and consumer interest in mind. It is true that our requirements are region specific but in today's fast moving field of technology we cannot take a passive role and wait for things to happen. We are sure to be dead if we don't move along with the world. On the other hand we have capabilities and we can certainly participate on equal basis with other nations in the process of development and utilization of the latest technology on a continuous basis.

In DoE we have undertaken a project called INPATS - Indian National Programme on Advanced TV. Ten institutions including R&D Centres, academic institutions and industry have been participating to develop use of digital technology for TV. Another effort is being made to achieve digital data compression. A number of channels compressed into one can provide more capacity for Doordarshan. Cable TV operators and private and public studios can use the digital storage and retrieval systems (DSRS) being developed. Most of these systems are MPEGI & MPEGII based Information Superhighways will soon become common in India's information society. However the video transmission that is talked about is all analog format and scenario that is emerging looks like-data compression both digital & analog at the source, analog transmission in a conventional way with some innovative modulation and transportation systems; and decoding and signal improving efforts at user premises. Perhaps set top boxes approach at the receiver to improve the resolution, for noise reduction, ghost cancellation etc is likely to set in. Certain data processing capabilities and marriage of home TV with the home PC to exploit the benefits of technology is certainly due for arrival. In short, HDTV is almost around the corner the world over. Integrated service digital broadcasting combining audio, video and data will become

a part and parcel of the society. Video-on-demand, home shopping, education and training, video conferencing, video-phones, telemedicine, health care, diagnostics & quality surveillance, information archival & retrieval, aviation simulators & designs in virtual reality, home interactive video terminals, multimedia systems in almost every walk of life, and all such systems will require a

HDTV with digital audio/video of high quality. The single most widely used system would be home entertainment - video on demand, interactive programmes of games and movies and education at home.

It is obvious that video technology will continue to grow at even faster rate. It is for us engineers to usher in this technology into our society.

## Knowledge and Communication

R CHIDAMBARAM, HFIETE, AND P S DHEKNE

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**D**R Vikram Sarabhai, a founder of the Indian Space Program also led the atomic energy program during the crucial years following Dr Homi Bhabha's death. He was a visionary with brilliant ideas like Agro-industrial complexes around nuclear power plants, satellite communication to villages, etc. India has shown tremendous progress in Information Technology (IT) in recent years and our spectacular advances in space technology, in which Dr Sarabhai played a pioneering and visionary role, have helped in this growth.

What is knowledge? The great philosopher Immanuel Kant who tried to understand the limits of human understanding, said more than 200 years ago: "Concepts without factual content are empty; sense data without concepts are blind. The understanding cannot see. The senses cannot think. By this union only, can knowledge be produced". This is valid today also, even though senses can be sharpened by instruments and extended by communication.

In a knowledge-based society, acquisition of knowledge requires effective communication. Selective acquisition of knowledge in critical areas and discriminatory control over its communication can enable some countries to dominate technologically. Keeping pace in high technology is the only way to sidestep this kind of attempt at technological colonialism.

It is said that when starting research, you must know enough about the field you are entering into but not too much. Loading yourself with excessive information on a subject is not only time-consuming but may also inhibit creative thinking or even straightforward analysis. On the other hand, you do not want to waste time doing research to acquire already available knowledge. Similarly, digested information makes acquisition of existing knowledge easier but since you depend on somebody else's judgment, you may miss important nuances present in the raw information. Selective acquisition of the latest reliable information - and here your instinct may have to play a part - becomes necessary. One has to balance the need to access at least some primary information sources and the impossibility of accessing all such sources. The communication capabilities for dissemination of information have grown tremendously with the advances in IT and Internet. Availability of up-to-date knowledge at the right time is essential but having rapid access to

obsolete knowledge is useless.

We must use technology to reduce the gap between the rich & the poor. We should use all types of communication gadgets such as satellite, cable TV, terrestrial wireless, Mobile-phones etc to reach the remotest village and help farmers in various ways. When you consider our population of 950 millions spread over 5000 towns and cities and six lakh villages, you will realize the reach and breadth needed to provide communication to them all. If Web is the technology we must think how to develop cost effective solutions. PM's taskforce on IT had anticipated that PC prices might continue to be a barrier to rapid spread of the Internet. The total cost of ownership (TCO) of a Home-PC is still very huge in India compared to USA, Singapore and Europe. It costs about Rs 50,000 for a PC plus net connection cost, which can be up to Rs 2,500 per month, which even higher-income citizen of India cannot afford easily, leaving aside the poor villager.

India is all set to emerge as an e-commerce driven economy, with a large pool of trained manpower and with support of government. Our pro-IT Prime Minister has taken many steps and major initiatives by setting up the IT task force, reorganizing electronics and telecom into a strong IT Ministry and has set a new agenda and direction for IT in the country. National Telecom policy (NTP 99) of the Government should help increase Tele-density and e-commerce also. If industry estimates are to be believed the Web-commerce transactions in India may cross Rs 10,000 crores by 2001-2002. A large number of kiosks and cyber cafés have sprung up in big cities. But what is needed in the remote village is a Knowledge Center, which may be manned by educated people so that villagers can be given information about crop and climate including disaster warning, cyclone prediction etc. They can be advised on how to increase production, prevent disasters, conserve water and about food security and health care through an online knowledge system. The current global wave of switching to electronic communication and commerce can be used more effectively in the remote parts of our country, with an integrated strategy to stimulate rural on-farm and non-farm employment.

We must stress the need to shape IT as a pro-people technology. Benefits accruing from IT should be equitably distributed among all the sections of the society. This would be possible if IT is correlated with regional

languages so that non-English speaking people can develop strong holds on IT and widen the spread of IT. The progress in IT should be made without sacrificing our cultural ethos and tradition. We must appeal to people not to shy away from taking to info-tech. I recently read a report in the newspaper about the Internet-ready "Okha" village in Gujarat. The village has Internet connection and a computer laboratory in its secondary school. The village Sarpanch says, "Now we can teach our students from the best teacher in the world online." Of course, the best option is to develop the necessary software in India itself.

India must establish access to all sources of information and knowledge and technological means to access them but, at the same time, do this wisely to minimize the costs. Libraries in academic institutions, for example, have both conventional and non-conventional sources of information but communication among libraries is meaningful only if they have complementary information. There is no point in having very sophisticated technology products for communication if you do not have significant information to pass around. In the case of libraries, this means careful planning of subscriptions to journals and to other sources of scientific information.

India has the capacity to develop technologies without help from the western world. The success achieved by India in supercomputing technology against the denial from USA, Japan and Europe can be cited as an example. Supercomputers have always been perceived as a strategic tool and countries having the technology deny it to others to preserve their dominance and competitive edge. There was only one Cray-XMP Supercomputer in India at NCMRWF, New Delhi running operational weather forecasting code, which is kept under strict security guard of USA. ANUPAM-ALPHA supercomputer developed by BARC is now running these operational weather codes much faster at almost one tenth the cost of Cray-XMP supercomputer. The capabilities and expertise developed by various leading labs in India like ANURAG (DRDO), BARC, C-DAC etc in supercomputing has ensured that we no longer depend on others for our requirements in this field. Today any product we develop whether it is a drug, a reactor, a supercomputer or a missile should compare favorably with a similar product elsewhere in the world, both in quality and price. Self-reliance today should not be considered as equivalent to self-sufficiency. If something is available to us from abroad much cheaper or of much better quality than that of a local product-particularly if it is to be integrated into a larger complex system, we should import it. But if something is denied to us, we should have the capability to develop and manufacture it ourselves. Development of self-reliance - which I now define as immunity against technology denial in high technology area - and international collaboration on an "equal partner" basis are necessary to prevent technology domination by other countries.

India is a large country, and therefore it should be present in every area of S&T. But how much we invest in each area, at any point of time, requires careful and wise analysis taking national interests into account. India, today has practically every kind of S&T institution and synergy among these institutions would help in rapid national development. In fact, synergy among the institutions is not only an effective option but also an economically cheap option and is, in my opinion, the only solution for rapid growth under present Indian conditions. One approach could be through setting up of joint centers in Universities or IITS' by mission oriented agencies. For example, BARC has set up a Center for Software Validation & Verification in IIT, Powai with an aim to get nuclear engineering software products tested by an outside agency. Another approach used for carrying out a focused applied research program was the collaborative project between the M S Swaminathan Research Foundation and the DAE on the use of nuclear and biotechnological tools in coastal areas near nuclear power plants in Tamil Nadu, with the aim of improving the livelihood of the people in the neighborhood. Fortunately these synergetic approaches are getting stronger in India and have to be assigned high priority.

An important factor which is of significance in today's world is what I have called many years back as Velocity of R&D. We must complete an R&D project in a frontier area of science with the same velocity as our peers in developed countries abroad. It is also imperative to strengthen the University R&D system and to increase its synergy with the national laboratory system. When the velocity of our R&D system comes on par with that in the developed countries, India will see spectacular technology growth and we all should work towards that. Some of the key components for this are quick access to relevant up-to-date information and strong interaction with peer groups.

Today, more than fifty years after Independence, the motivation for doing science must be to make India into a developed country, which would include raising the quality of life in rural India to the level prevailing in the non-urban areas of already developed countries. India must become economically and commercially stronger to achieve these objectives. The synergistic growth of various technologies along with IT will help to make India into a 'developed' country in the broadest sense of term in the hopefully not too distant future.

Emerging farming technologies will be based on precision farming methods leading to plant scale rather than field scale husbandry. Farming will be knowledge intensive using information from remote sensing via satellite, Geographical Information System (GIS), Global Positioning System (GPS) and web based multimedia technologies. Farmers in industrialized countries are already using satellite imagery and GPS for early detection of diseases and pests, and to target the applications of

pesticides, fertilizer and water to those parts of their fields that need them most urgently. Among other recent tools, the GIS methodology is an effective one for solving complex planning, management and priority-setting problems. Similarly, Remote Sensing technology can be mobilized in programs designed to ensure drinking water security. The advantage with web technology is that large knowledge-based servers can be managed and maintained in large cities, where expertise exists, and knowledge can be made available even in a far away village to the farmers on demand basis. The farmer perhaps need not have to pay for the server which can be funded through advertisements just like in today's TV. A variety of activities like Environment and Natural resources, Forecasting and Wild life protection. Ground water assessment, Land-use and thematic mapping; Health care, Tele-medicine etc can be organized.

Perhaps the key to success is a Catalyst Application, which can kick-start the new developments in villages. Ultimately villagers must have access and easy ways to create new services on their own - probably through wireless technology - tailored to suit their life styles. One can think of providing location-based services such as video card, net money order etc. Thus a user controlled and demands-driven system is needed.

Though IT industry is technology intensive, the only product here is knowledge and it is owned by people. Hence it is extremely important to understand what motivates people to perform, what are their concerns and aspirations, what are their intellectual preferences and

what will keep them going and enable them to deliver the best.

"Knowledge is Power" is true up to a point. Knowledge can be managed for profit through intellectual property rights (IPR) and knowledge can be controlled for technology domination. As knowledge moves from the books, journals and other print media to the net and publishing goes more and more electronic, there is an increasing danger of stealing and misuse. Viruses and hackers on the net are countered by anti-viruses and firewalls (and encryptions). I am sure, with time better and more sophisticated tools will be developed to protect knowledge on the net.

Peter Drucker has said: "Communication is perception, it is expectations and it is involvement. To communicate a concept is impossible unless it is within the perception of the recipient, i.e., one has to talk to people in terms of their own experience. The human mind attempts to fit impressions and stimuli into a frame of expectations. The communicator should utilize this or attempt an 'awakening' that breaks through the recipient's expectations - if the communications fits in with the aspirations, the values, and the purposes of the recipient, it is powerful. "Looked at this way, Dr Sarabhai was a great communicator.

I am sure this two day meeting will discuss all these issues and try to develop IT into a strong & vibrant 'core competence' within various units & would boost our capabilities by providing enough incentives for our work force. I wish success for this symposium.

Date	Description	Debit	Credit	Balance
Jan 1	Balance			100.00
Jan 5	Wages	50.00		50.00
Jan 10	Expenses	20.00		30.00
Jan 15	Income		150.00	180.00
Jan 20	Expenses	10.00		170.00
Jan 25	Income		100.00	270.00
Jan 30	Expenses	5.00		265.00
Feb 1	Balance			265.00
Feb 5	Wages	60.00		205.00
Feb 10	Expenses	30.00		175.00
Feb 15	Income		120.00	295.00
Feb 20	Expenses	15.00		280.00
Feb 25	Income		80.00	360.00
Feb 30	Expenses	10.00		350.00
Mar 1	Balance			350.00
Mar 5	Wages	70.00		280.00
Mar 10	Expenses	40.00		240.00
Mar 15	Income		130.00	370.00
Mar 20	Expenses	20.00		350.00
Mar 25	Income		90.00	440.00
Mar 30	Expenses	15.00		425.00
Apr 1	Balance			425.00
Apr 5	Wages	80.00		345.00
Apr 10	Expenses	50.00		295.00
Apr 15	Income		140.00	435.00
Apr 20	Expenses	25.00		410.00
Apr 25	Income		100.00	510.00
Apr 30	Expenses	20.00		490.00
May 1	Balance			490.00
May 5	Wages	90.00		400.00
May 10	Expenses	60.00		340.00
May 15	Income		150.00	490.00
May 20	Expenses	30.00		460.00
May 25	Income		110.00	570.00
May 30	Expenses	25.00		545.00
Jun 1	Balance			545.00
Jun 5	Wages	100.00		445.00
Jun 10	Expenses	70.00		375.00
Jun 15	Income		160.00	535.00
Jun 20	Expenses	40.00		495.00
Jun 25	Income		120.00	615.00
Jun 30	Expenses	30.00		585.00
Jul 1	Balance			585.00
Jul 5	Wages	110.00		475.00
Jul 10	Expenses	80.00		395.00
Jul 15	Income		170.00	565.00
Jul 20	Expenses	50.00		515.00
Jul 25	Income		130.00	645.00
Jul 30	Expenses	40.00		605.00
Aug 1	Balance			605.00
Aug 5	Wages	120.00		485.00
Aug 10	Expenses	90.00		395.00
Aug 15	Income		180.00	575.00
Aug 20	Expenses	60.00		515.00
Aug 25	Income		140.00	655.00
Aug 30	Expenses	50.00		605.00
Sep 1	Balance			605.00
Sep 5	Wages	130.00		475.00
Sep 10	Expenses	100.00		375.00
Sep 15	Income		190.00	565.00
Sep 20	Expenses	70.00		495.00
Sep 25	Income		150.00	645.00
Sep 30	Expenses	60.00		585.00
Oct 1	Balance			585.00
Oct 5	Wages	140.00		445.00
Oct 10	Expenses	110.00		335.00
Oct 15	Income		200.00	535.00
Oct 20	Expenses	80.00		455.00
Oct 25	Income		160.00	615.00
Oct 30	Expenses	70.00		545.00
Nov 1	Balance			545.00
Nov 5	Wages	150.00		395.00
Nov 10	Expenses	120.00		275.00
Nov 15	Income		210.00	485.00
Nov 20	Expenses	90.00		395.00
Nov 25	Income		170.00	565.00
Nov 30	Expenses	80.00		485.00
Dec 1	Balance			485.00
Dec 5	Wages	160.00		325.00
Dec 10	Expenses	130.00		195.00
Dec 15	Income		220.00	415.00
Dec 20	Expenses	100.00		315.00
Dec 25	Income		180.00	495.00
Dec 30	Expenses	90.00		405.00
Jan 1	Balance			405.00

## Beyond Mere Competence

YASH PAL, HFIETE

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**V**IKRAM Sarabhai was a humane and passionate visionary. He was an institution builder who accomplished an enormous amount in a short span of his working life. He deeply influenced the lives of all those who came in contact with him. He was a scientist who did some excellent work in the field of cosmic radiation and solar terrestrial relations.

He founded a remarkable institution, the Physical Research Laboratory that has contributed significantly to the growth of science in the country. In that institution he guided several PhD students. But there came a time when he was so busy that some research students could meet him only when he was about to go on one of his frequent train trips to Bombay. It was not infrequent for a student to accompany him in his car to the train station and, if the conversation was not done by the time train had to leave, the student would often travel with him up to Baroda and return later to Ahmedabad. I do not think any of the students resented this inconvenience, because they got an hour or two of real quality time with their guide, a period when Vikram would cut off from a thousand other concerns and become completely immersed in the problem at hand. I was personally very taken with this aspect of his character and capability. His ability of switching off to concentrate on one thing at a time was extremely impressive. All other worries were forgotten. The urgent decisions to be taken next morning, his scheduled meetings with the high and mighty, or the deadlines of an impending space launch, all of these disappeared. When you were with him he was totally yours. He remembered your problems and your worries more than his own. He was not just courteous. He was truly involved and seemed grateful that you involved him. Everyone came out refreshed and enhanced and not because he gave his blessings or false encouragement. He had an uncanny ability to make you realize that you were more than you thought you were.

He was instrumental in the setting up of the Indian Institute of Management, at Ahmedabad. Yet I doubt if his style and methods of management have influenced the pedagogy of management education. One does not even know the procedure one would adopt for framing a curriculum. I doubt whether his ways of working would meet the approval of present day yuppie managers, perhaps not even of the professors of IIM, Ahmedabad.

There is no question that Vikram was a very competent scientist. But his special imprint came more from other facets of his personality - features that moved him way beyond mere competence. He had a love affair going with whole world. This is what I heard Mrinaliniben say at a meeting in Bombay in early 1972, soon after his death. And I fully agreed with this assessment. It was an activist's love affair, not mushy. His affection enhanced everyone on whom it was showered. People were surprised by the confidence he placed on them. Ordinary humans moved by his irresponsible confidence, rose to fulfill his vision. In turn they acquired a shine on their own personalities that no one, including themselves, had suspected was hidden within them.

It is nearly thirty years from the time Vikram left us. I would like to remind you some of the things he conceived and came to do - things that seemed to lie outside his formal responsibilities.

He was chairman of the Atomic Energy Commission. He had already taken on the responsibility of developing space activity in India. India was passing through a phase where we lived ship to mouth, with large imports of grain from the US. Green revolution had not quite happened, but it was clear that unless we did something to grow more food our future would be bleak. Amongst other efforts the need for communicating with the farmer became most urgent. Vikram thought about television. There was skepticism. Even if money could be found what was the assurance that the programs would have any impact. That is when the experiment of community television was born. The initiative came from Sarabhai, who managed to network with All India Radio, ministries of agriculture and rural development through the good office of the planning commission. TV sets were acquired by the Department of Atomic Energy and the program was planned and executed through a group of experts. That is how television came to India. Since there was only one transmitting station available, it was installed in Delhi and the villages were spread out within the reach of the transmitter. The program was the Krishi Darshan and it is a marvel that it is still going on under the same name. There have been arguments about the extent to which the program succeeded. But this program made a clear statement that if a powerful technological development comes on the scene there is an ethical requirement that it be crafted into a form

that gives power to those who are most powerless. To give substance to this vision many additional innovations are needed and many new capabilities have to be developed. Even when the basic technology is obvious, methods of social communication and evaluation do not fall from the skies, nor are they directly taken over from those trained in the culture of advertising. All these categories began to grow and in every aspects of this adventure one could see the intense involvement of Sarabhai.

It was the way of thinking that drove Vikram to the belief that India should have a space program whose basic driving force would be societal. The blue prints of the Satellite Instructional Television Experiment grew from this source, as did the final configuration of the Space Program. The boldness of the Sarabhai vision was truly astounding for a time when we had no experts, little resources and no international precedent. But his stance and passion were so infectious that he gathered enthusiastic young people around him, and he was able to persuade the Governments to accept this as a program. He was also able to persuade a hard-nosed organization like the NASA to collaborate. And it was collaboration of a kind hard to imagine in the world of today. Perhaps NASA of that time already had a few starry eyed people like Sarabhai, perhaps they also got infected by the vision, charm and enthusiasm of this unique human being. They agreed to modify for our purpose and commit for our use their most ambitious technology satellite of that era, a satellite that was still on the drawing board when Sarabhai talked with them. There was no transfer of funds: They provided the satellite and involved our people in ensuring that the component that we would use was according to specifications jointly developed. We were responsible for the technological development of the ground segment - earth stations, community receivers, including the low noise amplifiers, and deploying and maintaining them in thousands of villages across the country. We also had the total control and responsibility for producing the software and for the extensive social and technical evaluation of the "greatest communication experiment in history", as Arthur C Clark called it. It is not my purpose here to give any details about how this experiment was done, what was achieved and what it led to. It is enough to say that though the actual experiment happened four years after Sarabhai left us his spirit fuelled this mad enterprise. I call it mad because beyond dreams and a passionate desire to do things oneself we did not even have a project report. We just had a broad budget but the directions we chose and things we accomplished were influenced by what we learnt as we went along. If we had prepared a detailed project document we would have felt imprisoned. We did follow all the management practices, with milestones and PERT charts, but they were for components of the project. But we felt free to adjust the components so long as the objectives of technology development and the social goals were only enhanced, never sacrificed. In this regard every participant was an internal auditor.

Sarabhai did so many things and gave the vision for so many others that happened after he was gone that it is not possible to discuss most of them in this short presentation. However, I would like to mention the episode when he fought to get the responsibility for building India's first Intelsat earth station at Arvi. India had no track record of building large antennas. The station was to be imported and the responsibility for this area was that of the communications ministry. On the face of it the Department of Atomic Energy had no business butting in. But that would not stop Vikram. He sought out people from defence, from academic Institutes like the TIFR and also from the ministry of communications to show that the job could be accomplished in India, using the academic and industry capabilities already existing and those that could be developed. When people went to the prime minister to argue against taking a risk like that he asked her. "if our own country does not give us challenges who will". That clinched the issue. Arvi was built and lot of capability developed for things to be done in future. In these days of liberalization and globalization wanting to do it oneself has ceased to be convincing arguments. Shop windows or arsenals full global things from outside hide the fact that we are designing and building less and less ourselves. Indeed the difference between 'bringing in' technology and 'creating' technology is not even understood.

This is what worries me even in regard to communication and information technology or, for that matter, the whole area of electronics. We seem to have given up on establishing a base for ourselves. We are much too impressed and overawed by what others have already done. We think that nothing is left and if it is, then it is not our responsibility. In between there was a period when the C-DoT initiated and pushed. The hurdles on the way were overcome but the progress has certainly been delayed. Similarly the initiative of Jhunjhunwala of IIT Chennai incompletely utilized.

I do not know why we start nitpicking when something local begins to develop beyond a threshold. I am sure there are other influence, but a conviction that something beginning to grow here is precious is also absent. Such a conviction is the precondition for ensuring that new communication and information technologies do not end up increasing dependence in the long run. If we are going into globalization then we have to claim at least a small part of the globe for ourselves. This cannot be done only through cheap labour, using the IT-enabled service sector route.

I have always believed that being engaged in technology creation is like a 'karma'. Any society not so engaged is bound to become a permanently dependent society. There is no content in an Independence where some of the crucial elements of the technological support systems are not designed and built within the country. God has not ordained that every thing new must come from

outside. Without ever alluding to the Tehalka tapes we are all aware that there are powerful lobbies whose interest lies in getting things from abroad. This is not new. Our technological establishments and our industry like to ride on the popular brand names - made popular through advertising, through brainwashing and by word of mouth of middle men. If our experts do not go all the way, if they do not find enough support from industry or the Government, they end up being agents and touts for things produced abroad. This particular enterprise has gained additional respect in the name of globalisation. That is why I would like to go on stressing the need for going beyond mere competence.

There is another reason why I have become a little vary of narrow experts. This applies not only to us but also to the rising influence of super-specialists all over the world. It would be best if I express my ideas in this regard by quoting from my remarks at the valedictory session of the Space Generation Forum organised at the time of the third United Nations Conference on "Peaceful Uses of Outer Space" held in Vienna in 1999. That was addressed to one set of experts. With due modification the remarks might be relevant to the experts within the IETE community. Here goes:

#### **"Space Generation Forum" - Closing Lecture by Yash Pal**

Space is about perspectives, the long vision, both in space and time. So is science in general, especially astronomy, geology, biology and archaeology.

Those who get hooked on space should get more connected with the planet and its inhabitants, not separated or alienated.

As for many other technologies, in space also common solutions do not work for everyone.

Even the laws of nature cannot provide you results unless the initial conditions are entered in properly. The classic example is long range weather prediction.

We have to realize that the world is very unequal and getting more so every year. This is a formula for ultimate disaster.

In devising our solutions we have to introduce specificities. This is seldom done. If the common solutions do not work we blame society! That is arrogant.

Everyone has a right to be a participant, not just a spectator or a potential beneficiary.

To give a few examples: The Gramin Bank of Bangla Desh could not have been thought of or planned in corporate boardroom. A couple of other examples from India are the programmes of the self-employed women's association and the milk revolution brought about through the dairy cooperatives following the example of Amul.

Specificities get in automatically if we engage in a number of end to end programmes, or missions. This is particularly required for space projects that are meant to ultimately benefit the common man or woman. This may often require meddling with things that are not in your department. Do so.

The building, intensification and widening of the super highways of information and communication are important. However, the world cannot be all super highways. That would be drab, uninteresting and diminishing. We need a large number of footpaths—tracks and trails. These are made by people walking, along slopes they can manage, in accordance with their whims, needs and inclination. How to make walking easier, more attractive? Depends on the terrain. This is different in different geo-social territories. So we come back to specificities.

Specificities will always remain. They should remain. The human animal grows in intimacies. It requires intimacy.

The challenge is to situate these intimacies in the global template we now have become aware of. And those we will in near future.

Without a cosmic vision, the space vision, intimacies can become, have become, parochial adversarial and, often, destructive.

I have come to a paradoxical conclusion intimacies are vital for human flowering, but they become sustainable only when there is a cosmic vision. In a cosmic vision cultural diversity would be treasured. It would be celebrated, not feared or offended. It would be seen as a heritage of whole humankind, a heritage to delight in. Those who would 'cola-nice' the world, and make it uniform, do not understand this.

Just look at some of the conflicts in the world today - Ireland, Albania, Serbia, Kosovo, many in Africa, the middle East, India, Pakistan, Sri-Lanka, East Asia, also Americas. Most of these have arisen because intimacies feel threatened. Much like living organisms they respond with unduly strong immunological responses. This often exacerbates the situation even further and cycle continues.

We have to realize that globalizing efforts to rub out the intimacies will make the situation even worse. We have to learn to place them on global canvass, a cosmic canvass, with space vision.

Who would bring in the world of space vision? You can but on one condition. Do not become mere experts. Design and build your space systems, go to the Moon or Mars, build solar power satellites, bring in ever new and cunning devices to improve communications, and many more things. But do not become mere experts. Such people can be rather dangerous. This is not to say that those who

are not experts in anything cannot be dangerous, besides beings redundant. Many academics, politicians and diplomats also belong in that category. There are moments when I wonder whether I am also a member of the same fraternity.

Your vision comes through your expertise and your passion, only if you are not imprisoned by your expertise. Do not be seduced into believing that the well-being of this earth, including the spiritual and ethical climate of the planet, is a concern that belongs in another department.

This is not just an evangelical sermon. I have observed your enthusiasm, your striving spirit, your capacity to

dream and your capabilities. There are innovations waiting to be discovered, science to be done and technologies invented. Engage in all this but do not let go of your space vision and a deep respect for specificities. If you do let go you may still have a successful future but your success will be limited and not up to your real potential. I urge you to seek your potential.

You belong to a group that could begin the task. There is a possibility of unprecedented personal fulfillment in the venture. I command it to you.

Remember. The space vision implies that from now on the whole earth is the responsibility of the whole earth.



1858 – 1937

*SIR JAGADIS CHANDRA BOSE* was a physicist who was well known for his path breaking invention of millimetric electromagnetic waves. He became professor of Physics at Presidency College, Calcutta when this post was given only to Englishmen. He had an unique personality; Always on the look out for new ideas.

He set up a Laboratory for his research work with the Instruments designed and assembled with his own money in a small room of Calcutta University. He had successfully generated and transmitted wireless at very short wavelength almost at the same time as Marconi did. Marconi was able to announce his research work and show how wireless Telegraphy worked, earlier than Sir J C Bose. However, Royal Society of England recognized his work in 1896 through his Research article on "Electro-magnetic waves" and Professor Bose was honoured with the degree of Doctor of Science. Calibre of Dr Jagadis Chandra Bose as a scientist was recognized by famous scientists of his time like Marconi, Neil Bohr, Rutherford, Righi etc.

After 1900 his attention was primarily devoted towards intensive study of the behaviour of plant tissues under different types of stimuli which led him to devise many remarkably delicate measuring and recording instruments having one to ten million magnification, almost 100 times more sensitive than the contemporary instruments.

In 1995 exactly after hundred years of Sir J C Bose's demonstration of generation and transmission of electromagnetic waves, the IETE paid a fitting tribute to the illustrious and pioneering scientist of India with the initiation of a new lecture series in his memory. This lecture is held every year on 30th November on the birth anniversary of Sir J C Bose at the venues alternating between Delhi and Kolkata each successive year.



## From Short Waves in the Laboratory to Communication Revolution Across the Globe

U R RAO

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**I**T is indeed a great honour to be invited to deliver the third J C Bose Memorial Lecture, whose name has become a sacred legend in the field of communication. Sir J C Bose's monumental scientific research work spanning over four decades began around 1890 with his truly pioneering research on the generation and transmission of short electromagnetic waves. After 1900 his attention was primarily devoted towards intensive study of the behaviour of plant tissues under different types of stimuli which led him to device many remarkably delicate measuring and recording instruments having one to ten million magnification, almost 100 times more sensitive than the contemporary instruments. This he achieved under primitive workshop facilities available in Calcutta at that time, is indeed a remarkable achievement by any standards.

The story of electrical communication begins with the brilliant work of Heinrich Rudolf Hertz who first produced the electromagnetic waves in 1888, a spectacular confirmation of Maxwell's theory. Unfortunately Hertz died at the young age of 37 shortly after which Lodge in his commemorative lecture at the Royal Institution in 1894 described the work of Hertz which greatly influenced and prompted many young scientists like J C Bose, Rutherford, Righi, Marconi and Popav to start serious work on the generation of electromagnetic waves in different countries. J C Bose was the first to succeed in generating electromagnetic waves of 5mm wavelength which he communicated to Asiatic Society of Bengal in May 1895. His spectacular demonstration of transmission of these waves which travelled through air over several meters, penetrated a wall, rang a bell and finally exploded a mine placed in a closed room in the Town Hall of Calcutta in 1895 in the presence of a large gathering, was as dramatic as the originality of his work. He continued his work on the production of 5mm to 25mm radio waves and conducted detailed study of their optical properties, the fascinating story of which can be read in his collected papers he published himself, with a foreword from Sir J J Thompson. Sir J C Bose rightly belongs to the class of Hertz, Marconi and Popav whose work carried out a century ago forms the basic fountain of flame which sparked off the third wave communication and information revolution with the onset of space age. As my humble tribute to this great scientist, innovator and discoverer, I have chosen to talk on the

development, challenges and prospects of satellite communication in India.

Detailed and careful investigation of the optical properties of the electromagnetic radiation, their reflection, refraction and polarisation characteristics by Sir J C Bose was far ahead of any contemporary research including that of Marconi, Lodge and Popav which rightly brought him the title "Father of microwave analogue optics". The practical applications of millimeter microwave waves for long distance communication however had to wait till the onset of space age. Even with the coming of the radio at the turn of the century and extensive investigations of the properties of ionosphere which could reflect and bend radio waves for long distance communication, the frequency of usable radio waves was practically limited to 30 MHz or 10 meters, below the critical frequency of the ionosphere. The use of higher frequency in the range of several GHz for global communication, to achieve better signal reception over RF noise, increased bandwidth for higher data transmission and higher overall gain which essentially improves as inverse square of wavelength, had to wait till the availability of space platforms.

It took more than half a century after Tsiolkovsky's presentation of his ideas on the launch of artificial satellites circling the earth, before the recognition of the possible use of such satellites as repeater platforms for global communication and broadcasting. It was left to the great visionary Arthur C. Clarke to point out that an artificial satellite at a height of about 35,800 km over the equator would make one revolution every 24 hours, and hence would remain stationary above the same spot on the earth providing communication visibility for over a third of the Earth's surface. Three repeater satellites, 120 degrees apart in the geostationary orbit, could provide television and microwave coverage to the entire planet. In 1945, when this concept was first proposed, the artificial earth satellites were still in the realm of science fiction. Today, in less than fifty years from that enunciation, artificial satellites are supporting a multibillion dollar high technology international business and in fact are significantly affecting the life of mankind in several ways.

The successful relay of TV signals across the Atlantic in 1962 using Telestar, the first active repeater communication

satellite, ushered the satellite communication era. The remarkable developments in space communication in just three decades since the launching of the first operational communication satellite 'Early Bird' (Intelsat-1) in 1965 has brought us to the threshold of achieving the capability of establishing global human connectivity even to the remote corners of the world. The evolutionary nature of communication satellites is evinced in their increased capacity, from just 240 voice channels in 1965 to the present day satellites which on an average easily carry over 20,000 voice circuits, along with several TV channels. This remarkable growth is well reflected in the growth of INTELSAT, which has gone through seven generations in just three decades and is now operating more than 900 earth stations located in 180 countries and territories. In addition to international and regional satellite systems, a large number of countries including a number of developing nations have now established domestic communication network with their own dedicated satellites. The inherent advantage of satellite communication systems, which can cover wide areas from their vantage point in space and establish extremely reliable connectivity even with distant and inaccessible areas, makes them ideal for point-to-point, point-to-multi-point and for multi-point-to-point applications. Satellite networks not only offer a high degree of flexibility to meet the requirements of changing needs through reconfiguration but also have the distinct advantage over other media because of their ability to aggregate small requirements spread across vast territories to provide cost effective specialised services.

### SATELLITE COMMUNICATION REVOLUTION IN INDIA

Realising the potential benefits of satellite technology, ISRO first carried out an year long "Satellite Instructional Television Experiment (SITE)" in 1975-1976, which marked a major milestone in harnessing satellite technology for taking audio-visual education to 2400 remote rural villages. SITE fully demonstrated the capability of satellite communication to promote rural education in health, hygiene, better agricultural practices, family planning etc., thus establishing the relevance of satellite communication for achieving all round development and eradication of literacy. Following the success of SITE and its own experimental geostationary communication satellite APPLE which enabled the conduct of an end-to-end experiment, ISRO initiated a communication revolution in the country through the successful launching and operationalisation of INSAT series of multipurpose communication satellites, to provide continuous nation-wide services in communication, TV broadcast and meteorology. The successful launch and operationalisation of totally indigenously built INSAT-2A, 2B, 2C, and 2D, second generation satellites, each having 50% more capacity than INSAT-1 series, marks complete mastery of India in the state-of-the-art satellite

technology. The second generation INSAT-2 series have also added search and rescue as well as geostationary personal mobile communication services into the INSAT network.

Over the years INSAT system has grown rapidly to become one of the largest domestic satellite system in the world providing multitude of communication, broadcasting and meteorological services even to remote areas and off-shore islands in the country. With about 6000 two-way speech circuits covering 170 routes and an extensive ground network of 280 fixed and transportable earth stations, the nationwide geographic reach of INSAT has been advantageously used for a variety of applications such as administrative, business and computer communications, Remote Area Business and Message Network (RABMN), facsimile transmission, and emergency communication. One of the most innovative use of INSAT has been the implementation of the unique, unattended, local specific Disaster Warning System (DWS) consisting of over 250 DWS receivers deployed in selected, cyclone prone east coast areas of the country, which have been saving thousands of lives and livestock every year. The National Information Center's Network (NICNET) has established extensive data communication links inter-connecting district headquarters, state capitals, and central government departments using over 700 VSATs. The recently liberalised policy of privatisation of VSAT network/service through licensing of dedicated or shared hubs has provided the much needed impetus for the explosive growth of high speed VSAT's to meet the communication requirements of industrial establishments, service providers and other closed user groups. Within a short period, the number of operational VSAT's has already crossed 500 and is continuing to grow at a phenomenal pace, doubling every year.

Most dramatic impact of INSAT has been in the rapid expansion of TV dissemination in the country through installation of more than 850 TV transmitters providing access to over 87% of India's population. Regional Networking Services have already been implemented in many states of the country. Use of transportable earth stations such as Satellite News Gathering (SNG) vehicles now enable extensive real time coverage of all important events in any part of the nation. Two exclusive development communication channels are now being operated to feed over 500 distant education training class rooms spread across the country and several state government are establishing their own uplinks.

An effective educational system requires not just a one way system of instruction but a two way interactive communication system to enable the target audience to ask questions and obtain clarifications from experts, in real time. Selected large scale experiments using inexpensive talk back facilities have been conducted to demonstrate the effectiveness of the satellite media for imparting interactive

education. Three such experiments were devoted to provide instructions on better agricultural practices to farmers in Bhiwani, train village officials and social workers in the Rupal village of Gandhinagar district in Gujarat and training women panchayat officials in rural Karnataka. In association with UGC and IGNOU, a number of experiments were also successfully carried out to provide interactive education to students located at widely dispersed areas across the country. Under the continuing education programme, refresher courses were provided to shop floor workers in selected industrial establishments and to the junior staff of various banking institutions. Encouraged by the success of these, a large scale experiment has now been mounted in Jhabua district of Madhya Pradesh with 150 receive terminals for promoting development in predominantly tribal areas. While these experiments have demonstrated the practical feasibility of adopting such an interactive system for rapid dissemination of education, eradication of illiteracy as a goal requires the establishment of a virtual class room across the entire country through dedicated satellites, specially tailored to effectively disseminate culture and region specific information to each individual language groups and region entities. The launching of GRAMSAT in the next two years should enable us to achieve the goal of establishing extensive education and information networking across the entire nation.

#### FUTURE SCENARIO

Extraordinary developments in coding and video compression techniques now permit transmission of video programmes at very low bit rates for most economical use of the space segment. Significant reduction in the cost of satellite communication has been realised with the ability to transmit eight to ten TV channels on a single transponder which can be received on the ground with antenna dishes as small as 45 cms. Advances in video compression techniques today permit transmission of CD quality stereo programmes at 192 kilo bits per second and video pictures at less than 4 mega bits per second, which are bound to have a dramatic impact on satellite based educational and development services. Availability of about 200 channels from a single satellite location can entirely change the complexion of home entertainment. The spectacular developments in satellite technology allows dynamic allocation of bandwidth in each transponder for multiple channel transmission, by automatically adjusting the bandwidth requirement depending on the information and frequency content of the programme. The emergence of satellite based digital audio broadcasting which can be received anywhere with simple, low cost receivers is expected to revolutionise radio broadcasting technology. Capability to electronically switch spot beams at will on a dynamical basis with complex antenna systems to cater to various specific requirements has further enhanced the flexibility of satellite communication systems.

Availability of smaller and cheaper VSATs has already brought in 280,000 users into the network globally and is threatening to expand to cover millions of users. Innovative uses of VSAT combined with the developments in advanced modulation techniques such as TDMA, DAMA and compression technologies have already resulted in the introduction several value added services including video conferencing, multimedia services and internet access. Simple low cost systems incorporating a CCD mini-camera and voice-over data at 28.8 kbps are already in the market to provide videophone tele-conferencing systems using "Plain Old Telephone Service (POTS)" lines to transmit digitally compressed video and audio signals. Globally households using two-way video communication are expected to increase to five million by 2000, and fifty million by 2010. By 2020, two-way video communication is expected to become as commonplace as telephone and television. Virtual reality will no doubt become the next generation communication service within the next two decades.

Convergence of powerful personal computers with communication has made it possible to store, access, and disseminate vast amounts of information and data, enabling planners, scientists, technologists and policy makers to quickly respond to rapidly evolving events and situations. Micro computer systems with the capability of executing 10 giga bits of instructions/second are already available in the market. Transmission technology has been revolutionised with the use of network topologies, decentralised switching and multiplexing systems with high bandwidth, self healing ring architectures. Widespread use of wireless loops in local exchanges have facilitated speedy expansion of direct exchange lines. Computer communication, distributed processing systems and the ability to network all these have contributed to the substantial improvement in the spread of communications on a global basis, at the same time reducing the cost for exchange of information. The information revolution being initiated by Internet is one example of the spectacular changes taking place in communication.

Digitisation of information flow together with the video compression technology have virtually removed the distinction between TV, telephone and data dissemination resulting in the emergence of a whole new industry based on multi-media technology. Multimedia services involving trillion bits per second to transmit high resolution video, three dimensional images, voice, and data communication in different desired combinations have now become feasible. Multiple access protocols have been successfully developed to interconnect Local Area Networks (LAN) with wide band Wide Area Networks (WAN) and Metropolitan Area Networks (MAN) using low cost VSATs, to enable simultaneous transmission of high definition TV, digital data, voice, fax and internet services in Asynchronous Transfer Mode (ATM). Fixed satellite communication service, which only a decade ago was

considered to be of limited application, has once again gained importance as a multimedia service provider. Information on demand, video on demand, bandwidth on demand and direct to home television have become the common buzz words of the age of information super-highway, implementation of which on a selective basis is essential to enable India to successfully compete in the global market in the liberalised atmosphere.

Invariably all over the world, personalised communication is gaining ground for which the present satellite mobile communication is the precursor. The land mobile satellite systems with small mobile terminals are primarily designed to meet the requirements of the transport sector, emergency communications, and remote area communications, in a big way. Several Low Earth Orbiting (LEO) satellite systems such as the Iridium system of Motorola, Globalstar of Loral, Odyssey of TRW, ORBCOM of Orbital Sciences Corporation and Global ICO are under different stages of implementation for providing data, messaging and voice services to millions of users across the globe. The proposed establishment of large LEO constellations such as the Teledesic involving over 500 satellites in low earth orbit can effectively duplicate fibers in the sky. Latest entry in this venture is the Sky Station concept involving over 2500 geostationary stratospheric stations at 25 km altitude, which in principle can provide wide bandwidth communication facility either directly or through the public switched networking system in the 47 GHz band (6mm).

Emergence of truly mobile communication in the next two years will add a new dimension to the personal communication network to enable instantaneous access to individuals across the entire globe, through simple hand held communicators. The limited nature of the geostationary orbital resources combined with the requirement, of high power has been responsible for promoting the use of low earth and medium altitude orbits for global mobile personalised communication services, inspite of the requirement of larger number of satellites required for providing global coverage. Undoubtedly Global Mobile Personal Communication Services (GMPCS) will dominate the communication scenario in the next two decades. Consequently all usual satellite orbits, low, medium and geostationary will be used accompanied by a strong move toward the use of higher frequency Bose radio waves with wave lengths in the order of 1-10 mm, to avoid RF interference and orbit crowding problems. The choice of the orbit and frequency will essentially be based on compromised solution dictated by technological maturity and overall economic considerations. The addition of geostationary mobile communication service in INSATs and the proposal of ISRO to launch specifically tailored satellites for providing digital audio broadcasting and DTH-TV services are in keeping with the projected requirements of the country.

## IMPLICATIONS OF COMMUNICATION REVOLUTION

The phenomenal information explosion and the spectacular technological developments, particularly since the beginning of the space age four decades ago, have naturally led to the demolition of the second wave industrial society based on the mass education, mass distribution, mass media and mass entertainment. This has been totally replaced by a new and increasingly demassified society characterised by highly sophisticated knowledge centers, customised services, specialised production agencies and segmented niche markets. Explosive population growth, poor food grain productivity, limited agricultural land and lack of opportunities have inevitably resulted in the large scale migration of rural people to urban areas in search of gainful employment. If our country, with its limited natural resources and poor quality of life (ranked at 135 amongst 175 nations in the world), has to even maintain, let alone improve the quality of life of its people, we have no choice but to rapidly become a vibrant industrialised state. The total earning from exports from India is just about 33 billion dollars, less than a tenth of Germany which is ten times smaller than India, both in area and population. Rapid industrialisation has become essential to provide meaningful employment opportunities and economic security to the people which in turn requires rapid improvement in the communication to enable the country to compete in the global market. Unlike in the past, when predominantly agriculture based nations endowed with rich natural resources had the advantage, the comparative advantage in the globally integrated world economy has undoubtedly shifted to those countries with brain power, determined to absorb, adopt and assimilate the spectacular developments in science and technology and harness them for their national development. It is only through integral participation in the information revolution that our nation can hope to gain a competitive edge in the knowledge driven techno-economic world.

In the liberalised post GATT era, where governments, societies and individuals need to quickly respond to events and situations to enable them to compete in the global marketplace of interdependent economy, the paramount need is for timely collection, synthesis, analysis and dissemination of the vast data bank of information gathered from multiple sources. With the information being generated at the rate of 20 trillion bits a day, the accumulated information content of direct relevance is projected to exceed 150,000 trillion bits by 2005. In the words of Oltean, "The paradigm of today is the neo-encyclopedia. It is essential to have information of information, the so called secondary information". In this technology era, databases have become our modern encyclopedia and information has become the most powerful currency of power.

The challenges posed by rapid technological

obsolescence can only be overcome through rapid communication, instantaneous access to information and establishment of adequate database, without which neither the technological establishments nor the industrial undertakings can complete in knowledge-based integrated global economy. A properly developed information networking system has become essential to all industries for not only accessing latest technological information but also for efficient management including optimal management of stock inventory, monitoring of technological progress and interaction with their own subsidiaries and other business partners in a shared videoconference mode. The ability of satellite communication to act as education superhighway for imparting development education to remote rural area population is of greatest significance to a country like India where the percentage of illiterate people is still around 40 with more than 60% of female population being unable to read to write. Experience all over the world including in India as seen in Kerala, has demonstrated that only through improvement of literacy, we can realise decline in female fertility, better health care, enhanced agricultural productivity, increased industrial output and a vast improvement in quality of life. Information highway has made the entire world virtually transparent by providing immediate access to data and information anywhere in the world through internet connection, without compromising on the strategic and security aspects, which can be adequately protected through appropriate password and encryption mechanisms.

### ECONOMIC IMPLICATIONS

In spite of the spectacular developments in satellite communication in India with over 60 transponders operating in the sky, and considerable efforts put in towards modernization of ground infrastructure through development of a variety of digital switching equipment, sadly only one out of 80 people in the country today have access to a telephone as against one for every two persons in an advanced nation. The communication picture in the rural area is even more pathetic with over 2000 persons having to stretch across to have access to a telephone.

The full benefits from the rapid technological advances taking place in satellite communications and information networking can only accrue to the nation by appropriate restructuring of the administrative regulatory measures based on a clear appreciation of the necessity to rapidly establish flexible, pulsating organisations tuned to face the global challenges in the knowledge driven, globally integrated economy. Artificial distinction between basic telecom services and value added services such as closed user group networks, public data network, specialised VSAT services, video conferencing and business TV services have lost their meaning. Satellite telecom network has now become an integral part of the national and international network involving fibres, cables and satellites, demanding harmonious blending and seamless meshing of

these to provide multimedia services. The emergence of wide band multimedia communications has virtually demolished the distinction between video, audio, data, message, fixed satellite service and broadcast service, requiring formulation and adoption of flexible, market-place oriented regulatory measures through a coherent policy, based on the technological realities of the day.

Recognising the vital importance of modern communication infrastructure for development, the Indian Government finally departed from its policy of monopoly hold over all communication services based on the 1885 National Telegraphic Act. With the liberalization of telecom services through the enunciation of the new National Telecom Policy in 1994, many of the value added services such as electronic mail, voice mail, data services, audio and video text services and video conferencing have now been privatized. Video paging and cellular mobile services have also been privatized on a licensing basis. Privatisation, if properly implemented, can no doubt provide competent, highly reliable and user friendly efficient service to the emerging giant Indian Telecom market. This essentially means privatisation of TV broadcast services using Indian satellites, more liberal policies for rapid promotion of VAST networks, introduction of DTH and internet services on a large scale and avoidance of rigid restrictions regarding cross media censorship.

Introduction of interactive capability to the high powered DBS satellite, which can beam as many as 200-300 channels from a single location, is the obvious next logical step for promoting video on demand DTH service. DTH-TV service with internet access has the ability to bring the entire global information with network into the homes. A number of foreign operators such as Asiasat, Panamsat, Measat, Intelsat and Direct TV have already announced their plans to provide DTH-TV services to India. User awareness being at very high level and demanding, we have to recognise that the technological growth in telecommunication cannot be ignored any more and availability of direct-to-home television service in the near future is indeed going to be a reality. It is only through a proactive, development oriented and technically competent regulatory mechanism that we can protect the country's economic and strategic interest.

The prediction concerning the emerging global satellite telecom market indicates an astounding expansion in the coming years from the present 24 billion dollars a year to over 170 billion dollars a year by 2010. Even fixed satellite service which was considered to have reached its saturation only a few years ago has now become an important revenue earner because of the increasing demand on VSAT and multimedia services. Largest expansion is expected in personalised mobile communication and DTH services from 4 billion dollars a year to over 50 billion dollars a year by 2010. The bulk of the demand for communication services is going to be in the developing countries like India

because of the poor infrastructure presently available. Even based on a conservative estimate of the telephone density going up from the present 2 for 100 people to at least 10 per 100 by 2010, over 400 million telephones will be added in the developing nations, of which almost 80 million will be in India alone, as against a total of 100 million addition in all the developed nations together. The interest and pressure of multi-nationals to enter the Indian market in a large way is hardly surprising, given the magnitude of the emerging giant Indian market, estimated to be over 300 billion dollars for the next 10 years.

### CONCLUSION

The extraordinary discovery of centimeter and millimeter radio waves made by Sir J C Bose a century ago, combined with the spectacular advances made in space technology have today blossomed into a most powerful force for the advancement of the global society. Rapid communication, massive education and global information networking have emerged as the fundamental requirements for the development of a complex modern society of the

next millennium. The age of information superhighway ushered by the spectacular developments in space communication and associated enabling technologies on the ground, have for the first time in the history of man, opened up a vast spectrum of opportunities which can entirely transform the social, cultural and economic status of the entire societies. The merging of large computation and communication capabilities through technological innovations have paved the way for the establishment of seamless networks to provide personal communication and multimedia services, thus creating a world where communication, information, entertainment and motivation are literally at the will of one's finger tips. The dream of establishing instantaneous human connectivity anywhere on this planet, over the land, air or sea, has indeed become a practical reality. Given the talent, entrepreneurship and technical ability, amply demonstrated by our space scientists and implementation of liberal national proactive policies, India has the ability to become an important global player in the emerging gigantic global communication marketplace.

## Balancing the Indian National Interest in the Era of Globalisation: An S&T Perspective

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### 1. The Indian National Interest

1.1 We can take the following definition of India as a nation this evening, in the first place:

"A modern, democratic, secular, multi-lingual, multi-religious, multi-cultural, non-aligned Federation of States, committed to promoting the prosperity of its people in peace with equity"

1.2 We can also assume that the Indian masses, a melting pot, perceive a unique identity as part of the nation; a nation which they will defend against threats with all available resources.

1.3 Then, it follows that the threats to Indian nationhood could be both internal and external and be of a political, economic or military variety; created by neighbours or distant States as much as by internal actors.

1.4 It follows also that protection and promotion of India as a Nation-State has "core national interests" whose main elements can be listed as follows:

- protection of "inner core national values"

(mainly democracy, secularism, federalism, equitable economic development in a peaceful environment, independence in decision-making, eschewing of military alliances)

- protection of the sovereignty and integrity of the States from external and internal threats (military, non-military) with a defensive policy

- promotion of self-sufficiency in basic human needs and self-reliance in other areas.

1.5 This is necessarily a "broad brush" sketch. But then National Interest is broad-based and will cover a number of areas of national life and efforts. It is not "national security" alone in the sense of the military, the paramilitary or the police.

1.6 In the early decades, India pursued (rightly) an active international diplomacy in support of 'peaceful co-existence', freeing the colonial yoke and disarmament.

Some new areas of international concern which we have to address as we go along relate to the environment. Diplomacy, including economic diplomacy, is an important tool in protecting national interests - second only to the military forces.

1.7 It is obvious, again, that these national interests have to be pursued and defended by the Government of the day and the people through a spectrum of policies, practices and instruments.

1.8 To mix metaphors, there are indeed many, many orchestras involved in promoting "national interests" and the performance has to be in the nature of "massed bands". The need for "practice" to create more of harmonious music and less of cacophony is understood. But discordant notes do seem to occur, rather frequently.

1.9 To the extent that one of the defining sub-elements in India's self-sufficiency and self-reliance and national security is "technology", our ability to meet these threats successfully would depend quite strongly on our scientific and industrial infrastructure; apart, of course, from the policies of the State, its leaders and the led.

1.10 Creating, fostering and upgrading this important element of our infrastructure has, therefore, to be part of the set of "outer core" national values. Threats to this core value, whether caused internally or externally, must also be treated as national threats.

1.11 The "mid course" correction in our long journey on the road to peace and prosperity came in 1991 largely because of the way we managed our economy. This correction introduced "liberalization" and "globalisation" to a previously protected political economy.

1.12 We are still in the process of adjusting to this mid-course correction while trying to balance our "national interests" in this new era. The technology community is generally aware of what globalisation means and does. A summary of some of its main aspects, however, would be of use to place issues of concern in perspective.

1.13 Balancing the "national interest" implies that it is a dy-

*The views expressed here are those of the speaker in his personal capacity.*

namic, not static or static, act. It has to change with time based on internal and international developments. In 1991, we coined the imaginative phrase "continuity with change" to reflect ground realities of our political economy - a fairly substantial change with continuity lingering determinedly. Every change will be attended by vocal defence of privileged groups which prefer the "status quo". But, if the national interest - as opposed to sectoral or sectarian interests - is kept in focus, the nation ought to survive, if not thrive.

- 1.14 From the overall "technology perspective", this set of national interests implies that we would pursue "self-sufficiency" in basic needs (food, water, housing, mass health care, mass education, transportation etc). And self-reliance in industrial development. All in the "public interest". This, in turn, means that we have to promote activities that rise above exclusive group or sectoral interests; activities should in themselves and by themselves contribute to the larger national interest. Else, we would degenerate into an autocracy or oligarchy or similar unrepresentative and harmful regimes. These may have seeds of their decay and death, but as long as they last, we can kiss sweet goodbye to the public or national interest.

## 2. MAIN ASPECTS OF GLOBALISATION

- 2.1 There are many excellent tomes in recent literature on globalisation, most of them written by economists. (Economics is some times called the dismal science by economists!)
- 2.2 Engineers and technologists in India do have a feeling for economics. It is more difficult for classical economists in India to have a similar feeling for technology. Hence, the need exists for policy makers to listen to, or be suitably educated, before taking decisions. And, the national interest has to be "inclusive" with respect to technology. Like economists, engineers and scientists may have had a multiplicity of relevant views, but a "consensus" can be fostered and achieved.
- 2.3 We shall assume the following definition in addressing national interests here:
- "Globalisation is the expansion of economic activities across national borders to facilitate progressively higher integration, openness and inter-dependence between national economies".
- 2.4 The push towards Globalisation has its recent origins in 2 main factors:
- barrier lowering in trade and commerce
  - new organisation forms and management styles spawned by the 'communications' revolution.
- 2.5 Financial liberalisation (or 'globalisation of finance')

occurred at a "scorching pace" in the mid-1980s and has followed trade liberalisation. Though I am not convinced of a "cause-and-effect" relationship between them. Can we scientifically generalise on a limited set of data points?

- 2.6 But, these types of de-regulation and liberalisation have not visited the international technology scene; however desirable and equity-driven the developing world may feel it to be.
- 2.7 Advanced technologies, though having a short half-life, underpin the "economic advantage" of technology developers, in general.
- 2.8 But controls of a commercial and political nature are also brought to play to protect the perceived national interests of such developers and their countries. The economic and technological distance between industrialised and industrialising countries would increase with time, not decrease - unless we are vigilant.
- 2.9 The "inter-dependence" factor in the definition of Globalisation would be interpreted conveniently and selectively; more to individual, rather than mutual, benefit. Its substance, as opposed to the shadow, needs to be secured through diplomatic and technical tools.
- 2.10 A fillip to the virtues of "capitalism" came suddenly and unexpectedly with the collapse of USSR. The catastrophe arising from 'perestroika' has been called 'catastroika' and has cast long shadows on the Indian landscape; especially in defence preparedness and in bilateral trade involving a number of commodities.
- 2.11 The Soviet fall was proclaimed as the triumph of market economics over central economics and hailed as the "end of history". If Russia did not have nuclear vectors or had not reached remarkably high levels in technology, one wonders what USA and the West would have done. The fall has caused continuing head-aches for the developed world on the disposition of nuclear materials, and manpower. Perhaps, for other nations too.
- 2.12 The Soviet experience reveals that, holding the high ground in weapons technology at some social and economic costs, does not guarantee national progress; or indeed survival. This ought to be a sobering observation for those in India who look for "technology solutions" to "social problems". Technology is a tool, only a tool. Not a magic wand. There is a large number of other issues in using technology to transform traditional societies.
- 2.13 But is the fall of USSR the end of history? Not likely. Possibly only a chapter has been closed in the continuing serial called the history of nations.

- 2.14 New chapters may well be written; containing the victory of modified welfare economics. New chapters may well highlight the re-emergence of the importance of the State in a number of socially vital areas where the obsession with profits and return on investments would see the marked absence of market economics. The convenient "one size fits all" formula which some countries after 1991 would like to see for "risk reduction" does not, in my view, fit all nations; indeed even individuals. Ask Cinderella's sisters.
- 2.15 One of the more important side-effects of Globalisation appears to be the waning of the authority of the State and its ability to withstand pressures, be they from powerful nations or international financial institutions. Market intervention by the State is not considered as efficient.
- 2.16 And, new theorists assert that the decision-making systems of Governments with the mandated compulsion of "checks and balances" on behalf of the electorate are archaic where "business decisions" have to be made at the speed of light. Aren't these the days of "electronic commerce"? Perhaps so. But there is a need to realise also that risks taken by individuals or private firms cannot be, indeed should not be, taken by Governments. Check with the Governments and companies of developed countries. Even in USA, the "Business of Government is not fully the Government of Business". A tempting generalisation which loses sight of the American social agenda to win, and continue to win, elections.
- 2.17 There are reasons why, despite "preaching" the cause of reduced Governmental intervention in the marketplace, the developed countries are "practicing" a rather realistic policy in high technology issues. We in India, therefore, need not feel hypocritical or ashamed if we defend our national interests, taking a leaf or two from the shop-soiled manuscripts of the developed world.
- 2.18 There are recent cases where enforced "structural reforms" have led to increasing the difficulties of the masses; ultimately leading to the fall of Governments.
- 2.19 This is not meant to endorse incorrect financial policies in pursuit of the "urge to say in power". But to highlight the concern that overdue reforms need not wait for the external warning shot. We need not either panic or surrender on the first shot being fired.
- 2.20 New actors have also entered the crowded scene though the so-called "Social Clause" and the "Environment Clause". They have to be factored in.
- 2.21 Globalisation has been called the 'final frontier' of capitalism which has been reached or breached because of the "convergence" of the activities of Trans-National Corporations (TNCs) in trade, production and investment with the participation of international banks. The conducive climate has been created by the politics of hegemony, according to respected experts. All in the name of "political risk management".
- 2.22 An interesting parallel has been drawn with the economic policy in the age of colonialism. It was called 'laissez faire' and characterised the period 1870-1914.
- 2.23 Then, the investment flow vector, both in direction and magnitude, was different. For instance, in 1914, 45% of investments occurred in the colonised or under-developed world. Raw materials and primary goods went from these countries while manufactured goods were brought in. A host of inter-sectoral trade patterns. But today's Globalisation is different:
- (a) The primary sector is less important while manufacturing and trading have become more important. Further, there is more intra-firm commerce than intersectoral.
  - (b) The imperial period had no 'labour flows' restrictions. 50 million went Europe to the New World; and 50 million indentured labour from the colonies worked on railroads and plantations. Today's world is very restrictive.
- This is not a nostalgic whine in favour of such migration or labour practices. It is meant to highlight visa restrictions enforced in the era of globalisation.
- 2.24 The exercise of catching up with the developed West has been undertaken, of course, by the developing countries. Recent success stories in Asia include Taiwan, South Korea, Singapore and Malaysia. This was thought unattainable because of they were supposed to lack the "scientific culture". Disproved; though there are reasons to believe that the national policies of these Governments as much as geostrategic alliance/partnership considerations have contributed to their "success". But the fragility of these East Asian miracles, held up as models until recently for other developing countries, has starkly focused on the real problems of not having a democratic system. The comforts or returns from "crony capitalism" are short-lived; and, capital account convertibility has its documented perils.
- 2.25 Are "Technology Issues" important to the State in the process of Globalisation? Indeed they are.
- 2.26 Let us assume that "high technology" means that it is either capital-intensive or technology intensive or whose access is controlled for a variety of non-trade reasons. Typically, hitech encompasses today areas like sensors, robotics, micro-electronics, telecommunications, information technology, biotechnology,

- materials, pharmaceuticals, manufacturing, energy and propulsion. What would, or should, be the reasons for State action in high technology matters, when globalising?
- 2.27 Assume that a private firm has a hitech product (or commodity); invented a better digital mouse trap or, indeed, a better mouse through genetic engineering. It cannot keep the technology embedded in its products fully "private" for too long. Competitors will make their clones, substitutes or whatever; or even indulge in counterfeiting. Should we say also that, since the example taken is one of a mouse or a mouse trap meeting a potentially global market, there is bound to be an uncontrollable 'rat race'.
- 2.28 The firm, then, may not be able to reap maximum returns. And may not possibly invest substantially, or continuously, in research or upgrade production.
- 2.29 This would have an impact on common domestic concerns of Governments like employment and Balance of Payments (BOP). Recall the "chip wars" between USA and Japan. Hence, Govt action or intervention would be justified in the name of "public welfare". This action could include subsidies, Govt procurement policies and protection by another name. It may be like the Pope throwing away the Bible. But pragmatism rules, OK?
- 2.30 In US, Europe and Japan these became matters of "domestic political concern" and policies geared to "nurture" high technology industries have emerged. But the barriers erected by Governments can successfully impede technology and/or financial flows to the larger benefit of domestic constituencies. Should it not be a matter of considerable interest to India as well?
- 2.31 A new, convenient "Convergence Club" has come into being in the developed countries. Club formation has occurred because of education level, technology infrastructure, management skills, political relations etc; add technology diffusion and financial flows, after World War II, largely from USA.
- 2.32 More significantly, after the Gulf War, this Club has agreed on "shared concerns" about "proliferation issues" and the need for control of "dual use" commodities or technologies. There is considerable and interesting overlap in membership of "Technology Control Regimes" like the Australia Group, the Nuclear Suppliers Group and the Missile Technology Control Regime. These regimes are interesting from the diplomatic angle as well. They are orchestrated "private arrangements" outside UN processes using the ruse of national legislative action. Possibly, many in USA have forgotten one of the principles they fought for in their struggle for independence: "no taxation without representation". But then, is it surprising that USA prefers the "private club" over the UN debating club? If "tyranny of the majority" is uncomfortable, does tyranny of such private clubs and arrangements constitute permissible international duress? How much can the UN do, today, in these matters?
- 2.33 It is important that we recognise that developed countries do not speak with one voice. They have their internal differences. Recall the dispute about agriculture subsidies between France and USA.
- 2.34 "Ganging together" against another country or group of countries by way of "sanctions" or export controls has not always been effective; or lasted long. There is considerable evidence from contemporary history. And, the experience after the May 1998 events bears testimony, if testimony is indeed needed. The nation has to balance, of course, the worst possible scenarios with the best - and the realistic. To be led by the "worst case scenario" alone and shrivel from taking difficult decisions is a prescription for continuous Hamletising in matters of importance to the State. The leadership alone cannot be faulted in this regard; the "advice industry" in India has its share of agonising soul-searching to do as well.
- 2.35 The changing composition of trade in recent times among developed countries has been well studied. There is considerable international rivalry for market share and to benefit from economies of scale. Indeed, this rivalry has increased because of rise in fixed costs in R&D; and, reduction in the time to market. Management techniques like "rapid prototyping", "concurrent engineering" and "flexible manufacturing systems" have addressed these concerns, partly.
- 2.36 The role of TNCs (Trans-National Corporations) in "globalisation" has to be noted in this connection. Their Foreign Direct Investment (FDI) during 1975 - 1985 gave globalisation its name and content. Noteworthy also is the fact that about 60% of US merchandise exports in 1992 were intra-firm transactions. "Technology flows" (measured via royalties and fees) during this period had an annual growth rate jumping from 0.1% initially to an astonishing 19%; a factor of 19.
- 2.37 TNCs appear to have learnt, in the short period we are talking about, that trade and investment are essential and complementary in globalisation. But there are no clues as to how long this perception will last. Bilateral relations - touching political, economic and security issues - will continue to have a strong influence despite the much-publicised "independence" of TNCs in investment decisions.
- 2.38 There is also a "technology-security" nexus which

should not be lost sight of. The era of globalisation is also the era of sanctions; if one doesn't fit into the geo-strategic calculus of some powers or pursues a line independent of their policies.

2.39 The play of controls over "dual use" commodities and national legislations of some countries has invited some concern in India. The recent inclusion of some private companies as "entities" involved in "proliferation" activities by the US Dept of Commerce invites a comment. It has to be understood clearly, that Govt has the full capability to be autarkic and undertake work that is farmed out to Indian private sector. In good faith, we have tried to avail the infrastructure in the private sector to avoid unnecessary vertical integration within government. The private sector need not panic or abdicate. Such countries use the private sector extensively and obvious "double standards" have to be highlighted.

2.40 In the early days of the Cold War, the COCOM (NATO minus Ireland plus Japan) focussed on technology denials to Communist countries so that the relative 'western' technology edge was not diluted. Over time, commercial aspects have exposed cracks in the group. Trading with China opened up in the 70s. With the collapse of USSR, COCOM has been replaced by Wassenaar Agreement which addresses "dual use" commodities and technologies. The export control lists of USA and Wassenaar shows close harmonisation, though there are some obvious differences like "country lists".

2.41 The G-7 countries are more strongly focussed, after the Gulf war, on "proliferation" issues (chemical, biological, nuclear, missile). But that's another story. Suffice it to mention that the "technology-security" nexus has become stronger. In the US Export Administration Regulations, "national security" and "regional stability" are among the "control reasons". There is close scrutiny of "end user" and "end use". And, in recent weeks, the Indian "namakaran" ceremony or Indian "entity labelling" exercise must be common knowledge. Whether international inter-dependence driven by techno-economics is understood or not, some countries would not like even national programmes in high technology areas, with Govt-industry linkage, to succeed. Here again, national interests have to be defined and defended.

### 3. THE URUGUAY ROUND, WTO AND INDIA

3.1 The Uruguay Round of Multi-lateral Trade Negotiations ended in Dec 1993. Unlike GATT which was created in 1947 and confined itself to "border measures" alone, the Uruguay Round saw the following new items:

(a) extension to investment, intellectual property and services.

(GATT-untouched areas like textiles and agriculture included)

(b) imposition of "cross retaliation" across sectors for effective enforcement of obligations.

3.2 The Final Act was signed in Marrakesh in April 1994 and contains 25 documents, including agreements on Trade Related Investment Measures (TRIMS), Trade Related Intellectual Property Rights (TRIPS), and creation of the World Trade Organisation (WTO).

3.3 India's involvement in GATT negotiations has been quite vocal. Some have commented that this was slightly disproportionate given the fact that our share of world trade is just about 0.5%. We must pay a tribute to our GATT team; it is overdue.

3.4 India succeeded, significantly in my view, in highlighting the difference between agriculture subsidies of the developed countries (which have created "excess supply" conditions) and the scenario in developing countries where the focus is on food self-sufficiency. As a result of these efforts, it would be fair to say that India need not change its agriculture policy.

3.5 India also has succeeded in:

(a) pushing the 10-year time frame for phasing out the Multi-Fibre Agreement (MFA)

(b) commitments on movement of personnel when the thrust of the developed countries in services has been for increases in cross border trade and capital flows

(c) enabling 3 separate agreements for goods, services and TRIPS

(d) securing differential treatment of developed and developing countries in Quantitative Restrictions (QRs) and industrial subsidies, based on Balance of Payments (BoP) considerations.

3.6 Item (c) above is rather important. Disputes, of course, would be handled by one Settlement Body. However, the worrisome action of "cross retaliation" cannot proceed without exploring/exhausting action in the same sector. USA, for instance, cannot now unilaterally engage in cross retaliation through its national legislation. It has to use the dispute settlement mechanism of WTO before venturing further.

3.7 It is to be noted that there have been stand-offs between USA and the EC on the extent of liberalisation in agriculture and in IPRs. India had opposed it, but most developing countries acquiesced. Then came the Dunkel compromise text: reduction of subsidies by only 20% over 6 years; reduction of export subsidies by 24% and so on. The war continued. Through the Blair House agreement, the 20% reduction was to be done in the "aggregate", not crop-wise; and it was

agreed that export subsidies would come down from 24% to 21%.

TRIPS

3.8 Much debates has occurred in India on TRIPS. It covers 7 categories:

- copyright trademarks
- industrial designs geographical indications
- patents integrated circuits
- trade secrets

3.9 Clearly, the World Intellectual Property Organisation (WIPO) should normally handle such issues. But the developed world, led by USA, felt it was toothless. And the phrase "trade related" is a transparent veil to bring legitimacy of these rights via trading terminologies and the marketplace. En passant, WIPO is not the only UN body to be given such special treatment, when found inconvenient by some powerful nations.

3.10 There is clear universal realisation that technology is a trade-able asset and has become the primary factor in international competitiveness. And, the lead has been taken by developed countries to press and retain the advantages they hold.

3.11 They have chosen to call new products using the revolution in microprocessors and communications as "knowledge-based". One wonders whether earlier products were "ignorance-based". But the phrase has also been used to focus, perhaps excessively and emotively, on "intellectual" content.

3.12 As far as India concerned, the protection norms and standards for 6 of the 7 items covered in TRIPS do not appear to pose any special problem.

3.13 Copyrights is about reproduction, performing, recording, broadcasting, translation adaptation and motion pictures. The Indian Copyright Act (1957) was amended in 1994 to include protection of moral rights; source and object code in software. So, we don't face any special problems from TRIPS in copyrights.

3.14 A similar situation prevails in trademarks. We gave up insistence on hybrid trademarks in 1993; e.g., Lehar-Pepsi.

3.15 For IC designs, India is already a signatory to the Washington Treaty (1989). In any case, protection can be provided through copyrights, patents or industrial designs.

3.16 Geographical Indications concerns the use of geographical labels like "Assam Tea" or "Scotch Whisky". It is in our interests to have this cover.

3.17 For Undisclosed Information (or Trade Secrets),

TRIPS doesn't want specific national legislation. The owner must take protection steps; also, ensure that it is 'secret' and has commercial value. But we are obliged to refrain from acquisition without authorization or disclosure without permission. Not a big deal under normal circumstances.

3.18 What is left is the "patents" area where there are strong differences. The Indian Patents Act, 1970 permits only "process patents" in food, agriculture and chemicals. The Table, overleaf, summarises the position.

3.19 The Central Govt is preparing to introduce legislation to bring the Indian Patents Act in line with TRIPS.

3.20 There is a divide. Parties which opposed it while sitting opposite the Treasury Bench are now advocating it; and those who previously proposed it are now opposing it.

3.21 Whatever may be the political compulsions, it is time that we realise that we have been able to get the best we possibly can out of the Uruguay Round; but in TRIPS we have to radically change our policy. If we do not, we would certainly get branded as lonely foes of "intellectual property rights" in a country which has rich traditions of the intellect. We have to collectively face the patent challenge even as we move gently away, within the transition period, from the era of (necessary) protectionism of the past.

Indian Patents Act	TRIPS
<i>Coverage</i>	
substance in food, medicine or drug	all fields of technology
no right for products right for methods or processes	rights for products & processes
<i>Duration</i>	
5 years from sealing date or 7 years from date of patent, for above substances	uniformly 20 years
for other substances, 14 years from date of securing patent	
<i>Working of a patent</i>	
Import of a product not equal to working of a patent	rights enjoyable, whether imported or locally produced
<i>Compulsory Licensing</i>	
enforceable in public interest (e.g., under price or volume factors)	not ruled out; no automaticity

\* India has enjoyed a free-ride in pharmaceuticals and agrochemicals so far; can't last forever.

3.22 TRIPS has a normal transition period of 5 years for developing countries for implementation; and, an additional 5 years for countries (like India) which have to pass legislation to cover "product" patents to cover all fields of technology.

3.23 Specifically, for pharmaceuticals and agro-chemicals, TRIPS says that if products are granted patents and marketing approval in any country and a patent holder wants to introduce them into India, he should be given Exclusive Marketing Rights for 5 years, or till his pending patent in India is approved/rejected. This is called the "Swiss Pipeline Protection" and applies to patent applications filed after the Uruguay Round. It arises when a country wants the additional transition period of 5 years.

3.24 The normal 5-years period comes to an end early in 1999. It would be in our interest to bring our patent laws in line with TRIPS within the normal transition period and discard the "pipeline protection" clause which provides the additional transition period. A desirable, recommended, clean normal transition.

3.25 TRIPS covers micro-organisms and microbiological processes. Both not tightly defined. There is the good question of where does discovery end and invention begin. But in "genetically modified organisms (GMO)" there is clarity. We could allow GMO patents, provided they are for particular claims or use which we accept.

3.26 Plant varieties are protected by patents or a "sul generis" system or a combination thereof. It is in the realm of national choice. If patent protection is not to be given, we must have a "sul generis". India can, indeed, become "a world leader in seed technology" given its agro-ecological diversity. There should be no two opinions about this capability.

3.27 In enforcement, we have to take adequate steps. But no special courts or tribunals are necessary.

3.28 To sum up, we have to elastically stretch TRIPS provisions in our favour, to the maximum extent possible. There are some permissible "degrees of freedom" within implementation of TRIPS which are to be noted in this regard:

- balance between producers and consumers, including public health and nutrition
- tighter definition of "invention" in national legislation to prevent abuse; exclusion of "prior art" like traditional knowledge, e.g., to prevent patenting the properties of turmeric
- licensing another Party, if a patent holder is uncooperative, to make the product as a check against abuse under the Compulsory Licensing provision.

#### 4. BALANCING THE NATIONAL INTEREST ON THE (KACCHA) ROAD AHEAD

4.1 Balancing the 'national interest' means that we have to find the equilibrium in many, if not all facets of our national endeavour. And, in relations with neighbours on Planet Earth, far and near.

4.2 The balance is fundamentally one between rights and obligations under "conflict of interests" conditions. There is something to be surrendered to the State; there is something that the State must do. There is balancing to be done between sectors of the economy; and within sectors.

4.3 Eternal vigilance is supposed to be the price to be paid for liberty. It is also called for in dynamically balancing the "national interest". We have to ensure, as a people that we are not held hostage to narrow selfish interests to groups - be they in the political, economic, technological or security spheres. It is our duty to enable informed decision-making, by consensus, through public education and awareness of supposedly "complex" choices.

4.4 It took many, many decades for us to throw off the colonial yoke and gain "political freedom". It will take many decades, indeed, to achieve the type of development goals we set for ourselves and retain reasonable "economic freedom" in a globalising environment over which we may not have too much of control.

4.5 Recall how a small island nation ruled over many parts of Asia, including Bharat for a century and more. Factors like our own disunity and their "superior" military power are well known.

4.6 *I hold the view that one of the major elements in the continuing domination by the British came from a stroke of genius which may not have been fully comprehended by Macaulay. This is what I choose to call the "comprador" factor - whereby the local population was, sort of, co-opted in administration of the Raë through education and jobs. Of course, locals were used essentially in revenue, law and order, the military and so on. The executive levels were British, or predominantly British; even after the ICS created some "brown sahebs".*

4.7 Given this historical experience, I am concerned about the possible emergence today of a new "comprador" class in India. Conquests are no longer territorial.

4.8 The vehemence with which most of our fairly good policies after independence have been attacked in recent times, in words borrowed straight from foreign lexicons, is rather amazing and reminds one of cat-echism. And, these attacks are not confined to economic policies. They spill over, now, into complex areas of national security.

- 4.9 It would be unfair and unnecessary to label these critics and intellectuals as not being national, as some prickly defenders tend to do. But the reality seems to be that, while in colonial days it was jobs in India, today it is assignments, tenures, study commissionings and seminars in the salubrious groves of foreign academes or institutes. Possibly, we have to guard ourselves against the emergence of this new "comprador" class; lest history repeat itself. While noting these developments, we have also to resolutely meet their borrowed arguments in the open with dispassionate, logical counter-points; as part of defence of the national interest. In the "Information Age", petulance or silence cannot be useful tools.
- 4.10 Could we, jointly, now venture where angels fear to tread with a little courage and, possibly, a lot of naiveté. Shall we consider the top-down approach?
- 4.11 We can have only "questions" regarding the "top" part, hopefully the right ones.
- 4.12 In balancing the national interest, the urge to get political power, or retain it, at the State and at the Centre is natural.
- 4.13 But "populist", or divisive, policies which do not make normal economic or social sense could be followed by Governments. Of course, they are important for vote banks. Do we need external advice on the effects of such policies? Should we wait for the deterioration to occur and pass the problem to successor Governments? Can such policies be reduced?
- 4.14 Should not the "technology" and "financial engineering" involved in criminalisation of the body politic be effectively controlled and curbed?
- 4.15 Isn't it time that those whose noble calling is politics study and practice Integral Calculus rather than Differential Calculus?
- 4.16 If the "central glue" of the past decades has become weak in recent times, should not "regional glues" have the basic binder ingredient of "national interests" mixed in them? No State can be an island and its well being is quite strongly linked with other States. (To complete the words implicit in the island statement: Ask not for whom the bell tolls, it tolls for thee).
- 4.17 While we can quibble about the nature or character of the immortal Infinite and waste precious time, can the daunting task of economic development be allowed to be pursued in peace by lesser mortals? Is this an unnecessary question in balancing the national interest?
- 4.18 Now, a word about the bottom. In any organic system, decay processes can occur both at the top of the system and the bottom. Rising expectations coupled with low gainful employment can create a conflict of rights and obligations affecting the system at its roots. The quest for jobs in Govt is ceaseless. But there is concern that trend will be less of Govt jobs in the era of globalisation. If true, how do we address unemployment issues?
- 4.19 I would urge that answers, continuing answers because these questions are likely to be around for some time, have to be found using the Indian genius - by the leaders as much as the led.
- 4.20 There is no dearth of plans or ideas on revving up the economy. They tend to be almost the same, irrespective of which Govt is in power; more so, when the gestation period is long. The areas are well known:
- industry, large and small; and industrial research
  - education
  - agriculture
  - energy
  - telecommunications
  - transportation
  - mass health
  - financial management
  - public sector reform
  - labour policy
  - public distribution system
  - law and order
  - national security
- 4.21 What needs to be done is to ensure that at least on-going schemes and projects, which carry little or no technology or other risks, be completed on time. And there is stability in the budgetary process. We seem to be shy of fixing accountability and responsibility in such non-risk schemes. The slippages that have occurred seem to be from internal factors or infirmities. We ought to do better.
- 4.22 To move on now to S&T. A few generalisations from the "Hard Knocks University".
- (a) For the journey along this kachha road, we would have to progressively (if possible dramatically), shed some of the baggage of the past, most indeed of the accumulated "kachda".
  - (b) There is still a lot of feudal style in R&D which is inappropriate to the style of aggressive output needed from young (or middle age) engineers and scientists.
- This work has to yield results in performance and timeliness to grab the opportunities thrown up by globalisation; with incentives and high accountability.
- To plead that the S&T community should be immune from accountability because of fears of "demoralization" is specious. R&D failures are to be expected, sure, but the expectation is that really honest efforts have been made.

- (c) We should eliminate or reduce the damage to the S&T image by closing infructuous projects or by switching "project managers" or by re-defining project goals.
- (d) While some change in "management" methods is called for, we do not have to be "imitative" in the jargon and content of what passes off as "modern management" abroad. Some of these are hot house plants and will not flourish in our climate.
- (e) We must foster the country's entrepreneurial abilities and scientific/technical strength across sectors, not just in the Govt sector alone. In a partnership.

4.23 How could Indian S&T rise to the challenges of Globalisation and come out with trumps? Some suggestions, not all novel, but fully provocative to generate more light than heat, can definitely be made:

#### # 1 Critical Technologies

Seek and secure funding for investments in "critical technologies" to be established either in the Govt or private sector; the national interest calls for it

#### # 2 Drop Imitative/Incremental Research

The days of imitative research and import substitution are generally over, except may be in a few sectors where security concerns are dominant.

Apply the criteria of "novelty, non-obviousness and utility" used in patent issue to on-going research (basic, applied); apply the same to new projects

#### # 3 Innovative Research

Nurture original, innovative frontier research in academia and academic research institutes; they also have to rise to new challenges

#### # 4 Global R&D

Encourage plugging of good, performing institutions into the international R&D system; use IPR provisions to safeguard interests; (other laboratories would/could also be motivated)

#### # 5 Reverse engineering

Before undertaking "reverse engineering" or "import substitution", explore international availability on acceptable terms; if unavailable try to do it "smartly"

#### # 6 Partnership with Industry

Develop firm links with the Indian industry (public and private) which in the new era may have less reluctance to take "pre-competitive research" items from various national labs for commercial exploitation; in select areas, positively promote "alliances"

Private sector R&D, say in pharmaceuticals, will have to work on products based on new molecules; (this has started to occur)

#### # 7 Patenting

Support passing of legislation to bring our laws in line with TRIPs; enable easier patenting of Indian inventions; modernise patent offices

Increases awareness of patents; open a national kitty, to grow with a fraction of royalties; provide incentives for patenting

#### # 8 Promote Professionalism

As opposed to "careerism"

Defence of the scientific and technological "truth" is part of professionalism; not what is convenient to current management

#### # 9 Inter-face and Coordination Issues

These should not be left to whimsy, individual or institutional, or to chance

Grow a new breed of ego-free "inter-face" promoting individuals in organisations; because issues cut across science agencies, commerce, industry (public, private) and the foreign policy establishment

#### # 10 Banquo's Ghost: Incentives for the Scientist

Pay, incentive, working conditions, perks etc of the Indian S&T community needs re-visiting; flight of bright, young engineers and scientists in select areas is well known

Can a suitable working mechanism be worked out in Govt, by Govt? else, drones will remain in our labs, drawing pensions while in service

## 5. SUMMING UP

- 5.1 I personally am convinced that that there is considerable scope for optimism, based on our internal strengths and resilience, about balancing the Indian National Interest, in the larger sense. This set of strengths includes the vast S&T infrastructure, skills and manpower pool.
- 5.2 Provided, provided of course, we learn from past lessons and are clear what has to be done, why it has to be done and how it has to be done. If we don't, succeeding generations would wonder about our wisdom. Knowledge may slowly dawn in Government, but hopefully wisdom lights up in other sectors and lingers - in balancing the national interest in contemporary times.

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## Jagadis Chandra Bose and his Work on Electromagnetic Theory

S N GHOSH, FIETE

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**J**AGADIS Chandra Bose, a doyen of Indian Science, was one of the pioneers in the field of electromagnetic theory. He carried out research work on the generation, detection, propagation and properties of Electromagnetic Waves in the range known today as microwave and millimeter waves. Although he carried out this work in the early period of his research career and only for five years (1894-1899), it is of great significance.

### EARLY LIFE AND EDUCATION IN INDIA AND ENGLAND

Jagadis Chandra's father, Bhagaban Chandra, was in many respects a remarkable man. He became a Deputy Magistrate and afterwards an Assistant Commissioner. He started tea industry, founded a people's bank and staked his saving on starting weaving mills. He employed a released dacoit to carry Jagadis Chandra on his shoulders to school and back. On the way the dacoit used to narrate many fearful stories about dacoity which young Jagadis Chandra used to hear with raft attention.

After passing Entrance Examination of Calcutta University with a scholarship, Jagadis Chandra studied in St Xavier's College, Calcutta where he came under influence of renowned professor, Father Lafont, (Fig 1) who, attracted him to Physics. After passing BA examination of Calcutta University he intended to proceed

to England for higher studies but his father could not bear the cost of such studies as he was then almost a ruined man due to failure in industrial adventures. Jagadis Chandra then desired to qualify himself for Indian Civil Service (ICS) examination in order to pay off his father's debts. But his father objected to the proposal because he desired that Jagadis Chandra should not rule anybody but himself. He should be a scholar and not an administrator. Finally, Jagadis Chandra sailed for England in 1880 for higher studies.

In England, Jagadis Chandra was advised to pursue medical studies but after staying there for sometime he desired to study science at Cambridge University. There he came under influence of a stalwart like Lord Rayleigh, (Fig 2) whose careful experimentation and precise explanation of physical phenomena made an abiding impression on Jagadis Chandra. He passed Tripos Examination in Natural Science of Cambridge University and then BSc Examination of London University.

### RETURN TO INDIA AND JOINING OF PRESIDENCY COLLEGE, CALCUTTA

In 1885 Jagadis Chandra returned to Calcutta with a letter of introduction which was presented to Lord Ripon, the then Viceroy of India. He was appointed as an officiating Professor of Physics in the Presidency College,

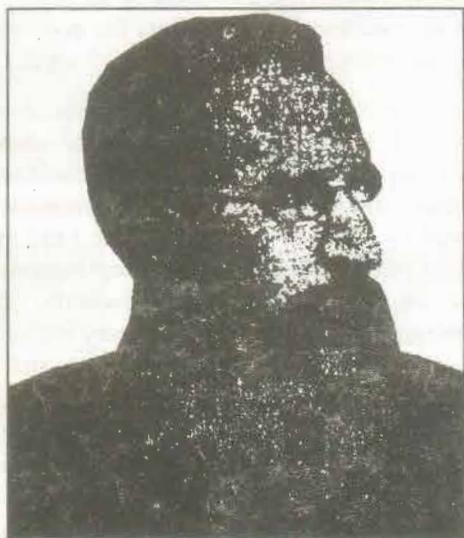


Fig 1 Father Lafont teacher of St Xavier's College, Calcutta

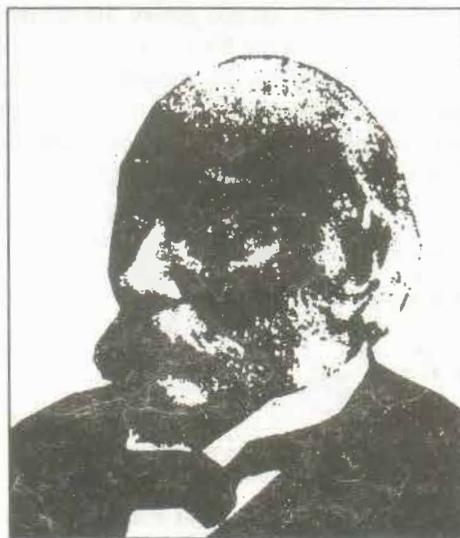


Fig 2 Lord Rayleigh, a stalwart in science of England

Calcutta. In those days professors in science of the college were British who objected to this appointment, because it was then thought by them that Indians were good in philosophy, language etc but not in science. His salary was fixed at two-third of that of a British incumbent. Again, because the appointment was a temporary one, he was to receive one-third of the pay normally attached to the post. Professor Jagadis Chandra Bose was very much disheartened and resolved not to accept the salary. This continued for three long years.

Professor Bose organised his laboratory and courses he had to teach. For carrying out research work he faced difficulties. In those days British science teachers were good in teaching, but rarely they carried out any research work and hence when he asked for space for research he got only a very small room of floor area of almost 30 sqft and that too near a bathroom. Recalling his early days of research in the Presidency College, Jagadis Chandra once remarked, 'There was no laboratory and no instrument maker. Everybody said that original scientific work was impossible to carry out in India. But it came to me as a flash that it was not for man to quarrel with circumstances, but bravely to accept, confront and dominate over them and furthermore we belong to a race, which had accomplished great things with simple means'.

Before elaborating Prof Bose's work in electromagnetic theory it would be desirable to describe briefly the em theory and work carried out by other workers in the field.

### ELECTROMAGNETIC THEORY POSTULATED BY MAXWELL

In 1840 Faraday had intuitively suggested that light waves might be produced by vibrations travelling along lines of electric and magnetic force. Around 1864, in a series of brilliant contributions, Maxwell laid the foundation of electromagnetic theory. He started with the theoretical structure on the background of experiments in electrostatics and magnetostatics together with observation that associated with an electric current there is a magnetic field and that electric current can be produced by the relative motion of a conductor in a magnetic field, namely that

$$\begin{aligned}\vec{\nabla} \times \vec{E} &= -\mu \frac{\partial \vec{H}}{\partial t} \\ \vec{\nabla} \times \vec{H} &= \vec{J} \\ \vec{\nabla} \cdot \vec{D} &= \rho \\ \vec{\nabla} \cdot \vec{B} &= 0\end{aligned}$$

Working on the electric and magnetic lines of force introduced by Faraday, Maxwell realised the essential symmetry between electric and magnetic phenomena.

The decisive step in Maxwell's Electromagnetic Theory is in adding the displacement current

$\epsilon \frac{\partial \vec{D}}{\partial t}$  with  $\vec{J}$ . The introduction of this term is a great

step in the forward direction about which Max Born, a Nobel Laureate remarked, 'It should be noted that Maxwell's decisive step consists in adding the missing term the displacement current, without proper empirical foundation, first guided by the mechanical model of ether, later by reason of mathematical perfection or beauty or you may describe it as an act of genius'.

By introducing the displacement current and assuming that it produces a magnetic field as conduction and convection currents do, Maxwell ascribed wave character to electromagnetic phenomena, that is, a disturbance created by electric and magnetic vibrations propagates as waves

$$\begin{aligned}\nabla^2 \vec{E} &= \mu \left[ \sigma \frac{\partial \vec{E}}{\partial t} + \epsilon \frac{\partial^2 \vec{E}}{\partial t^2} \right] \\ \nabla^2 \vec{H} &= \mu \left[ \sigma \frac{\partial \vec{H}}{\partial t} + \epsilon \frac{\partial^2 \vec{H}}{\partial t^2} \right]\end{aligned}$$

It is displacement current which leads to the propagation of waves with finite velocity, to the electromagnetic theory of light, to wireless and all the modern radio engineering stands.

Guided by the fact that the sound wave requires for its propagation a medium, Maxwell visualised the medium 'ether' through which electromagnetic waves propagate. However, Michelson and Morley carried out in 1880, a series of experiments that cast doubt on the existence of this supposedly essential medium, ether. The concept of it led to many inconsistencies and was finally dropped.

In the beginning of 20th century physical principles underwent considerable modification and change as a result of introduction of Planck's law, Relativistic theory and other discoveries. But electromagnetic theory postulated by Maxwell was found to be valid except the concept of ether. Its fundamental concept remains even today as the foundation of our present-day theory of electromagnetism. Maxwell's field theory is considered as the crowning jewel of nineteenth century physics.

### DEMONSTRATION OF ELECTROMAGNETIC THEORY

#### Hertz's work

The electromagnetic theory remained after its inception as a brilliant mathematical contribution.

However, it has no practical application because such waves were not generated experimentally.

In 1887, Hertz, (Fig 3) a brilliant German researcher, demonstrated waves of about 60 cm from a spark transmitter precisely of the same nature as predicted by Maxwell and of light waves except that these had a much longer wavelength. He made an oscillator in which the primary winding of an electromagnet was connected with an electric battery and a key (Fig 4).

The terminals of the secondary winding were connected to two metal balls so that a minute gap separated them. It was observed that sparks appeared in the gap when the key in the primary circuit was closed.

The stream of sparks provided Hertz with suitable oscillations of electromagnetic radiations. The detector which Hertz used consisted merely of a loop of copper with a break in it. When the oscillator began to produce sparks and the loop was held near it the sparks could be seen to jump across the break and were visible to the eye in the dark room (Fig. 5). To show that these newly discovered radiations were really waves, he carried the copper loop around a darkened room. At certain places sparks were produced showing interference as in the case of light waves. He also showed that waves could be reflected, refracted and polarised.

### Marconi's Work

Marconi put em-waves to practical use. He set up a successful wireless telegraph in his father's garden near Bologna, Italy. The transmitting set which Marconi employed utilised the induction coil and spark gap that were used by Hertz. He attached an automatic tapping

device. A telegraph recorder was placed in the circuit to take down dots and dashes carried by em-waves. He showed that messages could be sent through empty space.

In 1895 Marconi transmitted signals more than a mile, and through 18 miles in 1898. He then improved the basic device and in 1899 sent messages across the English Channel which for the first time saved life at sea. On December 12, 1901, he succeeded in sending the letter 'S' by pressing three dots in the Morse Code from Cornwall in England to new Foundland across the Atlantic Oceans (Fig 6). The success of this experiment was a source of considerable discussion in the scientific world. Subsequently, it was shown that an explanation of the experiment could be provided by assuming a conducting layer in the atmosphere. This layer was afterwards known to be produced by the ionization of the upper atmospheric constituent mainly by solar ultraviolet radiations.

As waves generated by Hertz and others did not require any wire for propagation, it found important and wide application known as the wireless communication between ships in the ocean. Wireless transmitters and receivers were set up in increasing number in ships. A significant instance can be cited in 1909. In the dense fog in the sea two ships named Republic and Florida collided. Wireless signals could be sent from the Republic. On receiving it another ship Baltic came to the spot and rescued all 1242 passengers of the two ships.

### BOSE'S WORK ON ELECTROMAGNETIC WAVES

At the time when Jagadis Chandra returned to India, a good amount of work was then carried out in Europe on the

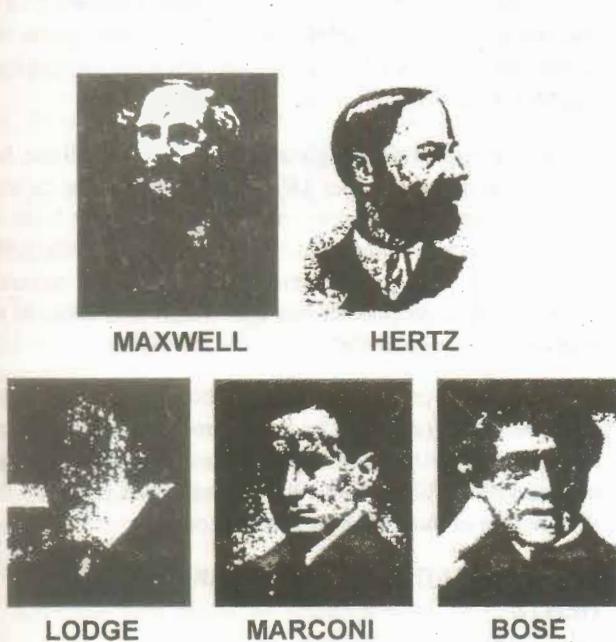


Fig 3 Photographs of (1) Clerk Maxwell (2) Heinrich Hertz (3) Oliver Lodge (4) Guglielmo Marconi (5) J C Bose

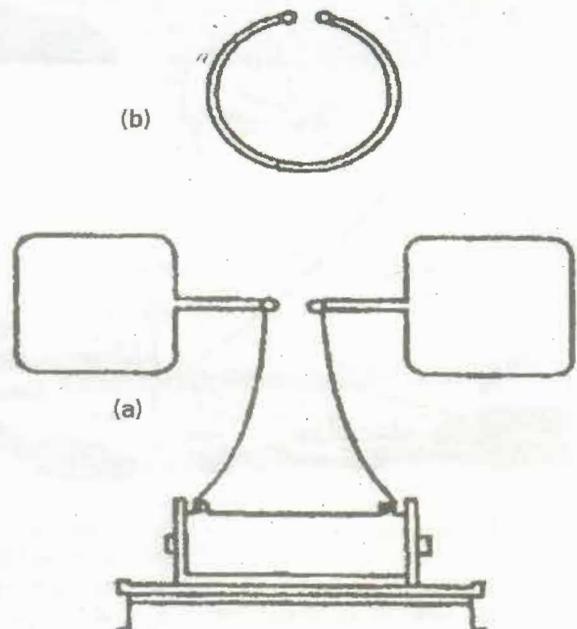


Fig 4 The apparatus used by Hertz for generation (a) and detection (b) of wireless signals



Fig 5 Production of em-waves and its detection

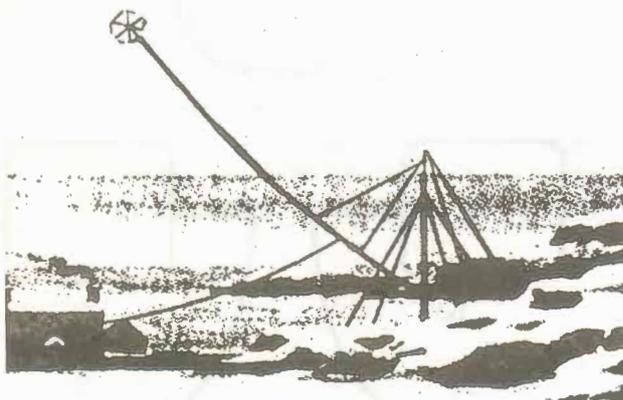
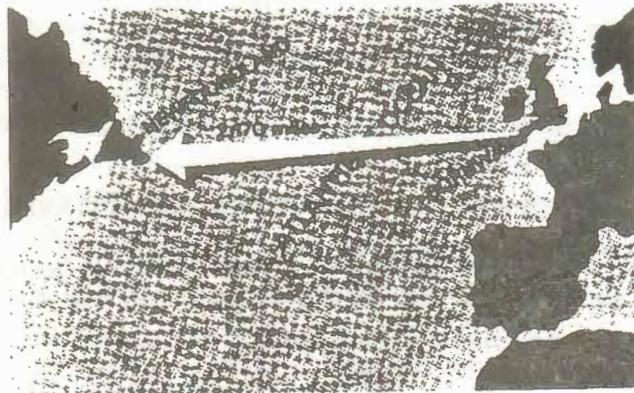


Fig 6 Marconi used a kite-flown aerial outside the barracks at signal Hill, of St. John's New Foundland in Canada and received on December, 12, 1901, wireless signal which was letter 'S' in Morse Code. The signal used on this historic occasion came across the Atlantic Ocean from Cornwall in England 2170 miles away through curved surface of the Earth.

generation and detection of em-waves. The young Prof Bose was attracted to it and specially when he read Jone's book entitled, 'Electric wave' (electromagnetic waves at first were called electric waves) published in 1893 by MacMillan Company, London, and another book entitled, 'Heinrick Hertz and His Successor' written by Oliver Lodge in 1894. Professor Bose decided to set up a laboratory in his college for studying these waves experimentally. He felt that it would not be possible to work with long waves of the order about 60 cm, with which European workers used to work, in the small room allotted to him for research work. So he turned to waves of small wavelengths which we call today as microwave and millimeter waves. Later during World War II these waves were extensively used in radar.

On May 1, 1895, Prof Bose could send em-waves from the room of Professor P C Ray to the room of Professor Pedlar in his college, and thereby showed that it was possible to send information and detect them through the use of these waves. In the same year, he published a small book, 'An account of experimental researches carried out in the Physical Laboratory of the Presidency College in the year 1895'. Towards the beginning of the next year, he submitted a thesis entitled 'On the determination of electric radiation by diffraction grating' for the DSc degree of London University and obtained it. He measured the wavelength of the radiation given by his radiator and found it to be of the order of 20 mm.

#### HIGH APPRECIATION OF BOSE'S WORK

Next year, he attended the meeting of the British Association, London and gave on September 21, 1896, a lecture on his findings. It was very much appreciated by the British scientists. His portable apparatus consisting of a spectrometer table, a spark gap, a small wave guide etc impressed the scientists (Fig 7). Lord Rayleigh greeted him and Mrs Bose with his hat off.

British papers paid high tribute to Professor Bose, for example in the September 1896, it came out: 'The culture of thirty centuries has blossomed into a scientific basis of an order which we cannot quite duplicate in the West. He (Prof Bose) is a prince among physiological research workers and a prophet of his age which had brought so many new powers of life'.

Professor Bose visited many laboratories in England and also in the continent and delivered lectures. After his return to India he continued research in the field and between Nov 1897 to Feb 1900 published six papers in the Proceeding of the Royal Society of London.

#### BASIC DIFFERENCES OF WORK OF BOSE AND HERTZ

There are basic differences between the work of Bose and Hertz.

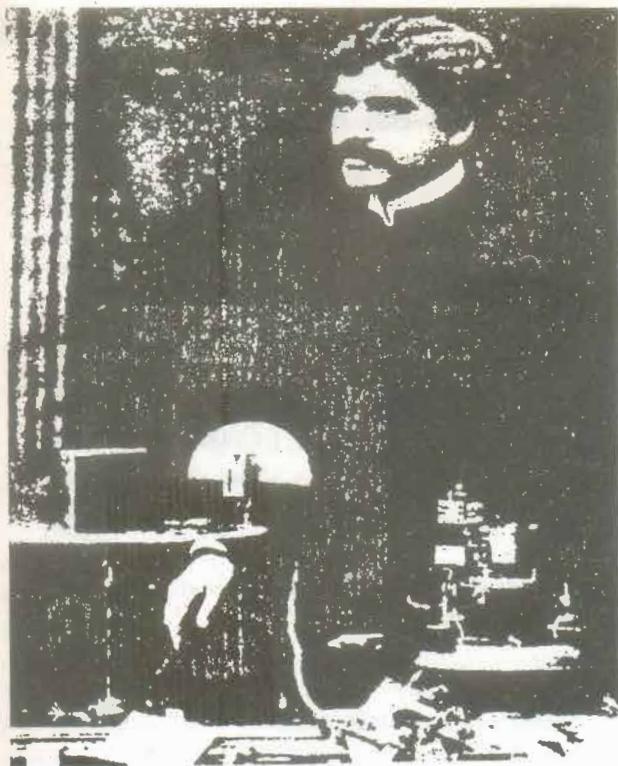


Fig 7 Sir J C Bose was giving a lecture at the British Association, London on September 21, 1896. He used a compact apparatus for generation and detection of wireless signals mounted on a spectrometer table

- (i) The em-waves generated by Hertz had long wavelength of the order of a few feet whereas the waves generated by Bose varied from 25 mm to 5 mm.
- (ii) For the detection of waves Bose used a small piece of galena and a small wire touching it.
- (iii) Bose was the first to use a wave-guide.
- (iv) Bose constructed a small portable apparatus for exhibiting the properties of em- waves.
- (v) He modified Lodge's emitter and detector.

#### BOSE'S NEW FIELDS OF RESEARCH

In 1899 a change came in Sir Jagadis Chandra Bose's field of investigation. He entered into a new field of research.

Thus came to an end a very fruitful period of research work. It may be guessed as an interesting exercise that had the work been continued many epoch making discoveries would have emerged from his fertile brain having a rare experimental skill.

After the first phase of research work (1894-1899), which was devoted to the production and studies of properties of short em-waves down to 5 mm and in verification of quasi-optical properties of these waves, Sir

Jagadis Chandra's second phase of research work (1899-1902) started and was spent in extensive studies of properties of detectors in different metals and crystals. He studied the response of many inorganic systems to the stimulus not only of electric waves but also of light waves, mechanical torsions etc. The responses manifest itself in change of resistance, emf variation and photoelectric effect. It was subjected to fatigue and was enhanced by stimulants. It showed similarity to the electric response to living tissues.

The third phase (1902-1933) of his investigation was spent in studying of response of plants. The complexities of their responses were intermediate between those of inorganic matters and animals.

#### CONCLUSION

Acharya Bose (Fig 8) was the pioneer investigator of microwaves and millimeter waves (Ramsay P.I.R.E Feb 1958) which has now proved to be a promising field of investigation in physics, communication, astrophysics and many other fields.

In addition to significant work in physical and biological sciences, Acharya Jagadis Chandra Bose has made an impact in Bengali literature also. His article, 'Quest of Origin of Ganges', is highly praised. Tagore and Bose were great friends. Sometime they used to spend weekends together when Bose described to Tagore the experiments he carried out in the previous week and on the other hand, Tagore narrated to Bose his writings in 'The Collection of Stories, Galpaguchha' in the last week.

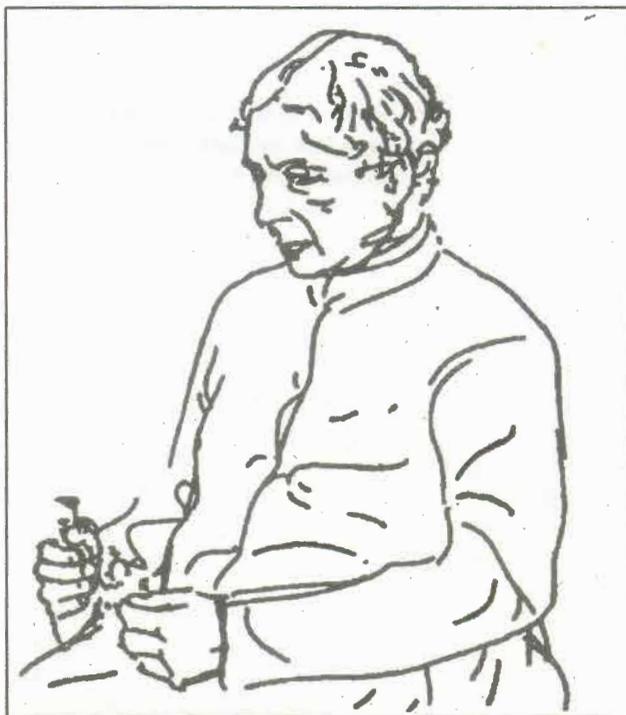


Fig 8 Acharya Jagadis Chandra, a doyen of Indian Science .

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# Role of Light as an Energy Source and Information Carrier in Plants

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**T**HE sun is the source of all life on earth. This has been aptly depicted in the following Sanskrit verse

आदित्यान जायते वृष्टी ।  
वृष्टेरन्नं ततः प्रजा ॥

Though this is true, a mechanism which can utilize this energy is very much essential. The only mechanism which can convert light energy into chemical energy is photosynthesis. In this respect, the evolution of photosynthesis on earth is a very significant phase in the sustenance of life on earth. The emergence of photosynthesis has helped in maintaining the balance of gaseous contents, mainly oxygen and carbon-di-oxide in the atmosphere. The photosynthetic process brings about the conversion of light energy into chemical energy. The schematic representation of this process is shown in Fig 1. The process involves the absorption of light by various pigments, transfer of this light to the reaction centre, utilization of the absorbed energy to form ATP and NADPH through the electron transfer process and lastly the fixation of carbon-di-oxide using energies from ATP and NADPH and proton gradient through the splitting of water.

The phenomenon of photosynthesis that takes place in plants has many interesting aspects related to it. The first and foremost is the precision with which this process takes place. Secondly, it is planned in a very small place, less than one micron in dimension. The collection of light and transfer of this light to the reaction center and transfer of electrons along the photosynthetic pathway is a marvelous process. It accounts for various physical and chemical principles. Some of these aspects are discussed below.

## ABSORPTION AND TRANSFER OF LIGHT

Various pigments such as chlorophyll *a*, chlorophyll *b*, phycoerythrin, phycocyanin and carotene, absorb the light in the range from 250nm to 700nm. The absorption spectra of these pigments is shown in Fig 2. It is evident that all these pigments together help to absorb light throughout the range mentioned above. Out of these pigments, chlorophyll *a* of the reaction centre (RC) is present in the dimeric form. All the other pigments transfer the energy absorbed to the chlorophyll *a* and hence these pigments are known as accessory pigments. The mechanism of transfer of excitation energy which takes place in the light harvesting complex is shown in Fig 3. At this stage, the transfer is without any loss of energy. This loss less transfer of energy

is very unique and there are two schools of thought regarding the mechanism responsible. One believes in the excitation transfer mechanism while the other believes in the resonance transfer mechanism (Fig 4).

## THE ELECTRON TRANSFER PROCESS - THE LIGHT AND DARK REACTIONS

The photosynthetic apparatus wherein the electron transfer process takes place, consists of 2 photosystems, Photosystem (PS) II and PS I, embedded in the thylakoid membrane of the chloroplast (Fig 5). PS II and PS I consist of a chain of molecules attached to the protein complexes (Fig 6). The organization of these molecules is decided by their relative redox potentials. The downhill transfer of the electrons from the PS II excited state to the PS I RC, results in formation of the energy currencies ATP and NADPH. The photosynthetic apparatus also consists of a water oxidation complex where the splitting of water takes place. This phenomenon has attracted scientists since ordinarily the splitting would require very high energy. However, in photosynthesis, this process takes place on a regular basis and almost at a constant temperature and pressure and with very little consumption of energy. The splitting of water involves the separation of charges in the cyclic states of a Manganese cluster. If this phenomenon is understood properly then it may help in developing batteries which would be more effective and economical. The electrons emitted as a result of the water splitting fill up the holes created at the PS II reaction centre, thereby, opening up the RC for further excitation. The ATP, NADPH and the proton gradient formed as a result of the so called 'light reaction' are utilized in the fixation of carbon-di-oxide in the dark reaction phase of photosynthesis. The energy which is made available in the conventional form makes all biochemical reactions associated with various organisms possible. This in turn helps in the growth and maintenance of animal life, right from bacteria to human being. Of course if one properly understands the intricacies of the complete process, it could result in producing artificial food, which may be a long term dream for us.

So far, we have seen how light has been used as an energy source. On the other hand, there are a number of processes where light plays the role of an information carrier. An important area where light is used as an information carrier in plants is in the photosensory phenomena, as described below.



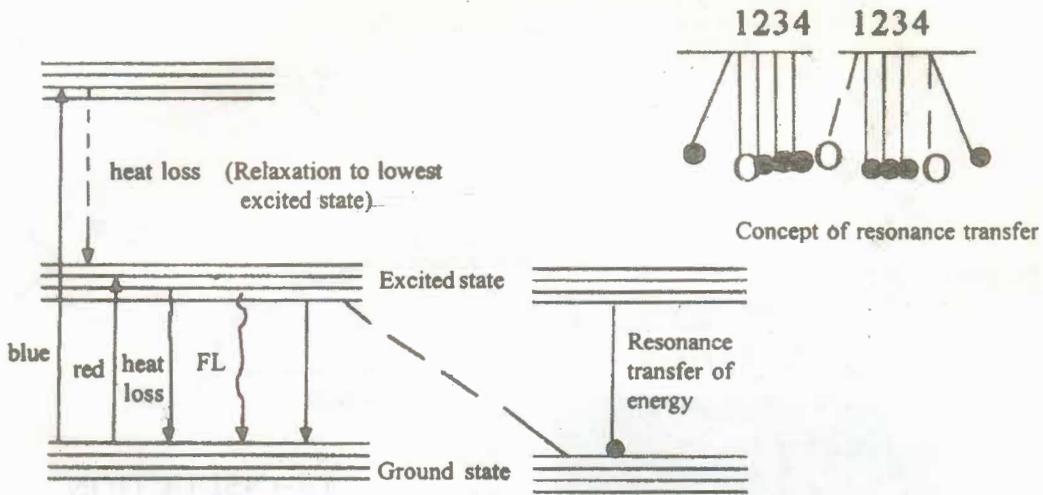


Fig 4 Mechanism for transfer of excitation energy

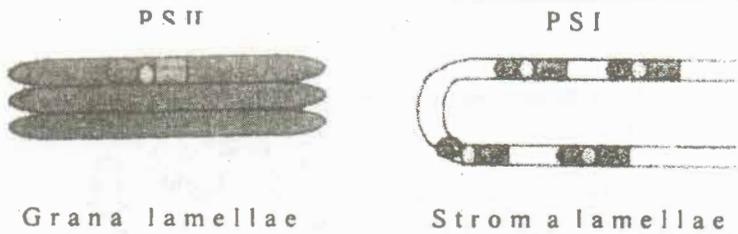


Fig 5 Light harvesting : light absorbing pigments in PS II & PS I

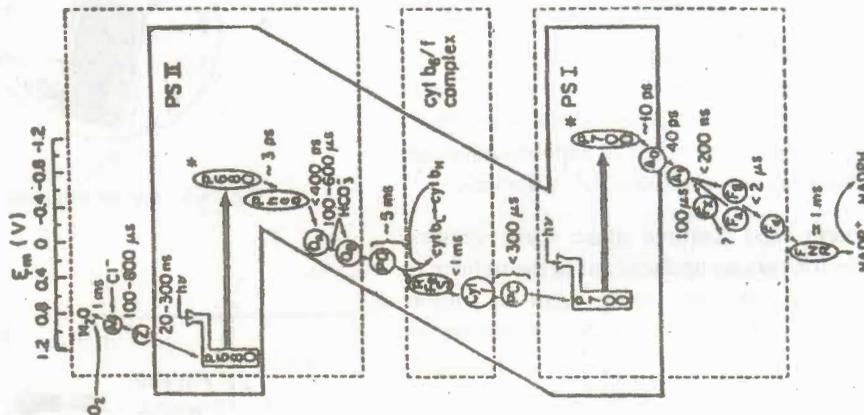


Fig 6 Scheme : electron transfer chain in higher plants

use light for sensing the direction, polarization, fluence rate and also to carry out attenuation and modulation of light. For sensing light direction, an absorption gradient is essential. However this requires two sites for absorption. In motile unicellular algae which contains only one sensitive site, a temporal absorption gradient replaces the spatial one. The temporal gradient is achieved by rotating the cell which results in periodic modulation of light at the sensory structure. Attenuation is brought about through the passage of light along the cell of the organ. The refraction of light takes place because of the higher refractive index of the cell structure compared to the medium. This results in focusing

the light to the distal part of the cell. In green flagellate *Chlamydomonas*, lipid layers reflect the light to the photosensory structure. As these structures are spaced by quarter wavelength each, the reflected light exhibits constructive interference. The dichroic orientation of photosensory pigment molecules allows the sensing of the polarization of light.

**SPECIAL FEATURES AND POSSIBLE APPLICATIONS**

The photo sensors existing in biological systems come

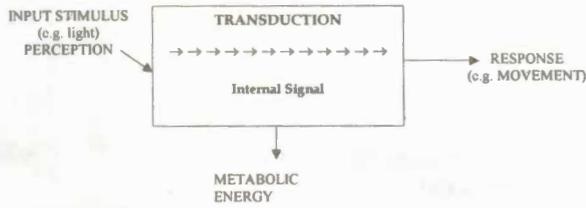


Fig 7 Sensory transduction chain

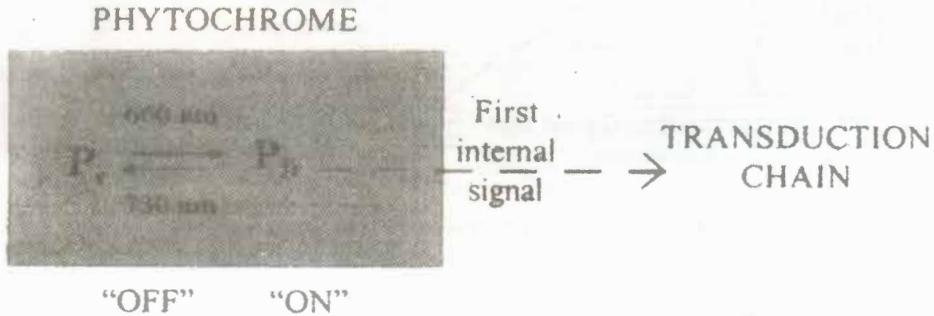


Fig 8 Phytochrome as a molecular ON-OFF switch

very close to an ideal detector as they add very less noise or distortion in the signal when they absorb energy from the optical field. Hence these natural sensing elements are incorporated in making artificial biosensors (Fig 10). In physical devices the minimum energy limit of few  $KT$  / bit can be achieved only by the use of very sophisticated devices such as the Josephson junction. On the contrary biological receptors normally operate at the level of 10-20  $KT$  energy per bit. Moreover, biosensors allow many more chip connections, which is a measure of sophistication, as compared to the conventional electronic logic devices.

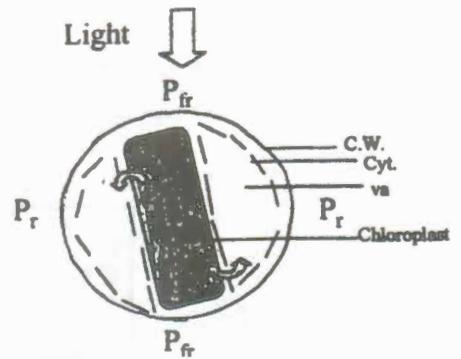


Fig 9 Chloroplast orientation in mougoutia

The above mentioned features make these sensors suitable candidates for various applications in the industrial and scientific field. Apart from using them as simple sensing devices such as light emitting diodes and photo diodes, these sensors can be used to build logic devices such as optical switches and shift registers. For examples the photosynthetic light harvesting system along with the reaction centre components provide a model for an efficient photo diode (Fig 11). Two-electron gates in photosynthesis have been discussed also, while a shift register memory based on porphyrin-diquinone molecules has been proposed by Hopefield. Solar cells which mimic natural photosynthesis have also been reported.

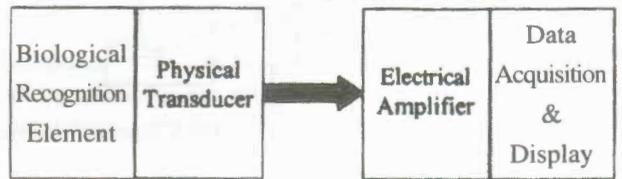


Fig 10 Essential biosensor components

The sensing systems which are used for photo movements and are wavelength specific, direction and polarization sensitive, can be effectively used in the field of robotics, along with potential applications in defense mechanisms.

Thus plant research has come a long way in the areas where sensing, assimilation and utilization of information

is concerned. Plants do sense. They also show intelligent behavior at local level. Thus mechanisms adopted by plants can provide useful clues in developing advanced technologies in the 21st century.

The importance of understanding plant life was brought forward by Sir J C Bose. Let us strive for it in future too. It would be a great tribute to the memory of this great Indian scientist.

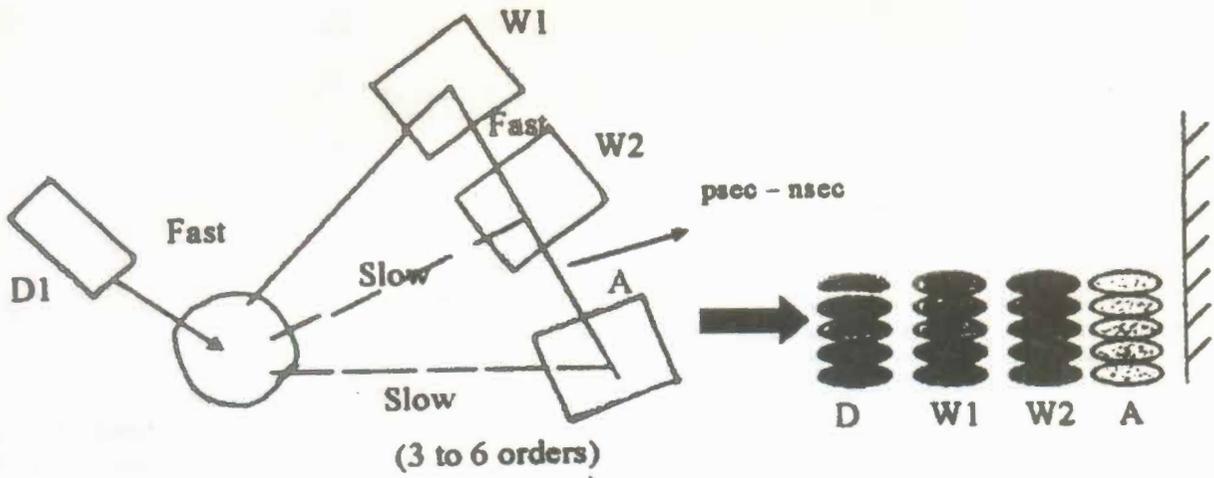


Fig 11 A naturally occurring photodiode

**ACKNOWLEDGEMENT**

The Figures taken from the proceedings of NATO workshop on Light as a energy source and information carrier *NATO ASI Series : Series A life Sciences, vol 287* are duly acknowledged.



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## Whither Bio-Science?

SUSHIL MUKHOPADHYAY

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A century ago, when bioscience was in a rudimentary stage and there was no tangible interaction with the basic sciences, an extraordinary biophysicist Jagadis Chandra Bose, demonstrated, with the help of extremely sensitive instrument fabricated by him, that plants are sensitive to light, heat, electric current and any others thus just like a living being.

Modern biophysicists started with an enormous amount of possibilities helped by a large number of discoveries on the nature of matter and radiation, together with diverse measuring instruments and concepts. For example, the use of X-ray crystallography to elucidate the structures of biomacromolecules like tobacco mosaic virus, hemoglobin, myoglobin, DNA and gene. Eminent physicists are trying to find out whether biological events could be explained on the basis of known laws of physics or are hoping to discover new laws. The physicists have thus been able to decipher the genetic code and elucidate genetic information and transfer mechanism and thereby to evolve the new branch of molecular biology. The outcome of the extension of molecular biology to a wider and more expensive domains has led to the evolution of biotechnology. With the help of this versatile discovery newer products in agriculture, medicine and industries have become possible. Our attention has, however, been drawn to the dangers of introducing new products, especially relating to food, unfamiliar to the environment. Some of the stalwarts in the field of molecular biology felt inclined to go over to neurobiology to the study of the brain. With that is associated such concepts as mind and consciousness. Some recent thoughts and concepts on mind and consciousness have been briefly touched upon.

It is interesting to note that the increase in diversity of organic molecules in all living organisms is reducible to glucose, 20 amino acids and 8 nucleotides, 4 each for DNA and RNA. All protein structures are complex but known. No biomolecules are functionless. Cells act as isotherm chemical engines, the chemical work being done by enzymes whose number is about 2000. Unlike manmade catalysts enzymes can carry out simultaneously many reactions with interference and 100% yield, and no by products. The Chromosome, an extremely small fraction of living cells is the storehouse of intense genetic information. It is wonder that the structure and contents of the cell have remained the same for over 100 million years.

Mind described as a system phenomenon characteristic

of living organisms, and matter no longer appear to belong to two separate categories but are seen as representing merely different aspects of the same phenomenon of life. The question then arises : What is the relationship of mind with brain? The exact relationship is still a mystery. According to the Santiago theory mind is not a thing, as Descartes thought, but a process, and brain is a specific structure. Penrose considers the mental functions to be completely non-computational.

Throughout the entire human history the application of science have been for good as well as evil purpose. Currently, human cloning is being debated from these points of view. Biological weapons which are not new have shown their ugly face in the context of the recent global war against terrorism. These two development in the areas of biological science have been briefly referred to.

### WHITHER BIOSCIENCE?

Bioscience, a century ago, was at the rudimentary stage, as an observational sciences, systematics oriented, growing independently of any tangible impact with the basic sciences, such as physics, chemistry and mathematics. In course of time a judicious application of basic sciences has transformed bioscience into a very fruitful scientific pursuit, almost beyond recognition. This story I am going to tell in what follows. But before that let us try to understand what a physicist of exceptional merit did a hundred years back. He was Jagadis Chandra Bose in whose memory this lecture is dedicated in deep devotion. I am sure that I am not competent to do so but those who made the choice have thought it otherwise. While carrying out his epoch-making discovery on the production and transmission of long wave radiation he noticed, to his surprise, that the coherer refused to respond, as it was doing a while ago, but only for a short while, after which it began to work as it should. It was similar to a living object which shows fatigue after working for sometime and recovers it left to rest for a while. This similarity, coupled with the philosophical outlook he possessed, born out of his knowledge of the Indian traditional thinking, viz, that the difference between living and non-living is born out of ignorance about their inherent properties. It struck him that while a so-called inert object like the coherer has fatigue, what about the plants which are, apparently, living objects in the sense that they grow and are affected by heat, light and stress. He then started the miraculous sets of experiments using plants of various kinds using instruments fabricated by him with the help to

his skilled workers. Since the response of plants of outside influence is very small his instruments were meant to enlarge them thousand or even million times. The experiments were so meticulously done and repeated several times that he was fully confident that his findings were absolutely correct. There were some non-believers who were finally convinced when he demonstrated beyond doubt that what were observed were true. He fabricated nearly one hundred instruments to measure and confirm the results and put them on a firm footing.

To quote him from one of his lectures at the Royal Institution in London: "I have shown you this evening autographic records of the history of stress and strain in the living and the non-living. How similar are the writings! So similar indeed that you cannot tell one apart from the other. We have watched the responsive pulse wax and wane in the one as in the other. We have seen the response sinking under fatigue, becoming exalted under stimulants and being killed by poisons in the non-living as in the living.

"Amongst such phenomena, how can we draw a line of demarcation, and say, here the physical ends and then the physiological begins"? Such elaborate barriers do not exist.

"Do not then records tell us of some property of matter common and persistent? Do they not show us that the responsive processes seen in life have been foreshadowed in non-life? That the physiological is related to the physico-chemical? That there is no abrupt break but a uniform and continuous march of law?"

"If it be so, we shall but turn with renewed courage to the investigation of mysteries, which have too long eluded us. For every step of science has been made by the inclusion of what seemed".

Contradictory or capricious in a new and harmonious simplicity, her advances have been always towards a clearer perception of the underlying unity in apparent diversity.

"It was when I came upon the mute witness of these self-made records and perceived in them one phase of pervading unity that bears within it all things the more that quivers ripples of light, the teeming life upon our earth and the radiant suns that shine above us - it was then that I understood for the first time a little of the message proclaimed by my ancestors on the banks of the Ganges thirty centuries ago. They who can see but one in all the shining manifoldness of this universe unto them belongs Eternal Truth - unto none else, unto none else".

J C Bose was the first biophysicist to bring about a shift in altitude of plant biologist from that espousing the predominance of chemical signaling in plants to one emphasizing electrical signaling. His comprehensive researchers with *Mimosa* and *Desmodium* are worm referring to in this connection.

## EMERGENCE OF MODERN BIOPHYSICS

Classical biophysics may be said to have started with Luigi Galvani's experiments with frog's legs and Alexander Volta's speculation that frog's leg merely serves as a detector. But the accepted view that electrical current can be generated by living tissues was demonstrated by du Bois Raymond's experiment with a very sensitive galvanometer. He was thus responsible for the start of electrophysiology and the beginning of modern biophysics. Such phenomena as osmosis and diffusion which were thoroughly explored by Fick, Van't Hoff, Ostwald and Arrhenius formed an important branch of biophysics, viz., of biophysical chemistry.

Modern biophysics may be said to have started with an enormous amount of possibilities, backed as it were, by a large number of discussions on the nature of matter and radiation, together with diverse measuring instruments and concepts. Radiation biology became in course of time a versatile subject with the discovery of X-ray, atomic and nuclear radiation: Bernal's X-ray crystallographic research on the internal structure of biomolecules in three dimensions were path-breaking. Similar were the works of Perutz and Kendrew on the crystal structures of hemoglobin and myoglobin and of Watson and Crick of DNA.

Then came such renowned physicists like Max Delbruck suggesting the nature of gene as a huge a periodic crystal, Niels Bohr speculating a kind of complementary relationship between physics and biology. Erwin Schrödinger trying to find out whether biological events could be explained on the basis of known laws of physics. Enthused by these topmost physicists, many physical scientists and also physicists were drawn to bioscience, hoping to discover new laws in the apparently enigmatic and exciting field of bioscience. Some of the pioneering works of such bioscientists have helped decipher the genetic code and elucidate genetic information. This has essentially enabled the evolution of transfer mechanism, and ultimately of a new branch of bioscience, namely, molecular biology, which has revolutionized the investigative methodologies of all branches of biological sciences. In course of time, it has under its fold the wider and more expensive domains of eucarae and finally the versatile biotechnology, offering tremendous possibilities and development of agriculture, medicine and industry. But one should not be oblivious of introducing harm, using biotechnical means. Adequate guarantee of safety about the new products of biotechnology must be ensured. This applies to all new materials that are unfamiliar with the environment.

Having been satisfied with their contributions in the domain of molecular biology comprising molecular mechanism of replication, recombination and repair, and mutations of the stalwarts in these fields of research have

become inclined to neurobiology, with the hope of understanding the functions and behaviour of the most complex "machine" of the human body, viz., the brain. With that is associated such concepts as mind and consciousness, whose mysteries are waiting to be unravelled. It is also possible that molecular neurobiology may marginally join hands with such disciplines as psychology and philosophy to forge ahead a new but imaginative discipline called cognitive science. More of this later.

### THE FANTASTIC PROPERTIES OF LIVING CELLS

The immense diversity of organic molecules in living organisms is ultimately reducible to a surprising simplicity: glucose, amino acids (20 in all), 3 nucleotides for DNA, and the same number for RNA. These 20 different amino acids and 8 nucleotides are same in all living species. Protein structures are complex but they are known. The building blocks of biomacromolecules are versatile and serve more than one function. For example the amino acids not only form proteins but also act as precursors of hormones, alkaloids, porphyrine, pigments etc. Nucleotide, apart from acting as building blocks of nucleic acids act also as coenzymes as energy carrying molecules. No biomolecules are functionless. The few axioms that underlie the organic functions of the cell are: (i) There are underlying simplicity in the molecular organization of the cell; (ii) All living organisms have a common ancestor; (iii) The identity of each species of organism is preserved by its possession of characteristic sets of nucleic acid and protein; (iv) There is an underlying principle of molecular economy in living organisms; (v) Living organisms create and maintain their essential orderliness at the expense of their environment which they cause to become more disordered and random.

Living systems are open systems, exist in a steady state, non-equilibrium open system. There is maximum efficiency in handling energy and matter.

The building blocks of living cells are unable to withstand high temperature, pressure strong electric currents, extremely acid and alkaline conditions, and strong electrolytes. They are essentially isothermal with small pressure difference between different parts. Axiom (vi) then reads like this: Cells act as isothermal chemical engines. The chemical work done by engines number nearly 2000.

Unlike any manmade catalysts, enzymes can carry out simultaneously many reactions without interference, giving 100% yield without by products. For energy transfer  $ATP = ADP$  process holds good everywhere.

It is wonder of wonders that a bacterial cell synthesizes simultaneously about 3000 different kinds of proteins in specific molar ratio to each other. Each protein may contain as many as 100 amino acids or more. The cell requires at 37°C 10 seconds to complete the synthesis of a protein. In comparison, the first synthesis of a protein in the laboratory

in 1969 required highly skilled chemists, many expensive reagents, hundreds of operations, complex automated equipment and several months. Still wonderful is the highly perfect fidelity for millions of generation and that fact chromosomes - tiny bits of the cell are the storehouse of immense genetic information.

The objective of narrating the fantastic behaviour of the living cells and their constituents is to indicate the challenge chemists and physicists have to face in unfolding their mysteries and to mimic than *in vitro*.

### MIND AND CONSCIOUSNESS

Mind is described as a systems phenomenon characteristic of living organisms, societies and ecosystems.

Mind and matter no longer appear to belong to two separate categories, but are seen as representing merely different aspects, or dimensions, of the same phenomenon of life.

To illustrate this conceptual advance represented by this unified view of mind matter and life, let us turn to a question that has confused scientists and philosophers for over a hundred years. What is the relationship between the mind and the brain? Neurologists have known since in 19th century that the brain structures and mental functions are intimately relation but the exact connection is still a mystery. According to a review published as late as 1994 there is no general agreement on the exact nature of this relationship. The Santiago theory proposed by Marituauna states that mind is not a thing, as Dexartes thought, but a process - the process of cognition, which is identical with the process of life. The brain, on the other hand, is a specific structure through which the process operates. The brain is the only structure through which the process of cognition operates. The entire dissipative structure of the organism participates in the process of cognition whether the organism has a brain or not.

Recent researches indicate that in human organism, the neurons, the immune and the endocrine systems form a single cognitive network. In this way a new synthesis of mind, matter and life is heralded.

Many of the key characteristics of Prigogine's dissipative structures, the sensitivity of small changes in the environment, the relevance of previous history at critical points of choice, the uncertainty and unpredictability of the future, are revolutionary new concepts from the point of view of classical science but are an integral part of human experience. Since dissipative structure are the basic structures of all living systems, including human beings, this should perhaps not come as a big surprise.

Instead of being a machine, Nature, at large, turns out to be more like human nature - unpredictable, sensitive to the

surrounding world and influenced by small fluctuations. Accordingly, the appropriate method of approaching Nature and to learn about her complexity and beauty is not through domination and control, but through respect, cooperation and dialogue. Indeed, Ilya Prigogine and Isabelle Stengers gave their popular book *Order out of Chaos* the subtitle "Man's New Dialogue with Nature".

In the deterministic world of Newton, there is no history and no creativity. In the living world of dissipative structures history plays an important role, the future is uncertain and the uncertainty is the heart of creativity. Prigogine reflects as follows: "Today the world we see outside and the world we see within are converging. This *convergence of two worlds is perhaps one of the important cultural events of our age*"

"Physical science", writes Fritzhof Capra in *Tao of Physics*, "in all its department is extending its bounds of knowledge, especially the knowledge of the fundamental unity behind the apparent diversity of the universe. Moreover, while physical science has succeeded in unfolding many of the mysteries of nature, it finds itself face to face with the mystery of man and of his mind and consciousness". It may be noted that such scientists of the early 20th century as Eddington, James Jeans, Max Planck, Einstein, Niels Bohr, Schrödinger, Dirac, Bose, Saha, Heisenberg, Wigner and other top scientists turned their attention not only to the observed sense data of the physical world but also of man, the observer.

Quantum theory has made it clear that atomic phenomena are understood as a chain of processes, the end of which lies in the consciousness of the human observer.

According to Julian Huxley and Teilhard de Chardin modern science, especially biology, seems to reveal the *within* of nature in addition to *without* of nature. Swami Ranganathananda said in one of his lectures: "Reality itself does not know any distinction between a *withany* and a *without*. These distinctions are made only by the human mind for the convenience of study and research". Swami Vivekananda in his lecture in London on the Absolute and Manifestation exhorted thus: "We find that searching through the mind we at last come to that Oneness, that universal One, the eternal soul of everything, the essence and reality of everything. Through material science, we come to the same Oneness".

Penfield, a distinguished neurosurgeon, who was responsible for the detailed mapping of the motor and sensory regions of the human brain is of the view that "Consciousness is a manifestation of activity of the upper brain stem but since, in addition, there needs to be something to be conscious of, it is not just the brain stem that is involved, but also some region of the cerebral cortex which is at that moment in communication with the upper brain stem and whose activity represents the subject (sense, perception or memory) or object (willed action) of that

consciousness. Other neurophysiologists have agreed, in particular, that the reticular formation might be taken to be the 'seat' of consciousness. A characteristic feature of the conscious thought is its oneness".

In the concluding pages of the Chapter on "Where lies the Physics of Mind?" Penrose writes: Consciousness seems to be such an important phenomenon that I simply cannot believe that it is something just accidentally conjured up by a complicated computation. It is the phenomenon whereby the Universe's very existence is made known. One can agree that a universe governed by laws that do not allow all the mathematical descriptions of a universe and that do not allow consciousness is not universe at all. I would even say that all the mathematical descriptions of a universe that have been given so far must fail this criterion. It is only the phenomenon of consciousness that can conjure a putative theoretical universe into actual existence.

He poses an interesting problem to the neuroanatomists: Although the total neuron counts in the cerebrum and the cerebellum are almost of the same order - 70 billions and 30 billions respectively - what makes (some of) the functions of the former conscious, whereas all functions of the latter unconscious? From this he argues that sheer degree of complications in the neural network of the brain cannot be the answer to the riddle of consciousness, for, that is more or less of the same magnitude in both. "It would surely be instructive to know what essential differences there might be in the cellular or cytoskeletal organization of the cerebellum, as opposed to that of the cerebrum, since it is with the latter structure that consciousness seems to have its much closer relationship. Moreover, he also wonders at why most of the nervous pathways from the receptors to the functional sites of the cerebrum cross over directions (left to right and vice-versa), while those in the case of the cerebellum do not. According to him it is the functions of the cerebellum that have some similarity "with the way that artificial neural networks are trained", the "cerebellum is, indeed, frequently referred to as 'just a computer' because of its entirely unconscious activity".

While he conscious that physics is far from solving the problem of consciousness within its strictly (classical or quantum) physical formalism as at present, Penrose firmly believes in the approaching possibilities of this new breakthrough in near future. For this, attempts towards reduction of biology, physiology or neurology into physics will not do. It is rather physics which will have to broaden its scope of study to be able to accommodate the complex functions of the human brain in its conscious activities. In the concluding section he writes: "The study of neuroanatomy, of neurological disorders, psychiatry and psychology has told us much about the detailed relationship between the physical nature of the brain and our mental conditions. There is no question of our being

able to understand such matters merely in terms of the physics of critical amounts of coherent mass movement. Yet without such an opening into a new physics, we shall be stuck within the strait-jacket of an entirely computational physics, or of a computational cum random physics. Within that strait-jacket, there can be no scientific role for intentionality and subjective experience. By breaking loose from it, we have at least the potentiality of such a role ..... I believe that there is already an indication, within the mysterious development of quantum mechanics, that the concepts or mentality are a little closer to our understandings of the physical universe than they had been before - although only a little closer. I would argue that when the necessary new physical developments come to light, these indications should become a good deal clearer than that. Science has a long way to develop yet; of that, I am certain!"

## TWO DEBATABLE CASES OF BIOSCIENCE RESEARCH

In the bioscience arena at least two elements of terror seem to loom large. They are the human cloning and the use of biological weapons. A brief mention of each of these two seems to be appropriate.

### CLONING

Cloning is the technique of creating the exact replica of a living organism. The technique with some variations is now available and used in many laboratories. The percentage of success was low in the beginning stages, but has now considerably improved.

Animal cloning, especially the domestic ones, is now being done in a number of institutes throughout the world. The question of human cloning is still a debatable proposition. The question is one of ethics. Governmental authorities throughout the world have denied funding for research on human cloning. Not only so, anyone found to indulge in human cloning in spite of the ban, the institute and the scientists engaged in such work are liable to rigorous punishment.

Even then he will not be surprising if someone somewhere is clandestinely trying his skill to perfect the technique of human cloning. This is not only out of curiosity but for aspirations of fame and money. At this stage it may be of interest to speculate on the pros and cons of human cloning.

It is reported that Great Britain is likely to withdraw the ban. An American physicist reported that he was going to start a human clone clinic in Chicago, ignoring the ban. Four volunteer couples have agreed to participate in the venture. Two Korean scientists have asserted that the technique of human cloning is within their capability. In spite of all bans interest are displaying human cloning organisations.

About the nature and characteristics of the clone, some doubts are likely to arise and dampen the aspirants. Physically, the clone may be identical but what about the age and mental and acquired qualities even if they are brought up under identical conditions? What also are the effects of drastically short circuiting the evolution?

Leaving aside the doubts expressed above there are some dangers listed below:

- (a) Will the clone be able to bring itself to equilibrium with the environment so quickly?
- (b) Clones if multiplied many times may disturb biodiversity.

Several are the advantages of cloning:

- (a) Preservation of likely extinct animals, e.g., A class of Panda in China;
- (b) Improved varieties of some animals, e.g., sheep; silkworm etc.
- (c) Making cancerous cells free from cancer organisms.
- (d) Diseased organs may be replaced by disease-free cloned organs.

### BIOLOGICAL WEAPONS

The use of biological weapons composed of microbes and viruses capable of spreading small pox, bubonic plague, cholera, typhoid, diphtheria, malaria, dengue, encephalitis, etc is not new. It was not widespread due to the fact that biological weapons are likely to affect the user as well as the enemy. There are also some problems in regard to deployment of biological weapons. Researches in this direction have solved this difficulty. This, together with the current war against terrorism, has increased the possibility of a global biological war.

The use of Anthrax, presumably by terrorists, is already in the news. Anthrax, it may be known, causes death of the affected person by destroying the membranes of lungs and intestine, remains active and lethal for nearly 40 years or more. There is also the possibility of mutation and self-perpetuation.

It is reported that despite a convention in 1972 on biological weapons, signed by as many as 159 countries, the stockpile of biological weapons in several countries is swelling.

Those who are prepared to use biological weapons and those who are devising preventive measures are not sure about whether they are worth the trouble. For instance, vaccination against germs modified genetically will not be effective. In this context, the human genomic research data are also viewed with suspicion.

The first part of the document discusses the importance of maintaining accurate records. It emphasizes that every transaction, no matter how small, should be properly documented. This includes recording the date, the amount, and the purpose of each entry. The text also mentions the need for regular audits to ensure the integrity of the data.

In the second section, the author describes various methods for organizing financial information. One approach is to use a ledger system, where each entry is recorded in a specific column. Another method involves using spreadsheets, which allow for more complex calculations and data analysis. The text suggests that the choice of method depends on the user's needs and the volume of data.

The final part of the document provides practical advice on how to implement these systems. It recommends starting with a simple system and gradually adding more features as needed. The author also stresses the importance of consistency and accuracy in all entries.

The following section details the steps for setting up a basic accounting system. It begins with identifying the types of transactions that will be recorded. Next, it discusses how to create a chart of accounts, which serves as a framework for organizing the data. The text then explains how to record transactions and how to calculate the ending balances for each account.

The author also addresses common challenges that users may encounter, such as missing data or errors in calculation. It provides tips on how to identify and correct these issues. Additionally, the text discusses the importance of backing up data regularly to prevent loss in case of a system failure.

The final part of this section offers suggestions for how to use the system effectively. It encourages users to review their records regularly and to seek professional advice if they are unsure about any aspect of the process.

The next section focuses on advanced techniques for financial analysis. It introduces the concept of budgeting and explains how to create a budget that reflects the user's goals and needs. The text also discusses how to track actual performance against the budget and how to adjust it as necessary.

Another key topic is the use of ratios and percentages to evaluate financial health. The author provides formulas for calculating various ratios, such as the debt-to-equity ratio and the current ratio. It explains how these metrics can be used to identify areas of concern and to make informed decisions.

The final part of the document discusses the importance of staying up-to-date on financial news and trends. It suggests that users should regularly read financial publications and attend seminars or workshops to stay informed. The text concludes by encouraging users to take control of their finances and to work towards their long-term goals.

## Biotechnology Research for Self-Reliance

MANJU SHARMA

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**S**IR J C Bose - intellect, simplicity, poetry and compassion personified in his magnificent personality are reflected in the excerpts from his diary.

(i) *"Beloved Lord, hear the cry of thy erring child. He has long wandered far and found no peace. Breathe in his dead soul and let it revive with thy love.*  
— *Compassion, 30th November 1882*

(ii) *"I have been long thinking whether the vast solar energy that is wasted in the tropical regions, can in any way be utilised. Of course, trees consume the solar energy. But is there no other way of directly utilising the radiant energy of the Sun?"*  
— *Science, 5th March, 1885*

Sir J C Bose, a doyen of Indian science, dedicated his whole life to research as one of the pioneers in the field of electromagnetic theory. The main areas in which he later worked include physical research, plant physiological investigations and the last 20 years of his research was devoted to comparative studies on the responses of plant and animal organisms. He nearly opened up the fields of microwave physics and communication, one of the great achievements in Indian science. He developed the microwave receiver and he was referred to as the first to employ a semiconductor 'Galena' as a self-recovering detector of electronic rays. India is proud of this invention. Today he is internationally famous as the father of modern biology. Isn't he an exceptional genius making landmarks in two non-correlated fields - physics and biology.

Sir J C Bose was just not a scientist par excellence; he was a poet, a professor and a saint. He set up the Bose Institute in Kolkata and he ensured that the surroundings of the Institute reflect the artistic personality and spirituality of the founder; he said:

*"I dedicate today this Institute as not merely a laboratory but a temple."*

He further said that *"The lectures given here will not be mere repetitions of second-hand knowledge"*. He also wanted the facilities of the Institute to be used by other scientists in the country. In his beautiful philosophical words, he remarked:

*"Although science is neither of the East or of the West*

*but rather international in its universality, yet India is specially fitted to make great contributions. The burning Indian imagination, which can extort new order out of a mass of apparently contradictory facts, is held in check by the habit of concentration. This restraint confers the power to hold the mind to the pursuit of truth with the infinite patience."*

Sir J C Bose became a Fellow of the Royal Society in 1920, and in 1927, he was the President of the Indian Science Congress. The great human being he was is reflected as *"It is invention which is of importance for the mankind, not the inventor."*

The third area in which Sir Bose put in major efforts was to emphasise on self-reliance in science and technology. Even the instruments which he used for his research were developed by him and he was very proud of it. It is the inspiration I drew from the life history of this great scientist that I decided to speak today before this august gathering, the relevance of self-reliance in biotechnology.

*"Attaining new heights in biotechnology research, shaping biotechnology into a premier precision tool of the future for creation of wealth and ensuring social justice - specially for the welfare of the poor"*.

— *From the Vision Document released by the Hon'ble Prime Minister of India September 7, 2001.*

### BIOTECHNOLOGY

The World has witnessed major technological revolutions which have changed the very fabric of the socio-economic scenario. The first revolution was in biological sciences; and the second in super computing and large-scale simulation. The scientists feel that the third revolution would be a social one with merger of biology and computer science; it may also involve the areas of physics, mathematics and engineering. Biotechnology in true sense represents a synergy of various disciplines; what Prof J C Bose considered important for scientific progress. The spectacular success of biotechnology in the 20th century is almost entirely based on discoveries and innovations in basic research; there has been great awareness to expand the investment in bioscience and knowledge base globally.

The biotechnological tools have helped researchers to dissect the innermost secrets of the cell and develop new ways for an early and correct diagnosis of diseases, prophylactic measures such as vaccines to impart immunity and therapeutic measures for treatment of diseases. Simultaneously, developments in the field of transgenic plants with enhanced productivity, disease resistance and stress tolerance offer means to feed the ever increasing population on this planet. These discoveries have had a major impact on environment such as microbial bioremediation, phytoremediation, etc towards an environmentally sustainable development. All this has been made possible by biochemists and molecular biologists who explore the tiny realm inside the cells, study the cause of diseases and search ways to improve life on earth.

If deadly diseases such as AIDS and cancer are to be cured, if the planet's pollution is to be cleaned up, if the food requirements of increasing population are to be met from limited arable land, new crop architecture is to be introduced to benefit the farmers. If the designer babies are to be produced, it will be the biochemists and molecular biologists together who will generate this knowledge and have more scientific breakthroughs.

Living organisms have the great ability to change and adapt for providing better understanding of the dynamics of life, from the secrets of cell to cell communication to the chemical changes in the brain which gives us the signal to change and adapt.

At the molecular level, there is need to understand the information in the DNA, to discover how portions of genetic material are turned "on and off" and to learn how the structure of protein determines its function. At macro level, scientists are struggling to study the interaction of different chemicals to form cells and that of cells to build different organisms. It is mind boggling to imagine how subtle differences in the instructions issued by the DNA are able to create vast array of life forms on this earth.

About 1.5 billion people in the world earn less than a dollar per day. In India, for population of more than a billion with limited arable land of 142.5 million hectare, the threat of large number of malnourished people, serious epidemics like malaria, tuberculosis, cholera and HIV AIDS are looming large on our horizon. The environmental burden of pollution and the rapid erosion of biodiversity of the country, lastly, a large number of unemployed people, biotechnology research and development would be a major tool to contribute towards self-reliance, to achieve our objective of sustainable development in harmony with environment for the entire population.

Biotechnology has made significant strides in the last century and this millennium world over is recognised as the era of biotechnology and information technology. A large

number of products have already been approved for marketing and many more are being developed. These products include dozens of therapeutics including human insulin for diabetes, growth factors used in bone marrow transplants, products for treating heart attacks, scores of diagnostic kits for AIDS, Hepatitis and other infective agents, enzymes used in food production etc. The first life saving drug Humulin was produced by recombinant DNA technology and this followed a plethora of drugs including Betaseron for treating multiple sclerosis, pulmozyme for cystic fibrosis, activase, a clot dissolving tissue plasminogen activator used for treating heart diseases. Not only now it is possible to produce these biopharmaceuticals in a form identical to that of normally occurring in the human body but also to design meaningful improvement in activity, stability or bio-availability. Such products are also free from contamination.

I am sure, we all recognise today that for humankind, to fulfill its minimum basic requirements, one area of science which offers enormous potential is biotechnology. I quote from the Address of the Hon'ble Minister (S&T), Prof Murli Manohar Joshi which he gave on the occasion of the 8th General Conference and 13th General Meeting of the Third World Academy of Sciences.

*"I propose for your consideration that 'Technology with a Human Face' could be that common agenda. Providing creative and innovative solutions in health services, population management, mitigating the damage to vast sections of our people from natural hazards like earthquake and cyclones, technologies for higher productivity in agriculture and desired levels of nutrition, technologies for conservation of land, water and resources and their integrated management for sustainable development and consumption leading to their ecologically balanced management could be some crucial elements of such an agenda."*

## AGRICULTURE

Biotechnology is helping to resolve that quandary by making it possible to grow more, healthier and nutritional food under unfavorable conditions of biotic and abiotic stress. Malnutrition has been one of the main concerns of the developing World as it results in nearly 12 million deaths every year of the third world children under five. Growing enough staple crops such as corn, rice, wheat, and potatoes without further extending the area of land will require sustained increase in yields per acre. Biotechnological innovations have a key role in fighting against malnutrition Worldwide.

Deficiencies of vitamin-A and iron, for instance are very serious health issues in many regions of the developing World, causing childhood blindness and maternal anemia in millions of people whose dietary staple food is rice. Biotechnology has been used to produce a new variety of rice "The Golden Rice"- that contains vitamin-A

precursor carotene and iron. This modified rice is expected to provide nutritional benefits to people suffering from vitamin-A deficiency related diseases. Adequate vitamin-A intake can also reduce the mortality associated with infectious diseases like diarrhea and childhood measles by enhancing the activity of human immune system. Genetically modified rice, which boosts yields by nearly 35%, has been developed.

Pioneer-Hi Bred (Nature Biotechnology, May 2000) devised a pin-point technique that could revolutionize the effectiveness of genetically improved plants. Just by changing a single base, herbicide resistance persist in successive generations of the modified plants.

Farmers have been battling for centuries using methods from conventional plant-breeding techniques, chemicals like pesticides and herbicides. But because of environmental and health concerns, the development and use of new chemical treatment regimes has declined. Advanced biology can endow plants with genes that help them to resist pests. For instance, cotton, potato and corn containing the Bt gene from a soil bacterium producing delta-toxin proteins that are selectively toxic to certain kinds of insects are harmless to other insects, humans and animals. Bt cotton has been launched for field trials in India with promising results.

In addition to pest resistance and herbicide tolerance, other traits are being added to crop plants that will allow them to withstand drought, freezing temperatures and salt toxicity. ICRISAT, Hyderabad has introduced short-duration chick pea varieties, maturing in 85-100 days. Two chick pea varieties Swetha and Kranthi not only could escape drought but also produced a yield as much as 1.7 tons per hectare. Another major problem we face in our crops is early pod shattering all over. Now the gene responsible for this trait has been identified. If this is inactivated, it prevents the seed shattering. This finding was reported in Nature. This is very significant as inactivation of these very genes in mustard, canola and other related commercially important crops would prevent dispersal of seeds which normally results in significant losses.

Recently a protein, the first of its kind, that switches in a plant natural defenses against diseases and insects has been approved in US in April 2000 giving farmers an alternative to chemical pesticides. The protein, named Messenger-produced from genetically engineered bacteria has been shown to increase yields in tomatoes and peppers by up to 22% besides, making plants more tolerant to drought. This Messenger protein is the first natural product that can turn on the immune systems of crops.

The merging of medical and agricultural biotechnology has opened up new vistas to develop plant varieties with characteristics to improve health. Research work is underway that will deliver medicines and vaccines through

common foods which could be used to immunize individuals against a wide variety of enteric and other infectious diseases.

Food production is the largest world-wide industry using bioengineering principles along with biology. Application of recombinant DNA to food industry is enormous. Functional quality of foods has also been improved by producing fruits and vegetables with improved flavor and texture. The effort to improve the functional quality of foods through biotechnology occurred in 1989, Flavr Savr tomato engineered to provide increased shelf life. Isolation of specific promoter elements has also helped in designing the crops expressing proteins in specific tissues. Now we can have blue roses and pink dahlias. These have a wider application in creating designed ornamentals for export purposes. Not only this, now we can prevent our fruits and vegetables from frost damage by genetic transformation. We need low cost nutritious food for children. Many technologies are available for this.

#### HEALTH RELATED ASPECTS - A MOLECULAR MEDICINE REGIME

Cloning or the exact duplication of specific genes has been an essential tool in biotechnology for more than 20 years. Cloning of human cells, organs and other tissues can produce replacement skin, cartilage and bone tissue for burn and accident victims. This could prove useful for developing internal organs for human transplantation.

The cloning of Dolly and Polly demonstrated that nuclear transfer technology could be used effectively. The breakthrough in developing stem cells holds the potential to control cancer, regenerate spinal cord and brain tissue, and successfully treat many diseases associated with aging.

Vaccines are one of the greatest developments of modern medicine. They have helped in eradicating diseases like small pox, pushed polio to the brink of extinction and spared countless people from numerous diseases like typhus, tetanus, measles, hepatitis A, hepatitis B, rotavirus and other dangerous infections.

In the words of Nobel Laureate Prof Rolf M Zinkernagel (1996 Nobel Prize)

*"Social medicine and access to basic necessities in life are as important as providing immunisation cover to population."*

(Last week in Delhi)

But still for many other diseases like, malaria, AIDS, herpes, hepatitis C, we have yet to find a successful vaccine. This gap exists due to the fact that standard immunization methods work poorly or pose unacceptable risks when targeted against a particular illness. Certainly alternate strategies are to be explored. One of the most promising ways is to develop vaccines out of the genetic material

either the DNA or RNA. DNA based vaccines will preserve all the positive aspects of the existing vaccines while avoiding the risks. They are easy to design and to generate in large quantities using recombinant DNA technology and as stable as others (even more so) when stored. Since they can be engineered to carry genes from different strains of a pathogen, they can potentially provide immunity against several other strains at once. DNA/RNA based vaccines are delivered directly into the cells and then these vaccines instruct the cell to synthesize the encoded antigenic proteins.

Indian scientists are making a concerted effort to develop vaccines for malaria, tuberculosis, rabies, JEV and HIV AIDS with good success and potential leads. We have already put the leprosy vaccine as an immunomodulator in the market and rota viral diarrhea vaccine is under field trials. In fact, we are also in an advanced stage of developing an anthrax vaccine. A number of diagnostic kits have been transferred to industry for use by the people of the country.

### **BIODIVERSITY & ENVIRONMENT**

Biotechnology has paved the way for conservation and sustainable use of biodiversity, our precious heritage, its conservation, evaluation and the study of genetic structure of species. Applications of modern biotechnology for bioremediation of contaminated land and water has made an impact. Bioremediation employs biological agents to render hazardous wastes into non-hazardous wastes. Even plants have been used for phytoremediation successfully.

Biotechnology as a tool has helped in recovery of degraded ecosystem. Some of the methods based on plant biotechnology include reforestation involving micropropagation and use of mycorrhiza. Micropropagation has resulted in increasing plant cover and thus preventing erosion and giving a climatic stability. Phytoplankton microscopic plants which freely float through the oceans and inhabit three-quarters of Earth's surface, hold a fundamental warming influence on the planet by capturing and absorbing the Sun's radiation. Thus, have a vital role in climate change. This concept has emerged as a result of studies carried out in the University of California, San Diego.

Our own scientists at TERI, New Delhi along with the support from DBT have developed technologies that can degrade crude oil and oil sludge. This can be packed in polybags and easily transported to the sites of refinery or accidental crude spill areas. Such are the innovations of biotechnology.

### **BIOENERGY**

Biotechnology also has a wider implication in increasing the bioenergy resources by increasing the acceptability of biomass, biogas, fuel alcohol as feasible

commercially available energy options for the future. Even the generation of biofuel cells by making use of catalytic properties of organisms and enzymes are used for energy conversion. Biofuel cells convert chemical energy into electrical energy. These biocells would be used as specific sensing devices for energy conservation.

### **BIOINFORMATICS**

Advent of computers have added a new dimension to biological research. With the rapidly evolving superfast computers, improved accuracy in legend screening, improved combinatorial chemistry designs, virtual explosion in the availability of three dimensional structural information and genome sequence database, the computational techniques will continue to take a centre stage in many different aspects of drug design and development process. Computer aided structure based drug design played a significant role in the recent successful development of drugs for the treatment of AIDS (HIV protease inhibitors) and of inflammation (COX-2 inhibitors).

Of late, biological materials in the form of biochips are going to have a tremendous impact on computer development per se. The biochips would replace the conventional silicon chips used in the computer. The development of biomolecular computers promise to be ten to thousand times smaller than the best super computers with much faster switching times and extremely low power dissipation.

Researchers at Advanced Centre for biochemical Engineering, London have succeeded in obtaining a tiny semiconductor structure from yeast *Schizosaccharomyces pombe*. The yeast produces structures as quantum semiconductors.

Computational tools for mining the genomic data, identifying the potential new drug targets, elucidating and/or predicting the three dimensional structure of targets from the primary structure are at the core of the present day bioinformatics technology. Computational approaches will continue to be essential part of the ongoing and future drug design and development process. Thus, future advances in biotechnology offer the promise of an impressive array of new and useful products and technologies for consumers, including farmers and rural population.

### **TO SUM UP**

Recent issue of 30th October of the Newsweek on the title page says "*The Biotech Boom*". In the words of Karen Lowry Miller:

*"Long dominated by the US, the field now bristles with new entrepreneurial players. The next Genetech may come from Rio, Munich or Delhi."*

India has enormous potential to harness the fruits of

biotechnology. How biotechnology has helped or is helping or would do so in future, I give some examples:

- (i) Over 2000 million people World wide have been helped by more than 80 biotechnology drug products and vaccines.
- (ii) There are many biotechnology tailored drug products and vaccines currently under human clinical trials and many more in early development.
- (iii) Scores of medical diagnostic kits that keep the blood supply safe from AIDS virus and detect other conditions early enough to be successfully treated. Home pregnancy tests are also biotechnology diagnostic products.
- (iv) Consumers are already enjoying food such as vine-ripened, long lasting tomatoes, better tasting carrots and peppers. A number of biopesticides and other agricultural biotech products are in use.
- (v) Innovations have led to expansion of numerous Biotech companies.
- (vi) Market capitalization, the amount of money invested by Govt. and private sector has also shown tremendous increase.
- (vii) Biotechnology as industry has given opportunities and created avenues for people.
- (viii) Biotechnology is one of the most research intensive industries in the World.

World has witnessed spectacular advances in the field of biotechnology after that breaking discovery of the double helix structure by Watson and Crick in 1953. On 26th June, the first "working draft" on Human Genome, the blue print of life was announced. Arabidopsis genome is complete; work on Rice Genome is nearing completion and so on. Genomic is a priority. Three billion ladders of the human genome provide enormous raw data for biotechnologists, medical and computer experts world over to move in their countless discovery regime. Hunger, poverty, ill health, unemployment and environmental calamities - as they would come in the way of progress of humankind, our dependence would increase manifold on this frontier area of science i.e., biotechnology. The challenge before us is to mount a massive effort on basic innovations in biology and build entirely new partnerships

with industries both private and public sectors, financial institutions, etc. The biotech industries - about 1300 in US; about 700 in Europe with massive investments, have already paved the way to a big bioindustrial revolution based on biotechnological innovations in the 20th Century. Presently, world over in US and Europe, 42 biotech products are in the market; about 230 in pipeline. In India, 11 biotech products have been introduced by drug industry. (Biotech Monitor, SGCOWEN March 2002), and many are in advanced stages of development.

The investment in these sectors is increasing manifold every year. My plea to the industry is that they must take the risk, make investment and try to speed up the revolution. Scientists alone would not be able to take the challenge. It will have to be a partnership and a team. Beside US, UK, other countries are speeding up. Japan is trying to catch up very fast in the post genome era. It is now for us to accept the major technological challenge and put in our best efforts to ensure a healthy, wealthy, prosperous and sustainable 21st Century for our people.

For indigenous self-reliance, it is essential that our scientific community works on Indian problems of agriculture, health and environment. The initiative of the Department in this direction is giving useful results. Our partnerships, with engineering community being strengthened now would be truly responsible for Biotechnology Incubator, Biotechnology Parks and industrial ventures.

Biotechnology is knowledge intensive, skill based field and is being nurtured all round for harnessing its full potential for the welfare of humankind.

Let me conclude:

Albert Einstein, the man of the Millennium, said:

*"Concern for man and his fate must always form the chief interest of all technical endeavours;..... In order that the creations of our minds shall be blessing and not a curse to mankind. Never forget this in the midst of your diagrams and equations".*

When we are steadily marching towards the path of innovations and discoveries, let us remember:

*Prajnanam Brahm - "Knowledge is God"*

1870  
The first of the year  
was a very dry one  
and the crops were  
very poor.

The second of the year  
was a very wet one  
and the crops were  
very good.

The third of the year  
was a very dry one  
and the crops were  
very poor.

The fourth of the year  
was a very wet one  
and the crops were  
very good.

The fifth of the year  
was a very dry one  
and the crops were  
very poor.

The sixth of the year  
was a very wet one  
and the crops were  
very good.

The seventh of the year  
was a very dry one  
and the crops were  
very poor.

1871  
The first of the year  
was a very dry one  
and the crops were  
very poor.

The second of the year  
was a very wet one  
and the crops were  
very good.

The third of the year  
was a very dry one  
and the crops were  
very poor.

The fourth of the year  
was a very wet one  
and the crops were  
very good.

The fifth of the year  
was a very dry one  
and the crops were  
very poor.

The sixth of the year  
was a very wet one  
and the crops were  
very good.

The seventh of the year  
was a very dry one  
and the crops were  
very poor.

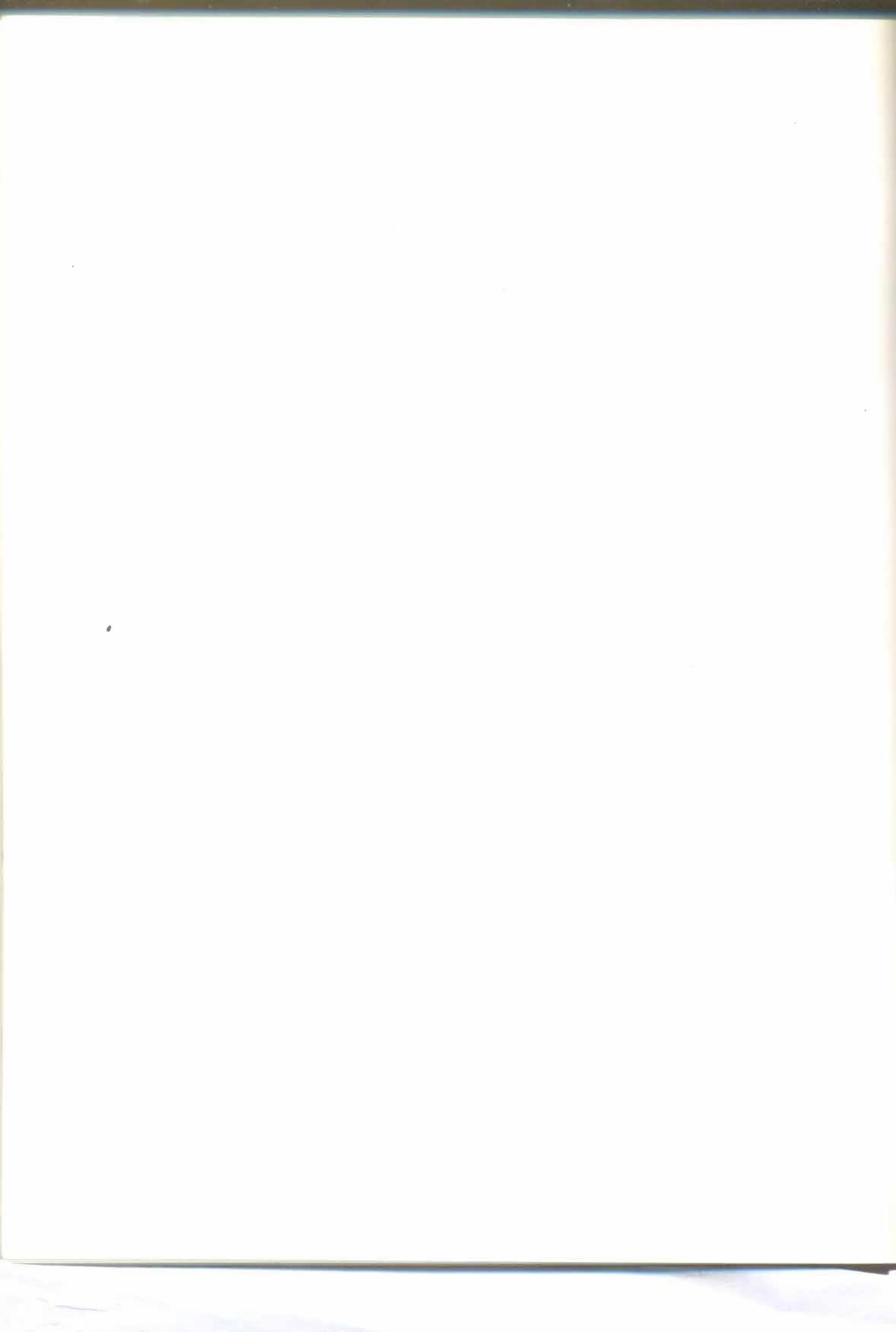


1888 – 1970

*SIR CHANDRASEKHARA VENKATA RAMAN, was the first noble laureate of India. Raman became professor of physics at the University of Calcutta in 1917. Studying the scattering of light in various substances, in 1928 he found that when light of one frequency was transmitted through a transparent medium, other frequencies were added and that they were characteristic of the material. These so-called Raman frequencies are equal to the infrared frequencies for the material and are caused by the exchange of energy between the light and the material. This phenomenon is known as "Raman Effect". Raman was knighted in 1929, and he received 1930 noble prize for physics for his discovery. In 1933 he moved to the Indian Institute of Science, at Bangalore, as head of the department of physics.*

*In 1947 he was named director of the Raman Research Institute, Bangalore and in 1961 became a member of the Pontifical Academy of Science. He contributed to the building up of nearly every Indian research institution in his time, founded the Indian journal of physics and the Indian Academy of Science, and trained hundreds of students who found important posts in universities and government.*

*The IETE has instituted a prestigious annual lecture series in the memory of Sir C V Raman. The venue for this lecture alternates between New Delhi and Bangalore every successive year.*



## Policies for Advancement of Science and Technology

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### Sir CV RAMAN As I Knew Him

**T**O see him was to be overawed. Sir CV Raman was tall and hefty and oozed self-confidence from every pore of his body. He never stood still. He was enthusiastic and his enthusiasm was infectious. Hearing him lecture was ever an unforgettable experience. I heard him first when I was only fifteen. He bowled us over even though we did not understand a word of what he was talking about! The next time my encounter with him was psychological, not physical. In my first day as an Honours student in the Presidency College, Madras, our professor reminded us that perhaps we were sitting in the same seat CV Raman sat when he himself was a student. That sense of awe never left us all the time we were students there.

My first year at the Indian Institute of Science was also to be the last one for Sir CV Raman to be professor there. We used to see him walking around (strutting around would be a more apt word because there was nothing sedate about him). I still have a vivid memory of the way he chased out the cameraman of the Documentary Films of India who had come to make a film on the Indian Institute of Science and, quite naturally, wanted to feature him. He shouted at them with words to the effect: "Your government is asinine and knows nothing about the promotion of science. Don't think taking a picture of me will do anything good to science and don't waste my time! Get out!" At that time, I did not quite understand why he was angry. It took some years for me to appreciate what he was talking about.

### Raman's Objections to R&D Laboratories

Raman was furious because, around that time, on the model of the National Physical Laboratory at Eddington in England, the government established the NPL in Delhi. Raman's argument was that the money should have gone to a university institution, naturally his own! Setting aside his personal pique, there was much justification for his annoyance. For a start, it is no accident that virtually all Nobel Prizes have gone to universities and few to far better endowed non-academic research laboratories. The reason is simple: good research needs young research students. Hence, diverting talented researchers from academic institutions to full time research hurts both ways: Full-time researchers lose the stimulation that only young research students can give. Students too lose because the best minds

are drawn away from teaching. In particular, applied research is liable to be siphoned away completely from universities. At the same time, without the discipline of teaching, researchers are liable to lose touch with basic principles and the quality of their research is liable to suffer. So, isolation of teaching from pure research (at times, even applied research) will hurt both research and teaching. All these fears of Raman have come true. Pre-independence India produced stalwarts like Raman, S N Bose, J C Bose, Meghnath Saha, H J Bhabha, Birbal Sahni and others. After Independence, such flow of talent has dried out in spite of massive increases in government funding. Primarily that is because of the diversion of both physical and human resources from universities. As a consequence, the quality of teaching too has come down. As a matter of poetic justice that has hurt the laboratories themselves - the scientists they recruit are less well educated than they could have been.

### SAD STATE OF SCIENCE EDUCATION IN THE COUNTRY

Today, fifty years after Independence, everyone admits that science education in the country is in the doldrums. The days are gone when bright youngsters fought for admission to science courses. Only when they fail to secure admission to engineering, medicine, commerce and every possible teaching shop for computer courses, do the thoughts of modern youth turn to science. That is a pity because without good science as a base there can be no good engineering or medicine. Engineering studies too are not in a good shape because, irrespective of the branch that the engineering students study, they are all crazy about dotcom and Internet. Whatever discipline they may join, students these days take the first opportunity to convert themselves into computer engineers - more accurately into computer technicians. This state of affairs is not helping the computer industry either because, the way they are trained, most students are fit only for, what Mr Vittal calls, techno-coolie jobs. It is a matter of grave doubt whether such persons will be able to take on international competition in this fastchanging, fast globalising world.

Bright youngsters need role models and that is what they lack most in India. When Raman retired, Professor R S Krishnan (among whose claims to fame includes the fact that he was Sri T N Seshan's father-in-law), never sat in the chair used by his Guru. That was "Professor's Chair",

meant for the "Professor" and none else. That was the veneration that he gave to Sir C V Raman. When Professor Krishnan moved out, the room occupied by Sir C V Raman was handed over to the Accounts Officer and it is possible that the chair Raman adorned has become the property of some lower division clerk. That is our sense of history. That is the respect we have for the greatest Indian scientist of the Twentieth Century. Then, why should it come as a surprise that today's youth have little or no respect for science and prefer to become accountants?

The state of engineering education is little better even though the demand for engineering education is enormous and there are now over 800 colleges claiming to teach the subject. In truth, most of them are teaching shops that give some sort of training and next to no education. Quantity is no substitute for quality.

Over the years, we have distorted education to a process of learning-by-heart "typical question and model answers". The system of Entrance Examinations starts that epidemic even before a student is admitted. Entrance examinations were first introduced by IITs partly to cope with the flood of applications, partly because the integrity of high school examinations came under a cloud and mostly to protect themselves from political interference. At any rate, it was merely a tool. Now, what was once a tool has now become deity!

### **BANE OF ENTRANCE EXAMINATIONS**

There is a proposal to have one single nationwide entrance test to decide the admission to every single engineering college in the country. The incongruity of forcing a single straitjacket on to every kind of engineering institution of this era of decentralisation appears to be lost on our policy makers. The problem with entrance examinations is that it breeds a class of students who can only prepare themselves to answer known questions and not solve unknown, unexpected ones. When CV Raman was sailing in the Red Sea on his way to England, he noticed the sea was blue. He asked himself the question, why was the sea blue. Millions of people has sailed before him and had never the curiosity to raise that question. Even if they had, they did not know how to answer the riddle. Raman could do both and therefore won the Nobel Prize. Can our education system arouse that sense of curiosity in our youth and train them to solve such basic questions?

Even at the mundane level of physical management a universal entrance examination is an anachronism. Imagine what a disaster it will be if the question paper leaks out in some corner of the country. We will have to re-examine a million students all over again just because there was one crook in some obscure town. There is yet another mechanical problem. The range of marks between the highest and the qualifying level will be about 50 in any one subject. Then, the maximum range for the three papers of mathematics, physics and chemistry taken together will be

150 marks. Within this range, the Entrance Examination will have to list in the order of merit over a 100,000 students. On an average, there will be nearly 700 students for any given aggregate mark, often that could be as many as 2000. For that reason, the system offers next to no discrimination for the purpose intended.

The intellectual limitation of the Common Entrance Test is even more serious because a single examination assumes that there is only one type of engineering and only one type of candidate can be a successful engineer. It certainly offers no scope for the likes of Einstein who failed in high school mathematics. It looks as though the Entrance Examination is collapsing by the weight of its own success. In moderate doses, entrance tests are undoubtedly useful. Taken to absurd extremes, it becomes unviable both academically and administratively.

Then, there are three fundamental issues that are vitiating education in science and technology in the country. One is the reluctance of bright youth to take up science as a career and the complementary stampede into engineering courses. There is too little of one and too much of the other. The second is the diversion of resources from universities to narrowly specialised research laboratories. Compounding these two problems is the siphoning of talent away from the teaching profession. It may sound as a hyperbole to say that the country's future prosperity depends on resolving these issues. Yet, such an assertion will not be far from truth. The remedy lies in fulfilling the needs of genuine scientists.

### **Maslow Needs**

**Physical Needs:** According to the psychologist Maslow, human needs are basically five in number and they appear in a sequential hierarchy. At the lowest level are Physical Needs. They will be satisfied only where there is adequate income. On that score, students can be attracted to science by raising the salaries of scientists. However, those that are attracted only by money are unlikely to become great scientists. Let us not forget that Raman took a substantial cut in income to shift from employment in the civil service to become the Palit Professor of Physics in Calcutta University. That is the spirit that creates great scientists.

Even otherwise, a professor in an Indian university earns twenty times the national per capita income; in the US, professor's salaries are generally barely three-four times the per capita income. Hence, in relation to the nation's capacity to pay, university professors are already generously paid. Thus, both from a physical and a psychological point of view, raising salaries is not a suitable solution.

**Security Needs:** Security Need is at the next higher Maslow level. University professors are already more than secure. In Western countries, the slogan is "publish or perish". In India, no matter how badly a teacher performs,

there is always a promotion round the corner - by becoming sufficiently senile. So, increased security too is not the best way of attracting scientific talent.

**Status Needs:** Status Need is at the third Maslow level. Traditionally, the status of teachers and scholars used to be high in India, often higher than even that of the rulers. That is no longer the case. Nowadays, clerks in the administration push them around, and therefore, enjoy *de facto* a higher status. On the other hand, that kind of humiliating treatment is the bane of everybody. Systematic destruction of self-respect of all persons, high or low, has become a notable feature of Indian democracy. IAS officers are subjected to untold humiliations all the time. Even cabinet ministers are often treated like domestic servants by their "supreme" leaders. In an environment where only power and money count, it is little wonder that professional expertise commands next to no respect. Scientists who have migrated abroad generally cite the absence of a scientific culture as the greatest deterrent to their return to their homeland. Absence of respect for scientific pursuits is another way of expressing that state of affairs.

Thus, giving teachers and scientists the respect that is due to them, the kind of respect they get as a matter of routine in developed countries, will remove one disincentive that discourages youth to pursue teaching and research careers. In general, raising the status of teachers and researchers needs no extra money; better manners will suffice. However, national and international travel to meet their counterparts is an age-old tradition among scholars and an essential status need. In India, at least for teachers travel facilities are poor and the procedures are humiliating in the extreme.

It is often said that the National Science Foundation of the United States will ask a proposal to be resubmitted if it does not include sufficient amount for travel. The Foundation takes the view that a study worth doing is worth disseminating widely. In India, there is no such sensitivity. The official view is attending seminars is a waste of time and money. Until this primitive notion is changed, and researchers attending seminars is treated as a matter of national prestige, ambitious youth will not be attracted to Indian science. Incidentally, such travel costs little. Indian universities have at the most a couple of thousand active researchers. A budget no larger than Rs. 30-50 crores a year will suffice to meet this Status Need for all of them.

**Autonomy Needs:** Autonomy Needs come next. Here a lot more needs to be done, even more than in the case of Status Needs. A university is expected to have three freedoms: the freedoms to decide whom to teach, who will teach and what to teach. Precisely on these counts, government interference is greatest. Sir Ashutosh Mukherji could invite a Raman who had no teaching experience whatever to occupy the most prestigious chair in science in Calcutta University. Can any

vice-chancellor dare do such a thing now? Imagine insisting that Bismilla Khan should take as shishyas only those who pass a common entrance test conducted by the government! But that is exactly what the government wants and to which intellectuals meekly acquiesce.

Modifying syllabi in our universities involves archaic and tortuous procedure's and subject to "democratic" rather than intellectual control. Scholarship is not the adoption of the average but the pursuit of the exceptional. Only those who are iconoclasts, who challenge authority and strike out on a new path of their own, become great scholars. Without such intellectual autonomy no university will become great. Great research needs questioning minds. Such minds will not flourish in a servile or stultifying atmosphere. That is why higher education is elitist and neither puerile democracy nor autocracy can build great universities, and certainly that is not the way to attract and nurture great minds. No doubt, such minds need royal patronage but they cannot survive under royal tutelage.

**Selfactualisation Needs:** Finally comes Self-actualisation Needs - the need to pursue whatever activity a person wants to excel in. There is hardly any one in the country who can honestly say that the country offers the opportunity, the freedom, let alone the encouragement to excel. The government is deeply concerned about the weak and the disadvantaged and rightly so. In that zeal, the government has thought it fit to handicap the competent, to discourage the brilliant and confine patronage to the incapable. No doubt the government makes much of a Kalam here or a Swaminathan there who manages to survive in an environment of total hostility to competence. That will not suffice where the infant mortality among talented youth is virtually hundred per cent.

Sadly, great minds are few. Of the millions who graduate from schools every year, barely a few thousand have the intellectual potential, the internal fire and motivation and the spiritual strength to pursue R&D as a career. It is fair and proper for the government to patronise the poor and the under-privileged. At the same time, it would be wise to set apart a small niche for those who are exceptionally well endowed intellectually. Just as the poor have their rights, the competent too deserve to have rights of their own, particularly the right to pursue knowledge at a pace faster than others and to mingle freely with like minds.

There is a well-known fable in which a jealous person obtained a boon on condition that his neighbour will get twice as much. So, he prayed that he might lose one eye so that the neighbour will lose both of his. Many of our politicians operate on that principle. They would rather impoverish their vote banks than let others prosper. No nation can prosper that ties down talent to the pace of the under-endowed, or let them flee to other countries the way we do.

## A SEARCH FOR SOLUTIONS

Success in any field, including science and technology requires innate talent, the specific talent matched to the requirements of each case. Obviously, with the best will in the world, one cannot make Lata Mangeshkar a tennis champion nor Tendulkar into a Tagore nor teach Arundhati Roy elementary arithmetic.

So many outstanding minds have emanated from poorly endowed families that it is certain that talent is not confined to the privileged classes alone. Dr Kalam is one such example. He started in life with every possible handicap imaginable. Though not illiterate, his parents were unschooled and poor. They belonged to a community of artisans that did not set much store on bookish learning and on any type of formal education. They also lived in a remote corner of the country with next to no educational facilities. At the same time, Dr Kalam did enjoy several advantages:

- (a) He was intelligent with mathematical skills far above his peers.
- (b) Though not educated, his parents were wise and inculcated in him high cultural values.
- (c) His family was willing even to pawn jewels to support his education.
- (d) He had a teacher who recognised his talents at a tender age, and went out of his way to encourage him and persuaded his parents to sacrifice their short-term profit to let him study in the middle school.
- (e) He had in him a desire to excel, to succeed.
- (f) He had the opportunity to work in ISRO where the work was of the highest quality and where everyone was driven to excel and succeed.

These advantages outweighed his handicaps. Similar factors will be found to be the case with many others who achieved great success in life in spite of emanating from disadvantaged backgrounds. Most of these advantages are internal, and the state can do little to help. Yet, it can, as a matter of policy, adopt the following:

- (a) Encourage mass media to promote high quality family-values and active interest in educating children.
- (b) Provide good quality nutrition to mothers and children.
- (c) Make school education affordable.
- (d) Provide, as Dr S Radhakrishnan suggested in his Education Commission Report, compensation to poor parents for the pecuniary loss they suffer when they send their children to the elementary school instead of having them perform full-time domestic chores.

None of these suggestions, except the one for compensating parents of school going children, involve additional financial outlay.\* However, the cost should be within the means of the central or state governments.

Politicians will object to selecting teachers on merit and prefer to use those appointments for political patronage. Which would help the poor children more - a Shivasubramnia Iyer or someone selected on the basis of caste and patronage?

The main thrust of the argument here is that the government should take particular care of talented youth. Then, the government would do well to adopt the following policy:

- (a) Identify talent in a tender age (That is the main reason for the phenomenal success of the Chinese in all endeavours).
- (b) Nurture selected talented children from a tender age by providing the means to cultivate that talent.
- (c) Provide a competitive environment to help such talented people hone each other's skills to the sharpest possible level of brilliance.
- (d) Select the best available teachers, the best intellectually, emotionally and culturally. (Teachers have to be the best because they are the intellectual seed of the next generation.)

Indian politicians are likely to object to the last suggestion as they normally wish to use teachers' selection for political patronage. Such politicians will do well to consider "Which will help the poor more - teachers like Sri Shivasubramania Iyer or the kind that the government appoints on political grounds?"

## IDENTIFYING AND NURTURING TALENT

The main thrust of the argument here is talented children should be identified at a tender age and accorded a challenging and stimulating environment. Usually centrally organised written examinations are used to select students for special treatment. Written tests with secret question papers, and open for all, have several disadvantages. They cannot match the large variety of backgrounds the children come from. They do not inspire much confidence. However well the questions are designed, somebody or other will complain that they were either too difficult or out of syllabus or inappropriate. Physical management, distribution of question papers, collecting answer books, valuing them, and maintaining secrecy are all difficult, if not impossible. Above all, secrecy is threatening.

\* One adult family member may be given paid work each day the child attends school and provided the total attendance is no less than 90 per cent. The daily wage may be kept at, say, two-thirds of the minimum wage, the remainder treated as the fee for education. At Rs 60 per day and for 150 days in the year, that will come to about Rs 10,000 per year per child. About 20 million children in primary schools may demand this facility. So, the total cost of this scheme will be of the order of Rs 20,000 crores per year.

As communication engineers, we all know that the characteristics of multi-stage filters will be superior to any single stage one. Hence, entrance to an IIT or any other prestigious institution is best organised in several stages as below:

- (a) All selection examinations will have open questions disclosed beforehand and set at a level only talented minds can answer.
- (b) Students' own teachers will conduct a preliminary test and shortlist a number depending on the numbers that qualified in earlier years.
- (c) The tests will be held at four stages - at the end of the primary, the middle, the secondary and the higher secondary levels for admission to select prestigious institutions at the next higher level.
- (d) In order to help late developers, lateral entry will be made available at each level.
- (e) The admitting institution will test the knowledge of the shortlisted candidates in depth and not in breadth - in the field of their own choice, as in the case of the Mastermind quiz on the BBC.
- (f) Each admitting institution will admit students only out of the shortlist, which will be no more than two-three times the numbers admitted.

This system empowers those who have taught the children to make the shortlist. It ensures they select the best because, if they play favourites, the number they can shortlist in the future is liable to get reduced. At the preliminary selection level, questions are open; so the tension is minimum. At the final selection stages, questions are both open and open-ended but the tension is still low because the candidates themselves choose the area where they like to be tested. That will separate those who think from those who mug up.

The administrative and financial burdens will be very low under this scheme. As the examinations are highly decentralised, students from backward regions will have as good a chance as those from cities. Multi-stage selection ensures that the numbers taper off gradually and not abruptly as in the current system of one-shot entrance examinations. Lateral entry offers extra opportunities for those who miss out at any stage for any reason whatever (Fig 1).

### EMPOWERING THE R&D LABORATORIES AND ACADEMIC INSTITUTIONS

Raman's concern, that full-time research laboratories will not be as fruitful in the advancement of basic principles as academic ones, remains to be addressed. As matters stand, it is not possible to transfer either the human or the physical resource from R&D establishments back to the universities. However, there is no major obstacle for each of

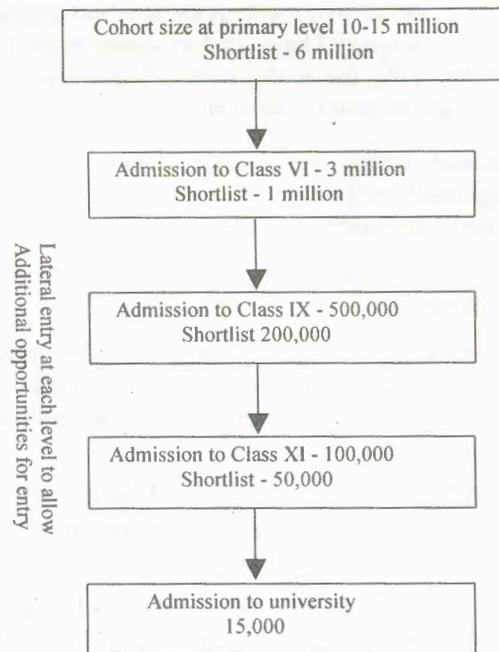


Fig 1 Proposed multi-stage talent search

these laboratories to become a Deemed University and take to teaching in addition to their normal R&D tasks. Such Deemed Universities may stimulate bright students even better than conventional ones.

One further reform is needed to empower these institutions. Status is very important for teachers and researchers. They cannot have a high status unless the institutions in which they work are prestigious. Those institutions will have prestige only when they are autonomous and free from political and other outside interference and control. The IITs are as good as they are mainly because they enjoy considerable autonomy. We need to institutionalise such and even more autonomy for all educational and research institutions.

For that purpose, we may consider installing two autonomous boards for each institution. One will be the Board of Trustees composed of those who provided the capital. They oversee the future development of the institution, operate the capital budget, and will also select the CEO, COO and the CFO of the institution. A second body, the Board of Governors will be composed of reputed academics headed by the CEO and assisted by the COO and the CFO. This Board will have autonomous jurisdiction over academic and research affairs and operate the recurring budget. Such an arrangement has worked well elsewhere. It is the best way of satisfying the autonomy needs of the academic and research staff without the fund providers losing managerial control.

### CONCLUSION

How can we identify and nurture talents like those of Sir

CV Raman, and do so however poor their background may be? That is the query I have tried to answer in this talk. In brief, I expect that the quality of both Indian teaching and R&D can be expected to rise to international levels if:

- (a) Talented children are identified at the primary school stage itself and however poor, they are all empowered to get high quality education.
- (b) Lateral entry at higher levels is introduced to help late developers.
- (c) Admission to prestigious colleges is done through a multi-stage, two-step process with shortlisting done by those who have taught the children and the final selection by the admitting institution.
- (d) R&D laboratories are made Deemed Universities to offer additional high quality academic opportunities for bright students.
- (e) All academic and R&D institutions enjoy full academic freedom, and administrative autonomy too, in day-to-day affairs.

Admission rate in centrally conducted entrance examination can be as little as one in fifty or even one in

hundred. That way many talented students are liable to get wrongly rejected. In the proposed system, at each stage, around one in two or three is selected. That minimises the probability of any talented candidate being rejected.

This system fulfils Maslow Needs quite well - but in reverse order. The multistage selection ensures that students do not make a random choice but self-actualise by repeatedly opting for the course they like best. Letting candidates select the area of final test satisfies their Autonomy Needs. Admission to prestigious institutions will satisfy Status Needs. That guarantees a secure future - and fairly substantial incomes too.

Will these steps ensure that bright students will not forsake science and technology for more remunerative careers like selling soap? They may not succeed every time but those who have spent years under motivated teachers are likely to choose as Sir CV Raman did - prefer academic challenge over power and money.

Let me hope that the ideas I have suggested here will find favour with policy makers and that we will start producing Nobel Prize winners in abundance in the near future.



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Founded in 1953, The Institution of Electronics and Telecommunication Engineers (IETE) is a leading professional society devoted to the advancement of science and technology of "Electronics, Telecommunications and IT". Government of India has recognised IETE as a Scientific and Industrial Research Organisation (SIRO) and also notified as an educational Institution of national eminence. IETE serves its more than 50,000 members both individuals and industries/ organizations through its 46 centres which will be 50 by end 2003, spread all over India and abroad. The broad objectives of the IETE are given below:-

- Organize conferences, symposia, workshops and brain-storming sessions involving all concerned professionals, students and industry associates for the advancement of the discipline.
- Provide a forum for the discussion on national policies and to provide suitable inputs to the policy makers.
- Promote and conduct basic engineering and continuing education programmes for human resource development.
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- Stimulate research and development in the discipline.
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