PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Into the World of Economic Broadband Systems

K. G. Corfield

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Into the world of economic broadband systems

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[Plates 1 and 2]

The advance of technology heralds changes to the structure of the telecommunications industry. Electronic components will form an increasing proportion of system hardware and there will be fewer components specialized for telecommunications. Equipment hardware will reduce in size and added value but the software content will become significantly higher.

With development and engineering being a major and increasing proportion of costs, there is need to concentrate national resources to provide designs which are both competitive in the export field and meet the operational needs of the national network.

Whereas speech is still the predominant medium, the forward trend will be to converge speech and data into a total communication package.

Technology already provides the potential for the provision of a wide range of services providing growth opportunity in peripheral equipment and greater utilization of the main network.

The greatest innovation will be the satisfaction of the latent demand for very wide band transmission through an overlay network using optical carrier technology and this will lead to new dimensions in telecommunications.

My task is to build on the picture, so vividly painted by the two previous papers, of what is little less than a revolution in telecommunications.

The march of technology now makes possible ideas which have long been depicted by science fiction writers, the projection by telecommunications of the total range of human senses – sound, sight, touch and smell. All is possible: the difference between aspiration and reality is the realization of truly economic, low cost, broadband systems. As a member of the telecommunications supply industry, I am concerned to advocate that this technology be exploited as part of the vital infrastructure of the nation; but as a private citizen I am no less convinced that the commitment of the appropriate resources to bridging the communication gap will be one of the greater gifts we can render to posterity.

For one hundred years telecommunications developed without resort to electronics. Most telecommunications plant is still electromechanical, huge numbers of wires connected by mechanical switches. Even the telephone at home is unlikely to contain electronics. It has no amplifier, no valve and no processor, and its microphone transmitter depends on a peculiar resistive phenomenon encountered in the interaction of a pile of carbon granules. Since World War II, electronics have come into telecommunications transmission in a big way and electronic circuitry is already greatly reducing transmission costs per circuit mile (figure 1).

Thus a fourfold reduction in costs per circuit mile has been achieved in the past 25 years even after the effects of inflation. It would be conservative to claim that real costs have been reduced by ten times. The estimates of costs per kilohertz per mile show the expected future trend (figure 2). Depending on terrain and diversity of service there are a number of systems which will play important rôles. Of these, that most relevant to a national interactive network appears to be optical fibre carrier transmission. The postulated system is a P–N junction diode in gallium arsenide, producing high intensity infrared light by laser action. This is transmittted by a silica fibre for distances up to about 20 km which may be extended by pulse regenerators of compact design having low power requirements.

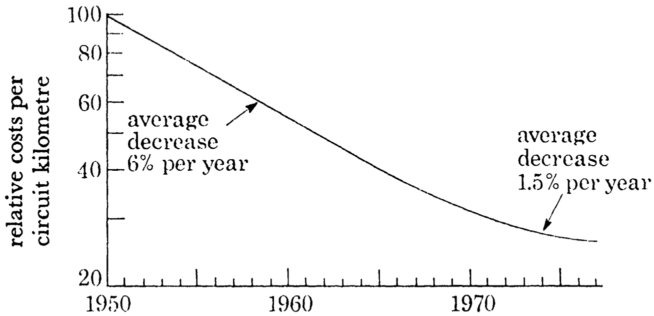

Figure 1. Relative long distance circuit costs (at constant prices).

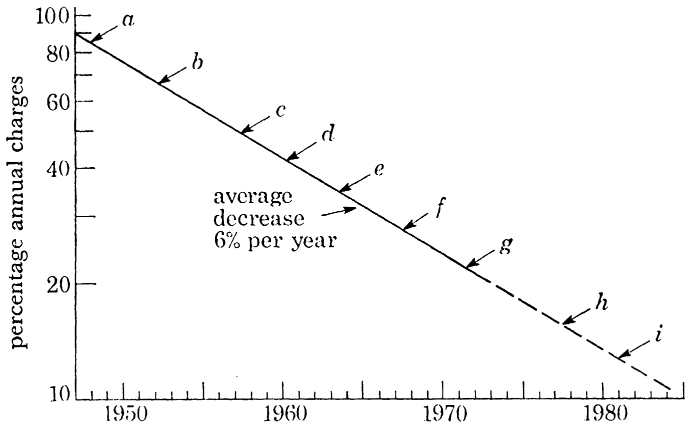

Figure 2. Relative line plant costs of a 100 mile (161 km) trunk circuit (at constant prices). *a*, 24 circuit carrier systems; *b*, 600 circuit coaxial systems (9.5 mm); *c*, 960 circuit coaxial systems (9.5 mm); *d*, 2700 circuit coaxial systems (9.5 mm); *e*, 960 circuit coaxial systems (4.4 mm); *f*, microwave radio systems; *g*, 2700 circuit coaxial systems (4.4 mm); *h*, 10800 circuit coaxial systems (9.5 mm); *i*, waveguide systems and optical fibre systems.

The microwave network is familiar and offers excellent line of sight transmission. Further developments in microwave sources will extend the already wide range of applications, especially in the mobile and transportable field. The waveguide, which takes the form of a hollow tube offers economic very-wide-band (100 GHz) transmission between fixed points over long distances using regenerators at similar intervals to that of optical fibre cable. The development of semiconductor-compatible transducers capable of interfacing a wide range of input and output requirements reduces the cost of variants and enables systems to be developed side by side until the decisive advantages of one or the other have become clear.

No mention of long distance transmission would be complete without consideration of the satellite (figure 3), which has been dramatic in its impact; particularly is this true of the growth of international live television exchange. If the future holds promise of peaceful coexistence then it equally holds increasing promise for huge growth in satellite communications, when their vulnerability to enemy action and relative lack of security is of low account.

Tropospheric scatter, sometimes called over or down the hill radio, has special appeal in unusual geographic conditions or field mobile work where a combination of distance and terrain makes microwave impractical, but tropospheric scatter does not fall in the true very wide waveband class.

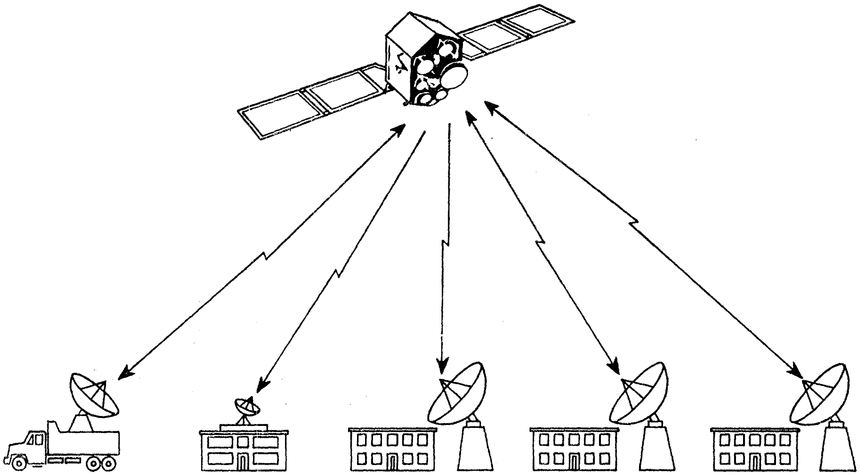

FIGURE 3. Long-distance transmission via satellite.

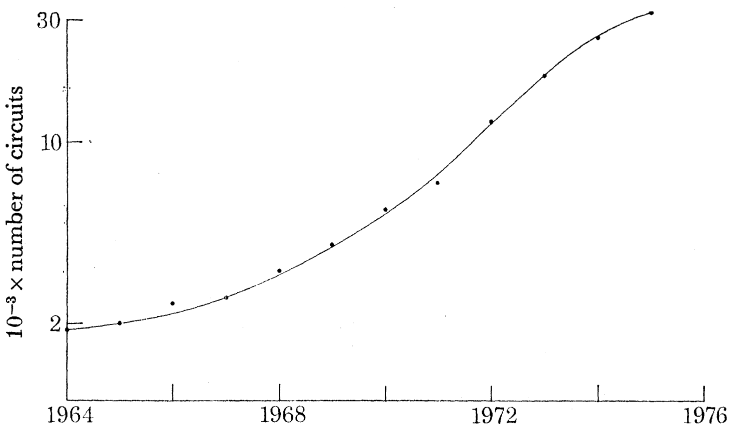

FIGURE 4. Worldwide submarine repeatered cable systems.

These technologies bring down the cost of long distance communications and, as fast as they are developed, the latent demand of the world population surfaces to take up the growing service. In figure 4 we see the increase in circuits of oceanic cable, and in figure 5 the reduction which has occurred in the cost of a one-minute transatlantic telephone conversation.

However, transmission alone does not provide diversity and the individuality of service: it must be matched by the ability to switch the transmission train from the originating subscriber to any one of millions of other subscribers that he can reach throughout the world

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Switching stayed electromechanical until well into the sixties but is now evolving, first as a result of processor control and secondly by the development of new systems based on the theory of pulse code modulation (p.c.m.), enabled by the technology of large scale integrated circuits and the production of microprocessors.

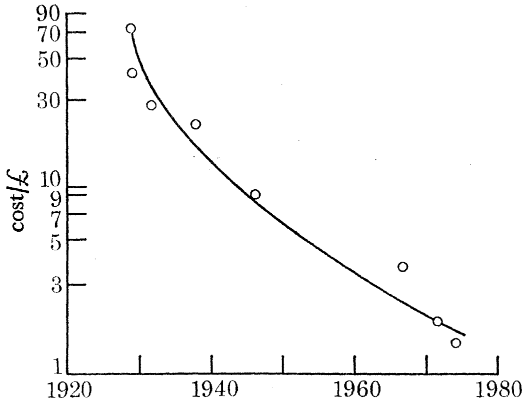

FIGURE 5. Cost of a 3 min telephone call from London to New York (at constant prices). Average annual decrease 7.5 %. Source: *Proc. Instn elect. Engrs*, January 1975.

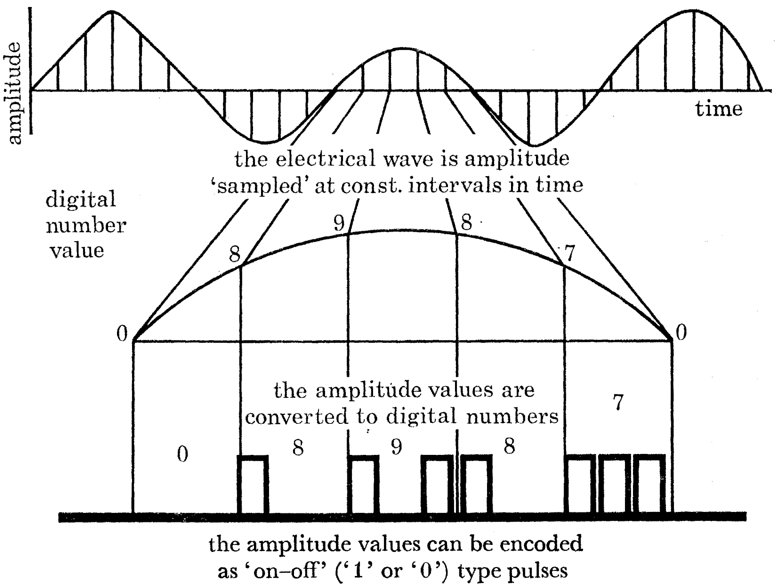

FIGURE 6. The principle of pulse code modulation.

Let us look for a moment at p.c.m., which is a means of converting speech into digits which can be handled by computers. It has the advantage of high-quality speech transmission regardless of distance, it enables many speech channels to be carried on a single pair of wires without interference, and enables speech and other analogue signals to be handled directly by the computers and microprocessors to which I refer. The familiar analogue system by which sound waves are converted directly into electrical waves is the basis on which all current systems were built. By sampling the electrical wave with high-speed electronic devices we arrive at sequential amplitude values which are then digitally encoded (figure 6). This is the basis of most future systems – p.c.m.

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The second contributor was l.s.i.: large scale integration. Most recent developments in silicon semiconductor technology have been concerned with producing more and more complex arrays of transistors within a single silicon chip. From the relatively simple bistable devices, gates, etc., which formed the first and currently most common integrated circuits, progress has now reached the point where several thousands of transistors may be fabricated and interconnected on one chip of silicon to produce devices as complex as microprocessors, 4000-bit random access memories, and so on. Electron and laser beam machining techniques are being developed to improve mask making capability; ion beam implantation, in which impurity atoms are 'shot' directly into the silicon material, are being used to improve upon diffusion; and plasma etching techniques are being developed to improve the definition of interconnection patterns.

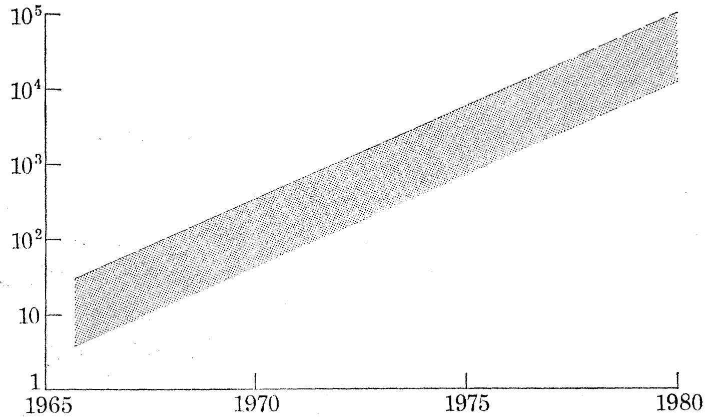

FIGURE 7. Plot of logic element density against year.

At least a further 10:1 increase in circuit complexity of a single silicon chip may be expected within the next ten years. The initial investment in design and tooling such a chip and the relatively low run-on cost per piece means that designs will maximize versatility. The user will select the nearest available chip erring on the more complex so that his design is achieved with a certain degree of redundancy, the cost of which will be negligible. Few chips will be exclusively made for telecommunications, or when they are they will be used by numerous systems.

The third great contributor is the microprocessor. We are all familiar with the extraordinary growth of the pocket calculator, the development of which grows directly out of the innovation of the semiconductor. Arguably the transistor was developed first in the United Kingdom but certainly no less than simultaneously with other world centres of research and development. That Britain has virtually no share in the pocket computer market, other than as an avid importer, is something on which I hope my audience will ponder, and ponder deeply, because it may give a clue as to why some of the great advances which I and others are describing to you today, are more likely to be developed in other parts of the world, even though their origins are clearly in the well trained minds of our British scientists – for it requires not only research and development or high intellectual attainment to be successful, it requires a climate – and I speak of a business and economic climate – in which these tender plants can be nurtured and brought to bear fruit.

Projections of the packaging density of logic elements (figure 7), and projections of cost per logic element (figure 8) should be sufficient to bring home to us the vast changes which will be wrought. They will call not only for changes in manufacturing but for a major reassessment of our thinking in the public sector.

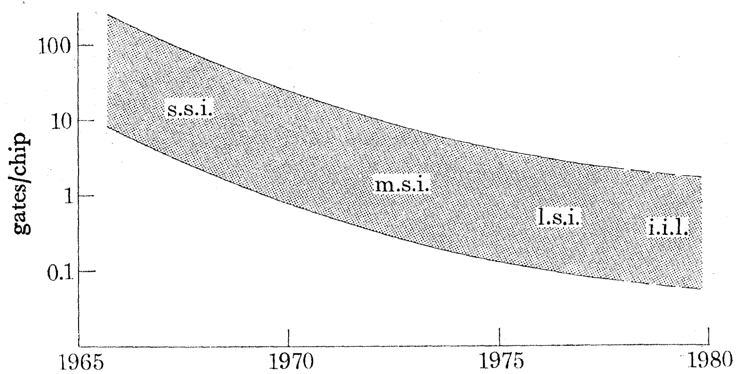

FIGURE 8. Plot of logic element costs against year.

Many of us will be familiar with the way in which reduced costs of processor manufacture have been passed on to the consumer with its resulting enlargement of the market. Let me point out that switching systems are only sold through telecommunications utilities, the final prices and the market size are in the hands, not of the manufacturers and their agents, but of government owned establishments whose purchasing may be dictated by Treasury economics. Thus a government may hold back the development of electronic communications systems as part of its budgetary package, while leaving unhindered the mass exploitation of the market for largely similar devices that fall outside the connected network. Once this self-denying bias is understood one must hope it will be removed for the illogical syndrome it is. Given that degree of commonsense and common interest, the most exciting transformation since the invention of the telephone itself will take place. Without it, the U.K. can look forward to losing one more major industry.

Switching size is 15 times smaller with l.s.i. and p.c.m. This means that the reduced cost of manufacture will be matched by the savings in buildings and installation. The limiting dimension in buildings will be the human frame, not the switching frame.

What will the new p.c.m. systems look like? The elements are the l.s.i. chip and its wafer, and the basic building block will be several of these interconnected on a substrate of which there will be one or two per subscriber line. Just what this means in terms of recognizable finished equipment I can perhaps best illustrate in a series of comparisons.

First, figure 9*a*, plate 1, shows a comparison of the relatively compact crossbar electromechanical system with the semielectronic TXE 4 system which follows it. And in my next illustration (figure 9*b*) I have enlarged the TXE 4 unit in order to compare it with the corresponding unit of System X which is the term currently used to describe the all-electronic and mainly digital system of the 1980s and 90s. A System X sub-assembly (figure 9*c*) shows how these units are brought together in a densely packaged space-saving switching exchange.

How will these systems be manufactured? The process becomes almost that of a laboratory, eliminating the dirt, drudgery and physical work of current manufacturing with its stamping, pressing, turning, milling, liquid soldering and labour intensive assembly. Indeed, as we go

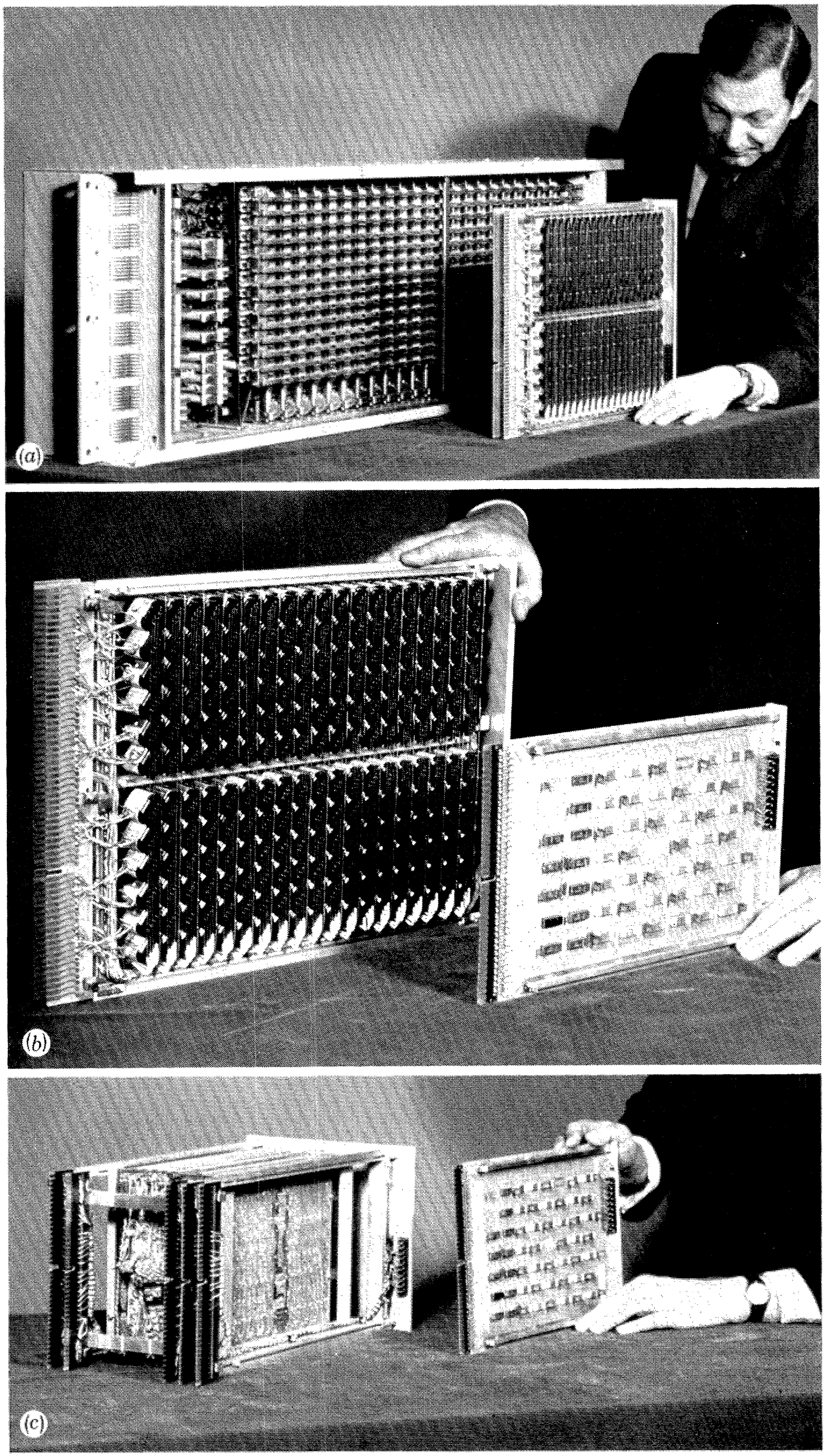

FIGURE 9. (*a*) Comparison of the crossbar electromechanical system and the TXE 4. (*b*) Comparison of TXE 4 and System X. (*c*) System X sub-assembly.

(*Facing p.* 34)

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FIGURE 12. (*a*) Machine shop, New Southgate; (*b*) wiring and cable forming; (*c*) automatic coil winding; (*d*) Prolog; (*e*) Clean room for the preparation of optical fibre; (*f*) artist's impression of the factory of the future.

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beyond the first conception of System X, manufacturing becomes increasingly a continuous process (figure 10). Flexible films will act as the carrier of semiconductor chips on to which they are bonded face down to mate with repetitively printed interconnections (figure 11). The flexible tape thus forms a bandoleer of devices ready for the next stage of connection. At this stage the individual frames are cut off the tape, complete with their connection pattern, the distant ends of which are connected into the very complex circuit of which it forms just a small part.

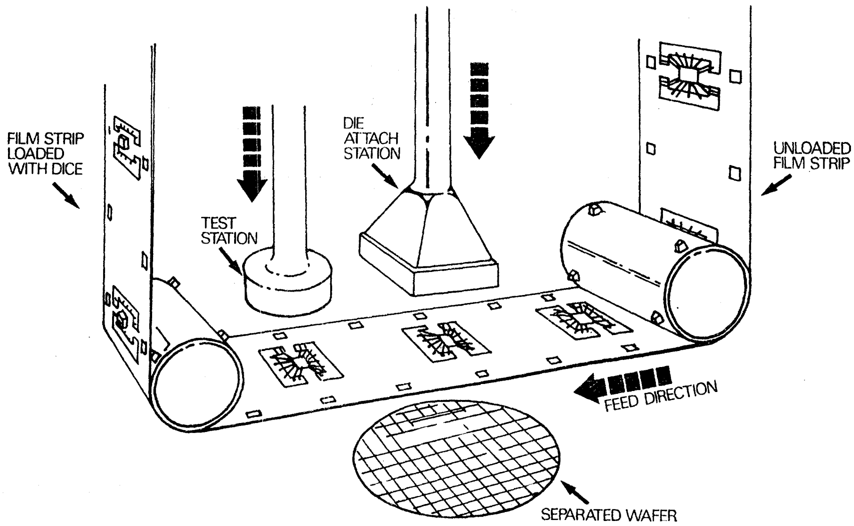

FIGURE 10. Die bonding to film strip.

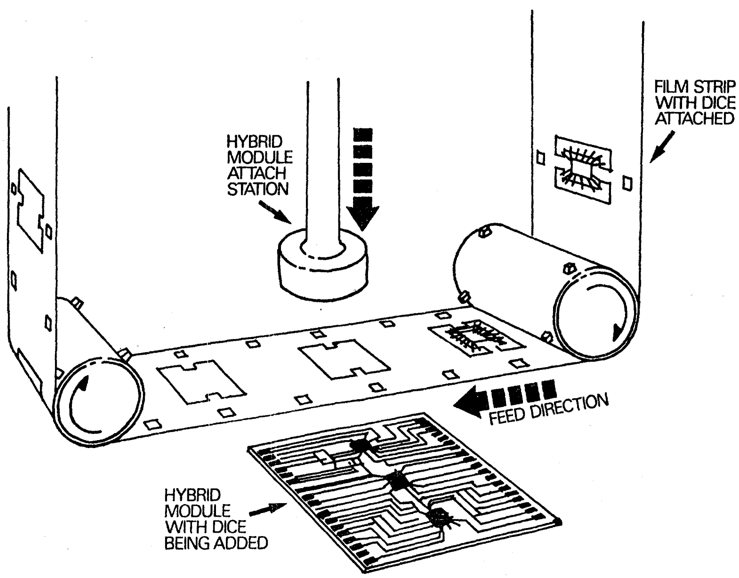

FIGURE 11. Film strip to hybrid module bonding.

Two things follow from this process: first, the total volume of the mounted semiconductor device is reduced by several hundred times, and secondly, the density of connections is much increased by comparison with the normal encapsulating device. Thus the construction of complex functional modules on a ceramic substrate can be undertaken as an automatic and economic controlled process. The substrates are envisaged to be about 50 mm square, each

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carrying about 16 semiconductor chips. Overall, therefore, with the improvements in semiconductor fabrication already referred to and this protection and interconnection technology, the next ten years should see a one thousand times increase in capability per unit volume.

The factories in which these systems are manufactured will undergo radical change from this electromechanical switching plant which has not changed significantly in fifty years (figure 12*a* and *b*, plate 2) through the current intermediate requirements of the semielectronic system TXE 4 which is being built up rapidly to bridge the technology gap (figure 12*c*, *d*), and so on to the fully electronic digital System X which becomes more of a laboratory process carried out in conditions like those shown in figure 12*e*, which in turn as volume increases will develop into the condition conveyed by our artist's impression (figure 12*f*).

Table 1. Numbers of people directly involved in switching plant manufacture (500 000 equivalent lines per year)

item	crossbar	semi-electronic	System X
materials (parts, p.c.b. and metalwork)	1000	150	20
assembly and wiring	2000	900	50
testing	250	200	50
total	**3300**	**1250**	**120**

It will be noted that the environmental conditions are becoming what a foundry worker of today would think of as ideal but which will, no doubt, bring with them their own problems stemming from the constancy and stability and the boredom which this can engender. The impact on our people will be dramatic and as is usually the case, it will probably be with us physically before we have made the necessary psychological and philosophical adjustments. Table 1 tells the story, although admittedly I am dealing with direct operatives. Already we are well underway with the first transition which reduces direct operatives by a factor of 2.6 as we move from electromechanical, step by step or crossbar to TXE 4. The physical emanation of this and the distressing unreadiness of the country to deal with the results of its own decisions can be read in your morning paper. The next stage if properly implemented will bring about a further 10:1 reduction.

How then do we see reasonable levels of employment – what can we help our people to make which will command their skills and their interest, and create the wealth upon which a healthy social environment can be built? In part the answer must lie in the peripherals which enable us to make use of the wide band transmission and switching systems of the future. Figure 13 shows a selection which will grace the office of the 1980s. I cannot fail to emphasize, however, that the country from which they will originate will depend greatly on the facilities offered by the telecommunications utility for their attachment and use in the network, for if all that we were going to achieve with these exciting technological advances were certain lower cost telephone services, our outlook would be a sorry one indeed as may be gauged by the saturation curve which shows reduced demand over the next 25 years.

This brings us to the question of widening the market by manufacturing for export. There is only one message that can usefully be conveyed, and to enlarge upon it can only dilute its impact. The message is that the equipment and services adopted by the monopoly buyer in the home market, i.e. the British Post Office Corporation, shall be wholly compatible with

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that required internationally and that the U.K. network should become a responsive and interactive testing ground for the export orientated equipment of our home based industry.

The last section of this paper takes us out of the traditional realm of the telephone and looks at the application of new technology to telecommunications in a wider form embracing broadcasting, education and leisure activities, all of which may be transformed by the availability of economic broad bandw dth.

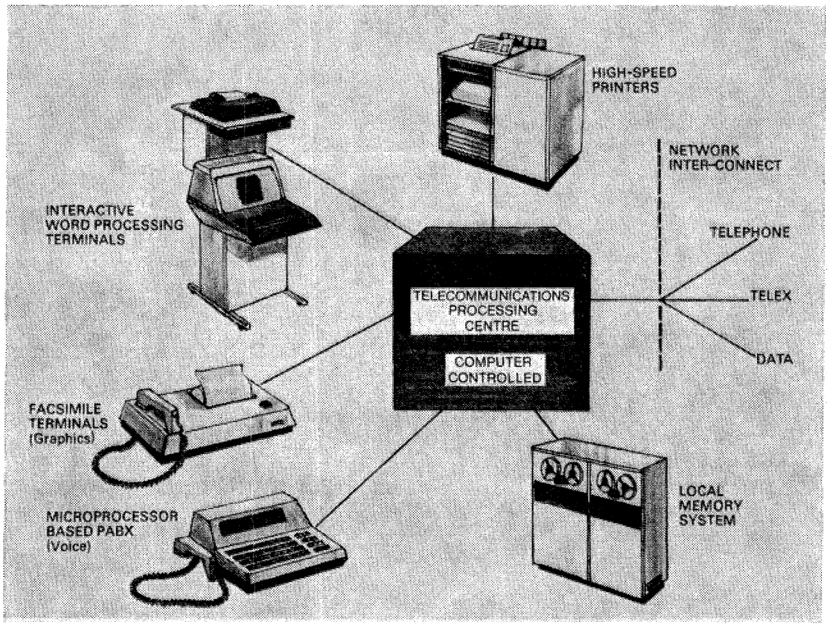

FIGURE 13. The integrated office system of the 1980s.

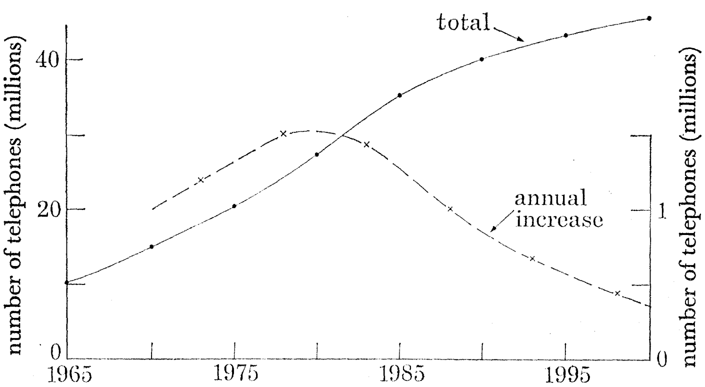

FIGURE 14. Telephones on the U.K. network: •, total telephone number; ×, annual increase.

Figure 15 charts the direction in which technical resource expenditure gives rise to increasing individuality of service, on the vertical scale, and increased channel capacity on the horizontal scale. The location of various services on this scale shows what can and will be available and some measure of the comparative costs. It shows that the rapid advance predicted for data transmission does not really consume bandwidth when compared with speech. On the other hand, video transmission is seen to be a big bandwidth user.

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Broadcasting video on the radio bandwidth, as with one-way television, uses radio bandwidth greedily and leaves little room for other developments even when taking radio bandwidth up to 1 GHz. Broadcast video takes away bandwidth from other uses for which substitution is less practical, for example, the mobile telephone, the growth of which is shown in figure 16. It also inhibits the growth of citizen band radio, which despite its detractors should arguably not be denied to the citizens of a free country, and which brings with it many opportunities for product development and export. The demand for and growth of citizen band radio in the U.S.A. is demonstrated in figure 17.

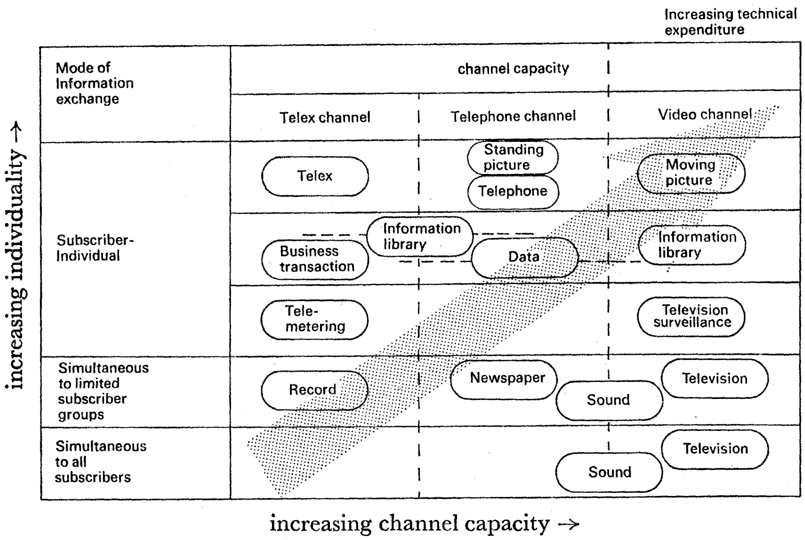

FIGURE 15. Trends in technical resource expenditure.

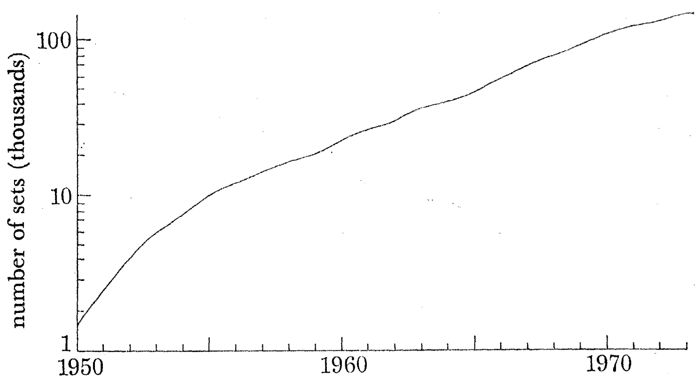

FIGURE 16. Growth of land and maritime mobile radio in the U.K.

The sea of aerials (or are they antennae?) which spoil urban and city appearance is an offshoot of video broadcasting and yet present day television gives very limited choice in material and constrains the timing of its availability. To some extent the video recorder offers a postponement of viewing time and market forecasts such as figure 18 show that people do want more control over when they watch a particular programme.

Again the expectations of teletext services such as the B.B.C.'s Ceefax and I.B.A.'s Oracle shows that the people want more from their television. Viewdata is a most laudable step towards the facilities I expect to see opened up. It recognizes the essential requirement of two-way communication which it performs over the only link currently available to it – namely the telephone line. To display a single full colour slide would, however, take the better part of an hour which excludes the presentation of moving pictures. An economic broadband system would remove these limitations and enable the full potential of the system to be explored.

The development of the Open University (figure 19) is again one of the projects which promises for Britain the preservation and development of the quality of life for which we are still the envy of many peoples. However, a few hours listening and watching will convince the creative mind that we are only on the threshold of what could be achieved by interactive learning programmes.

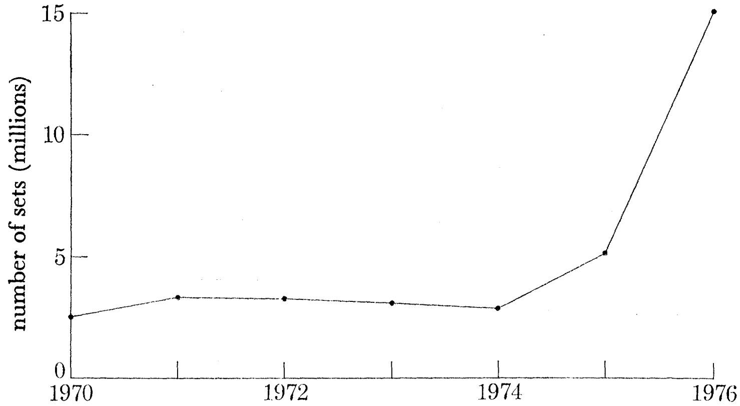

FIGURE 17. Citizens' band radio sets sold in the U.S.A.

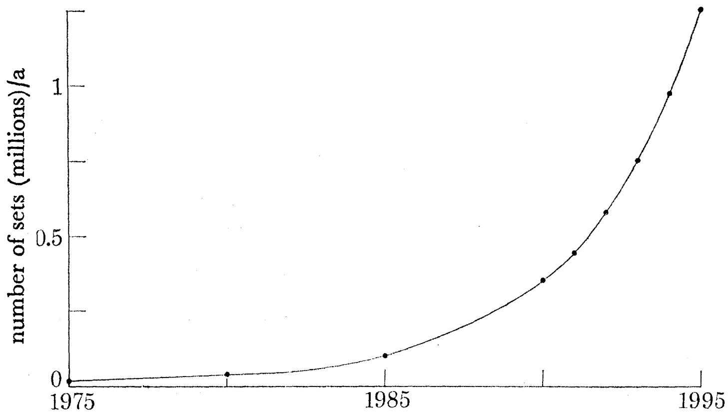

FIGURE 18. Forecast sales of video recorder/players in the U.K., based on a 25% household penetration in 1995.

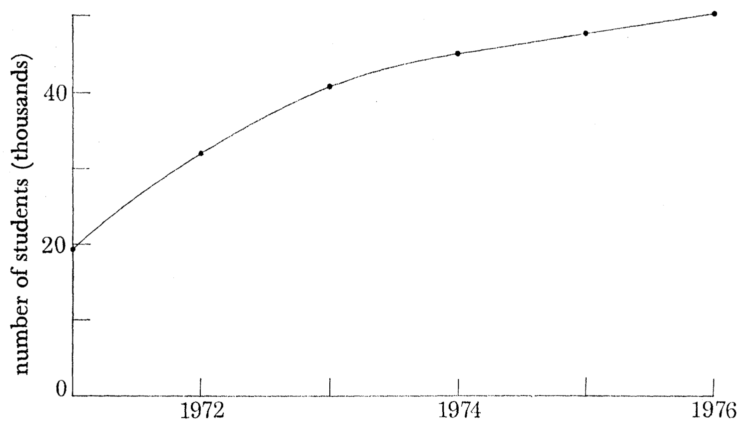

FIGURE 19. Students at the Open University.

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Television is used for entertainment, information and education: the proportions of the time allocated on all three channels to each category is approximated in figure 20.

The demand for dedicated channels for education and leisure will be met through the provision of the broadband network. Society will benefit; people will develop their own and more varied lifestyle as more education becomes available through a switched broadband network. A documentary that could be dialled when needed; a library available in the home, school or office; a wide choice of films and other recorded material for relaxation and a complete learning laboratory; all these will be accepted as naturally as television now is.

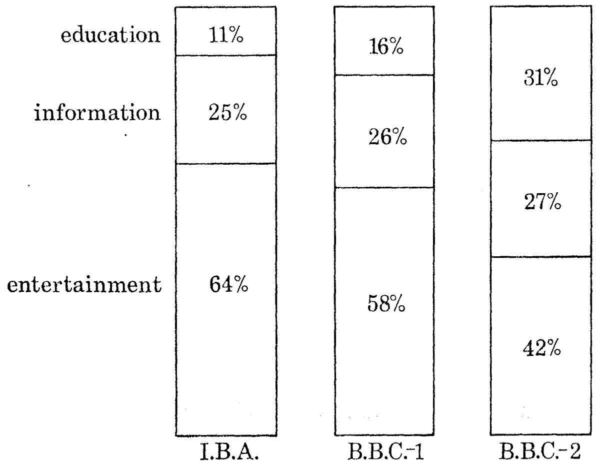

FIGURE 20. Television programme balance, 1975–6.

These are some of the alternate satisfactions which will make civilized man's life richer and help to reduce the strain of the competition to gain a larger share of the natural resources of complex food and drink, minerals and fossil products which comprise the core of traditional human satisfactions. This principle which I have called the doctrine of 'alternate satisfactions' could be the key to finding the rewarding lifestyle of the 21st century when new values will, hopefully, have been established which outlaw the depredation of nature and prize the development of that vast store of individual accomplishments of which the human being is capable and which lies dormant in so many.

Things which in our traditional philosophy of money values have seemed too expensive to contemplate will become commonplace because they create, not destroy. Things which have seemed cheap, like the fat of the whale, will be beyond price. Even the ubiquitous egg on which we are implored to go to work will give ground to the prime cereals from which it is expensively created. Of the many alternative satisfactions, that with which I am now concerned is the extension of human experience by the vastly enhanced communications network. Of the various technologies which could achieve it, the most relevant is the optical transmission medium.

This is not a vain dream of the future – it is with us today, and if we have the clarity of vision and the resolve, it could be one of the major factors in the emergence of high technology Britain. Optical fibre, and an investment now amounting to no more than the extension of the 1973 level of Post Office capital expenditure, could start an overlay network, and investment in the telecommunications industry would be maintained to the benefit of the U.K. and soon to the E.E.C. as a whole.

In the dozen and more papers which follow, the factors and parameters governing the precise form of our technological revolution in telecommunications will be brought out. It has not been my intention to prejudge the route which will be followed but rather to illustrate the prize at the end of the journey. Nor am I unconscious of the fact that the conclusion of one journey merely heralds the beginning of another. I set no time limit on the viability of coaxial cable or waveguides which will coexist and complement indefinitely the optical fibre which I chose by way of illustration. Indeed it is of paramount importance that the philosophical contribution of telecommunications to the wellbeing of our new world should not be hidden or hindered by prolonged argument about the means. For this has but one sure and certain effect, which is to inhibit real progress and contain it within the narrow reaches of semantics and tentative essays.

What is needed is a bold vision of the reality which will be the future of telecommunications in the 1980s and after: the recognition that that reality can be here as readily as in any other part of the globe, and the determination to get from now to then in the shortest practical time and by the most direct known route. The technology is here: who will apply it in the service of the people?

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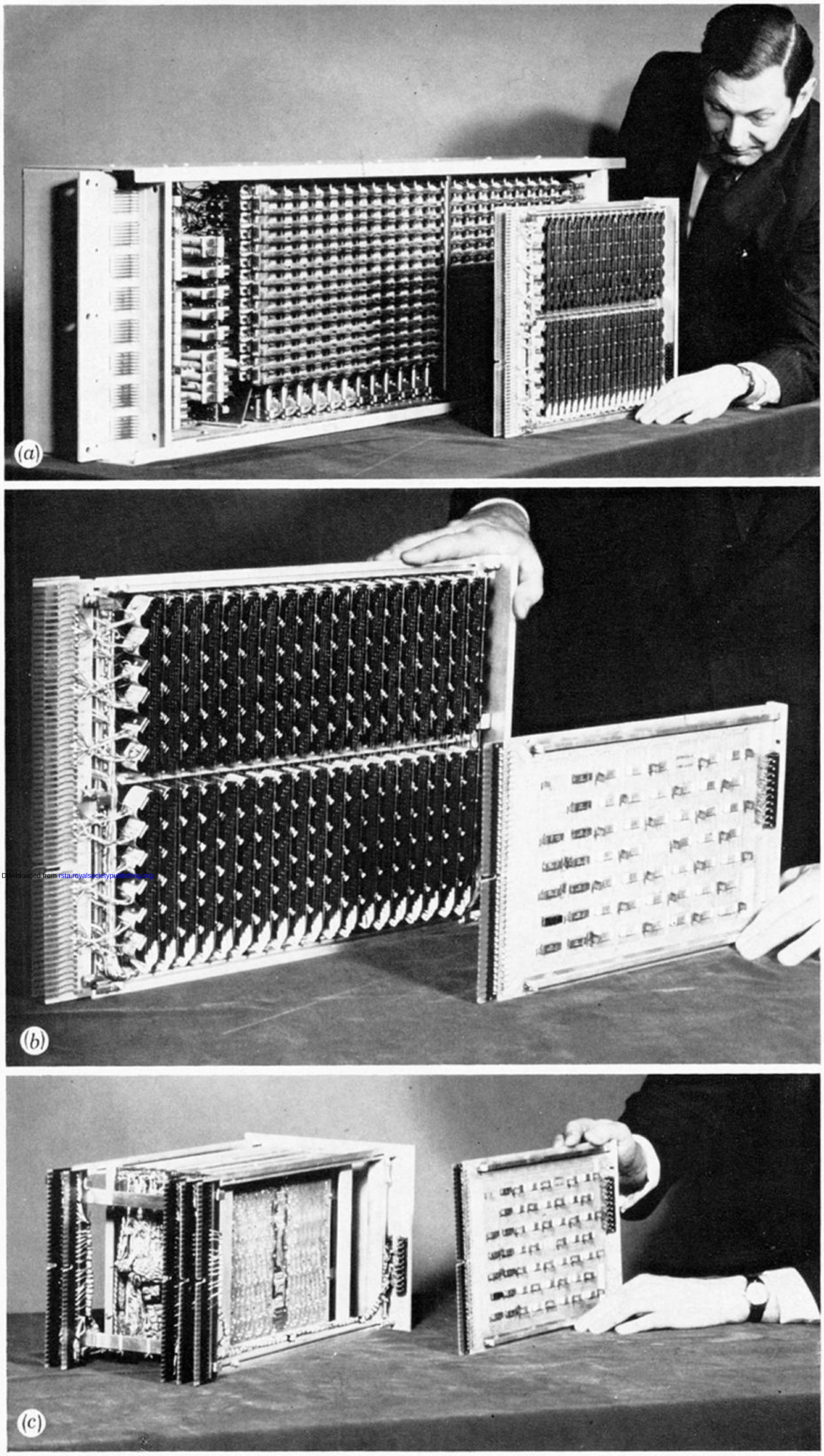

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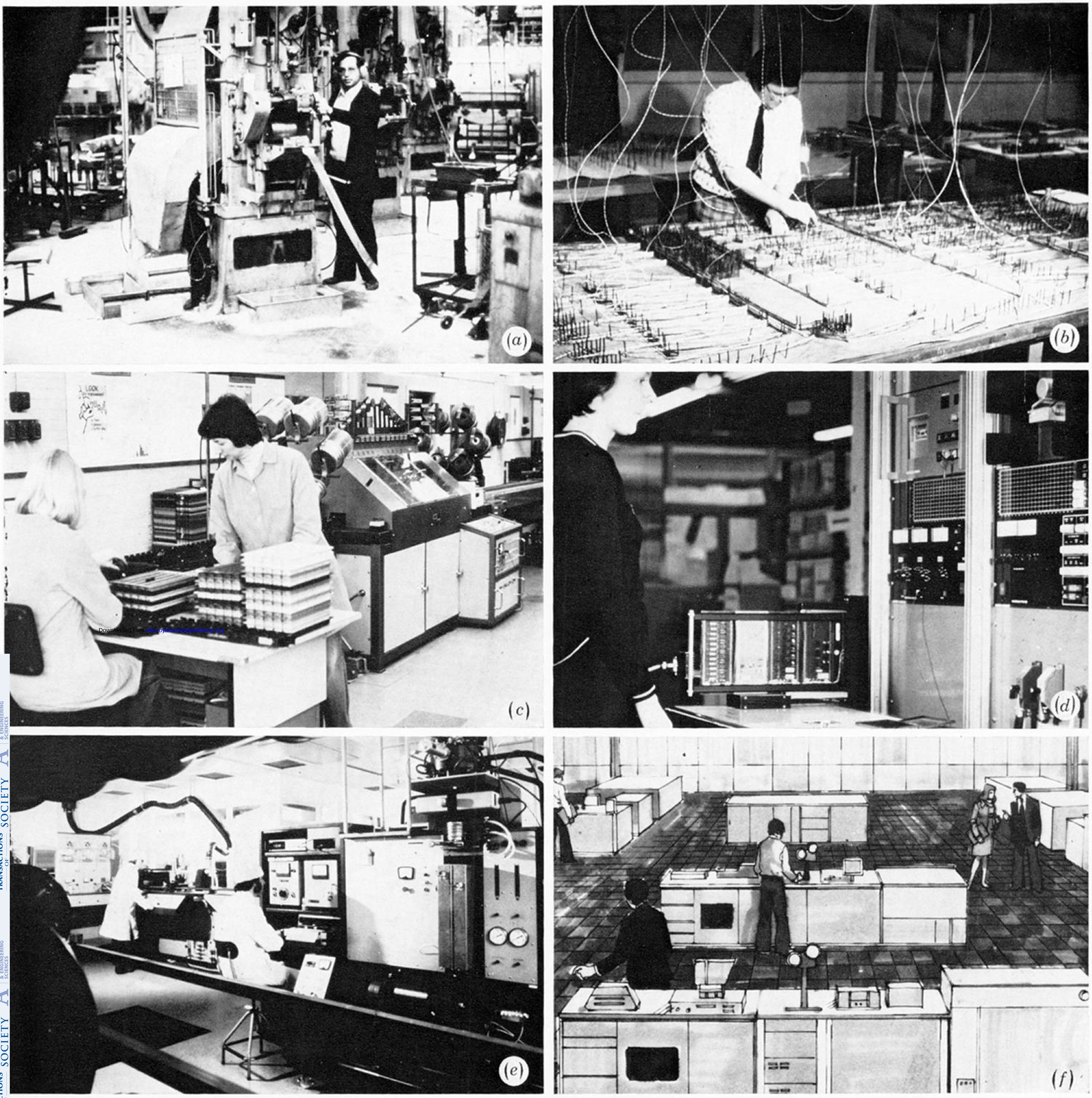

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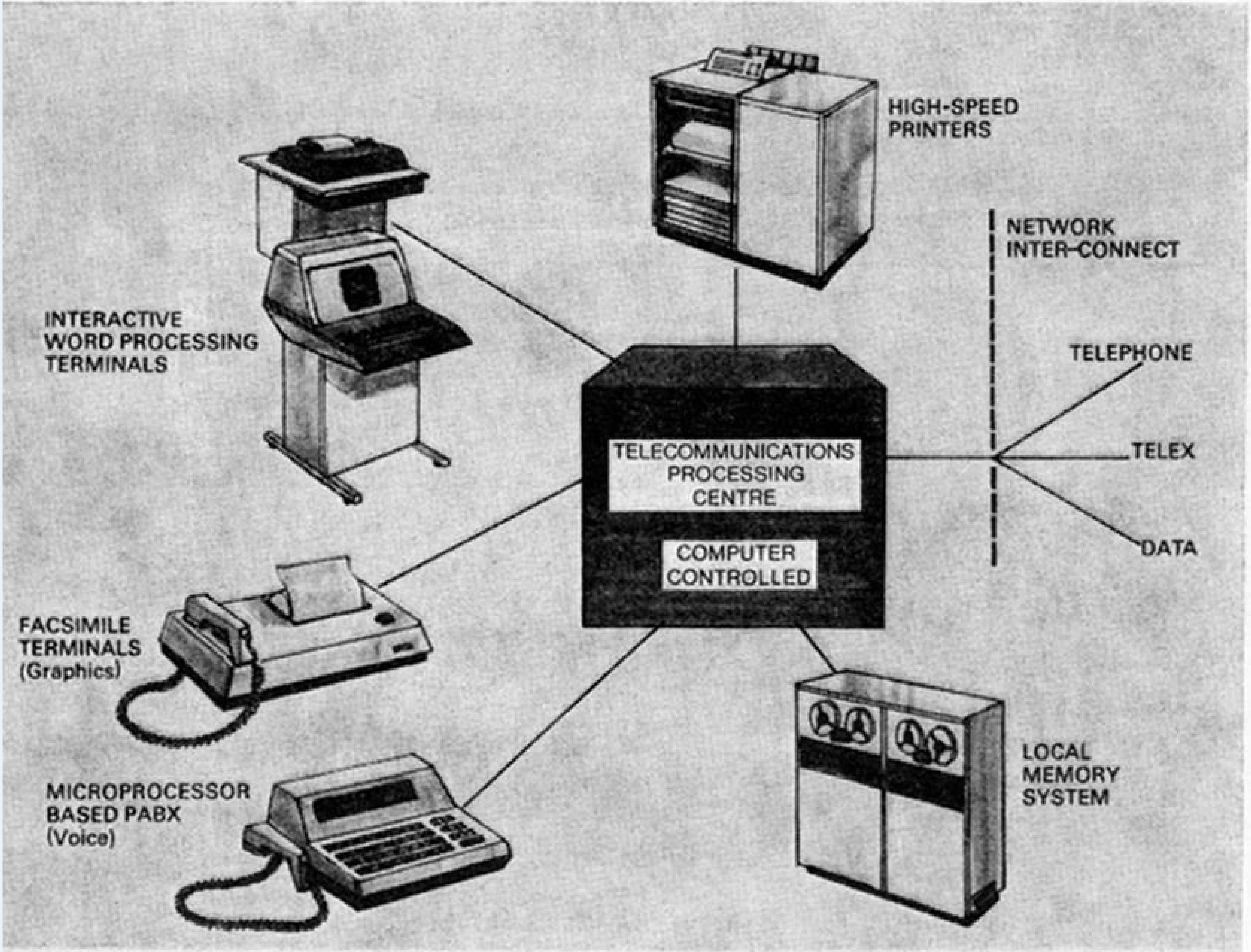

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