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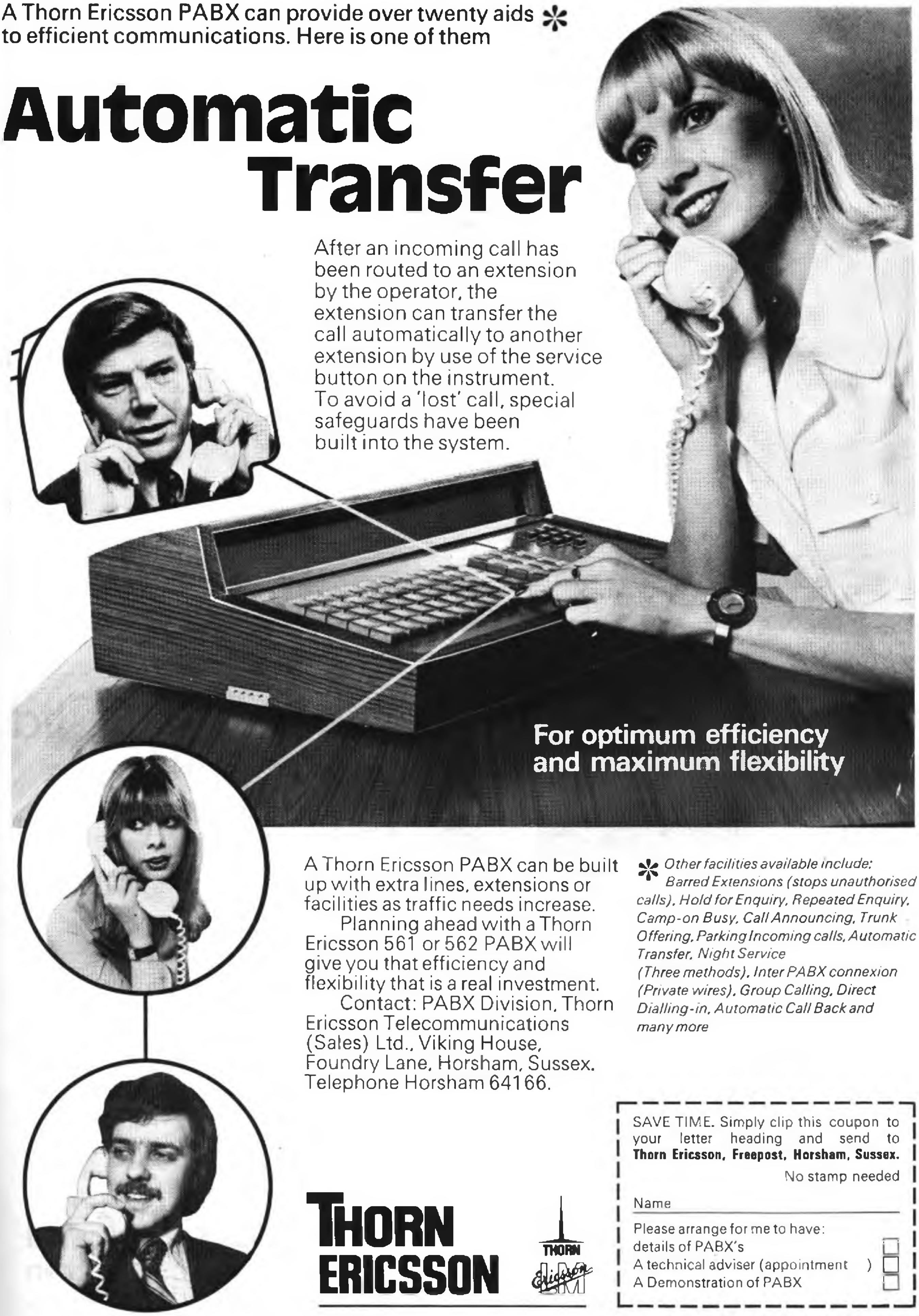

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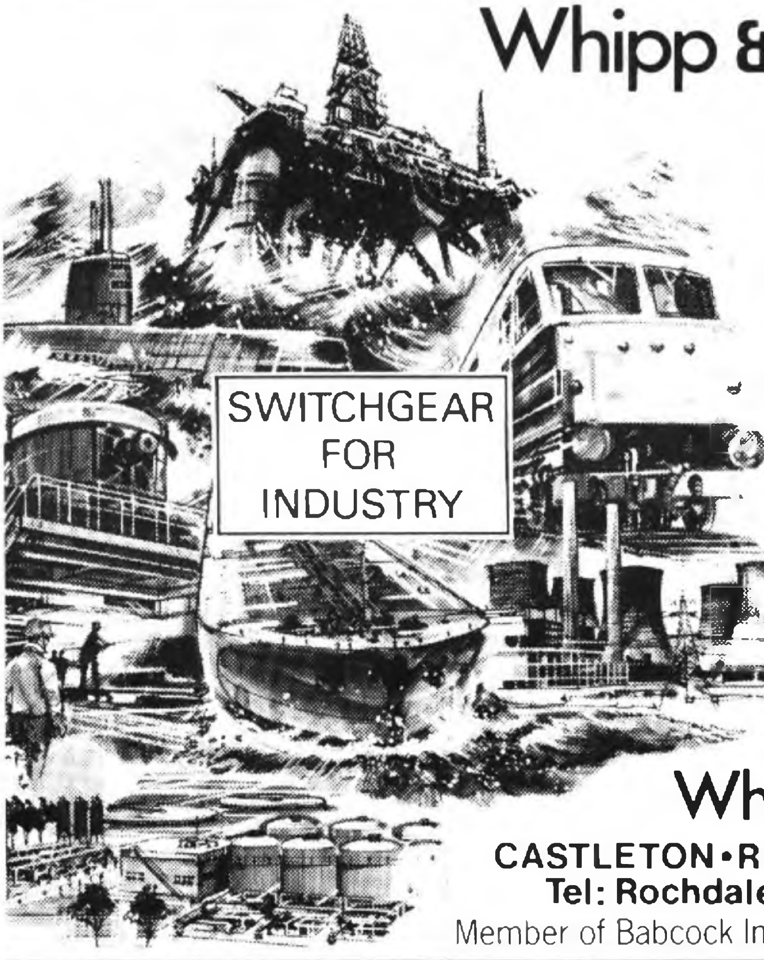
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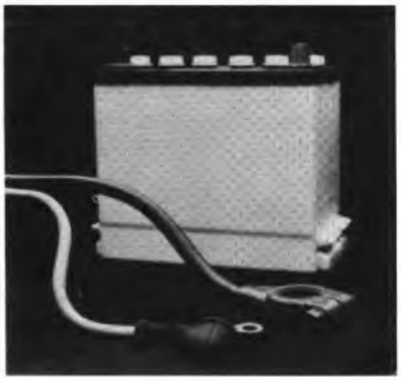

The Post Office Electrical Engineers' Journal

EDITORIAL

In all spheres of electronic engineering there are great expectations that the 1980s will bring still further advancements in the application of new technology; in particular, the use of 'chips' and microprocessors. In the British Post Office (BPO), the introduction of a network of digital transmission and switching systems is anticipated. It is perhaps appropriate, at the start of a new decade, to review briefly the origins of the *Journal* and the role it has played in recording the history of the growth and development of the BPO telephone network and its communication services.

The Institution of Post Office Electrical Engineers (IPOEE) was formed in 1906 "to promote the general advancement of electrical and telegraphic science and its applications, and to facilitate the exchange of information and ideas on these subjects amongst the members of the Institution . . .". These essential principles have remained intact throughout the lifetime of the Institution. The *Journal* of the IPOEE was first published in April 1908 to promote the aims of the IPOEE.

At all times in its long history, the *Journal* has endeavoured to keep the members of the IPOEE advised of the latest developments in the many areas of BPO involvement, and has provided a service to students sitting the City and Guilds of London Institute examinations (and, more recently, those of the Technician Education Council).

The *Journal* has earned a reputation as a prestigious publication, not only among IPOEE members but by a significant number of people outside the BPO, both within the UK and abroad (the *Journal* is distributed to readers in over a 100 countries).

The Editors strive to maintain a balance of content and technical level to meet the needs of its many IPOEE readers, who are drawn from all levels and many disciplines within the BPO. To this end, contributions from readers are invited.

To quote from the foreword to the first-ever publication of the *Journal*, "It shall be our earnest endeavour to keep our pages open for the free and healthy discussion of all subjects relevant to our profession, and at the same time to secure that nothing unworthy shall sully them".

Digital Local Networks

J. M. GRIFFITHS†

UDC 621.395.743: 621.374

This article briefly reviews previous proposals for digital operation in the local network. It then considers possible methods for providing 64 kbit/s voice-equivalent paths to customers using existing pairs, together with the signalling techniques and applications of such a system.

INTRODUCTION

Telecommunications has developed from the telegraph to include telephony, data transmission, facsimile and many other services. These services have essentially one feature in common—they use electronic means to convey information from one place to another. Apart from the very early years of telecommunications, in the UK, telephony has been the dominant service[1] and, as a result, other services have often exploited the public switched telephone network (PSTN). In some cases, the characteristics of the PSTN have proved excessively restrictive to other services, which have transferred to their own specialized networks; examples are the Telex[2] and data networks[3].

In the case of television distribution, the PSTN was clearly unsuitable and a separate network was required from the outset[4]. The restrictions leading to the formation of separate networks are due to several features of the PSTN:

(*a*) the limited bandwidth;

(*b*) the slow call set-up; and

(*c*) the limited signalling interaction possible between customer and network, particularly for terminals that do not need human intervention.

These restrictions are a result of the distributed control, electromechanical exchanges, and the traditional 3·4 kHz bandwidth provided for analogue telephony transmission. Digital telephony transmission systems are now being used by the British Post Office (BPO)[5], in which speech is transmitted as a 64 kbit/s data signal, and System X digital exchanges[6] will also switch speech paths in this form. Alternatively, the 64 kbit/s path can be used to provide a much higher rate digital data channel than that available on the present PSTN. For telephony, digital transmission gives the advantage of a reduced range of speech levels offered to the customer, because of the elimination of switching and transmission losses in the main and junction networks. Call set-up is also more rapid with electronic exchange control.

However, these advantages cannot be fully exploited unless digital paths are extended all the way to the customer. If digital links are provided in the local network, together with an integral comprehensive and fast signalling system, this restriction of the PSTN is removed.

Having thereby enhanced the PSTN, the need for separate data networks probably disappears and all services can co-exist, thus obtaining economies of scale. This enhanced PSTN is known as an *integrated services digital network* (ISDN).

The digital switching stages, and junction and main network digital transmission links, are now, or soon will be, ready for installation. The needs of, and methods to be used in, local networks are currently being intensively studied throughout the world. The BPO Research Department has been involved in such studies for more than 10 years and this article reviews this work, and considers how the existing local network may be exploited for future digital working.

RING NETWORK

Economics play a very large part in the requirements of any equipment used in the local network. The traffic is unconcentrated and so costs must be reflected in full in the charges made to the customer. One way of reducing this problem is to arrange for concentration of traffic very close to the customer, and proposals based on cables arranged in rings have been made[7]. Electronic equipment, known as *accessors*, would be placed along the ring at distribution points within about 200 m of the customer's premises. The name *accessor* was coined for these equipments as they give customers *access* to the channels carried on a unidirectional ring of cable linking them. The ring starts from the exchange, carrying a multiplexed signal encoded by pulse-code modulation (PCM); at each accessor, the required channel is extracted and passed to the customer. The now vacant time-slot is filled with the information from the customer. Thus, the signals arriving at the exchange from the ring are all from the customers. Several difficulties arise from such a scheme and these are discussed below.

Reliability

It is difficult to ensure the reliability of operation as a break anywhere in a simple ring disconnects all customers connected to the ring. Also, the cable length involved is considerably greater than for a radial distribution system. If the ring were truly circular, the cable would be π times as long as the distance direct to the most distant subscriber; practical layouts give a factor nearer 5. Thus, assuming that damage to a cable is equally likely anywhere along its length, the extra cable involved reduces the reliability significantly, without taking into account the additional electronics. Supplementary rings may be provided, into which traffic is diverted when a fault is detected but, to provide security, the supplementary ring must be physically separate and the fault detector must be highly reliable[8]. Both of these are difficult and expensive to guarantee.

Cables

Existing cables are not arranged in rings and it would be difficult to rearrange them. Previous ring proposals used community antenna television (CATV) cable systems, but the expected rapid expansion of CATV in Britain has not materialized, and so this solution is less attractive.

Growth

When the first customer in an exchange area requires digital service, an accessor has to be installed at his distribution

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† Research Department, Telecommunications Headquarters

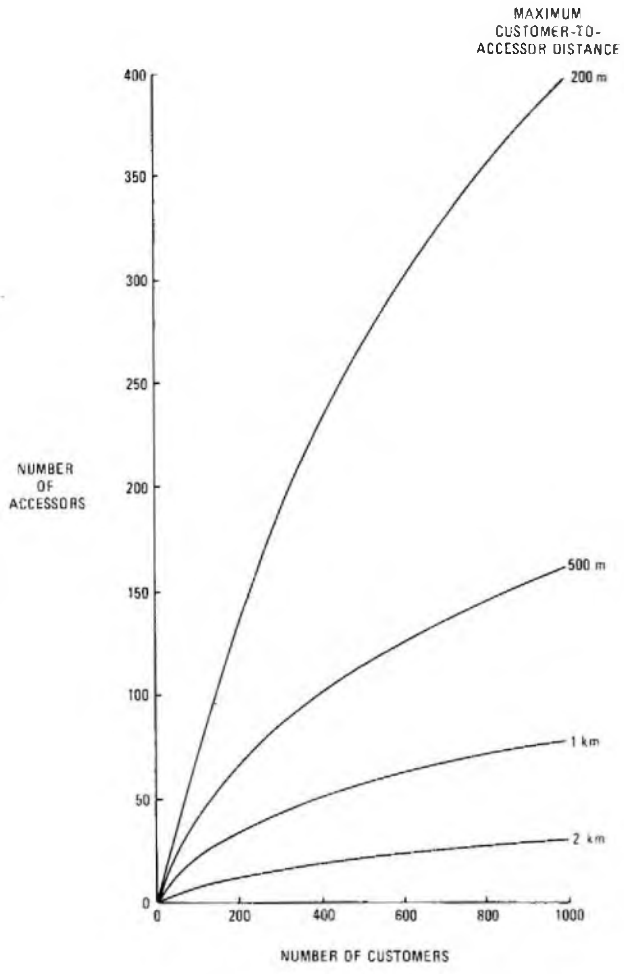


FIG. 1—Number of accessors required

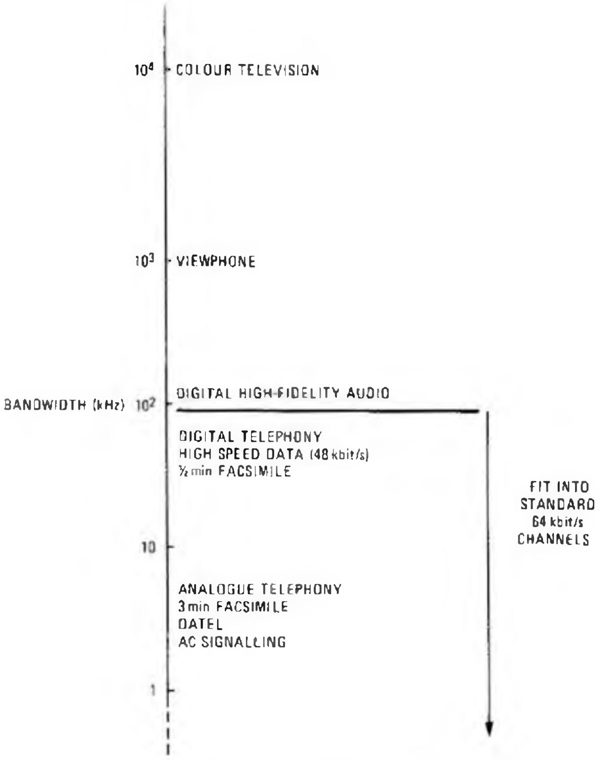


FIG. 2—Bandwidth of services

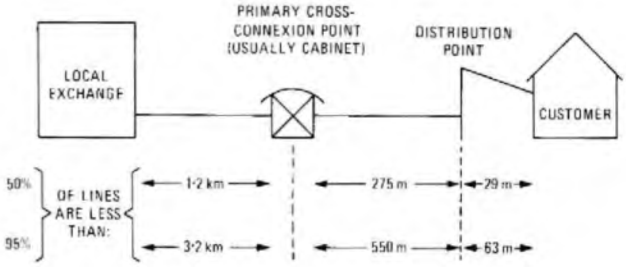


FIG. 3—Lengths of connexions in the BPO local network

point. This accessor could also serve any other customers within 200 m of the distribution point. However, if demand occurs at random, it is likely that the next requirement for service will be outside this distance; thus, another accessor at another distribution point will be required, and so on. Initially, there will therefore be one customer per accessor. As demand increases, so does the probability that a new customer will be within range of an existing accessor.

Simulations show that, for an average British exchange area, when the demand is for 1000 digital connexions, the average number of customers on each accessor will be 2·4. This is shown in Fig. 1. To be economic, even higher demand is necessary; only telephony is likely to provide this demand and it is difficult to justify wholesale conversion of telephones to digital operation on the grounds of customer requirements, as will be discussed later. Fig. 1 shows that, if the accessor-to-customer distance can be increased, the probability of new customers being within the reach of an existing accessor is considerably higher and fewer accessors will be needed.

RE-APPRAISAL

A careful appraisal of the problems of providing digital local networks led to the following requirements:

(*a*) The scheme should be economic for both small and large penetrations.

(*b*) Effort should be made to exploit the existing local network in its present layout.

(*c*) Because of the known crosstalk and attenuation characteristics of the existing local network, efforts should be concentrated on providing only digital voice-equivalent channels (that is, 64 kbit/s). As Fig. 2 shows, this encompasses everything except moving pictures and music.

(*d*) The existing cost and reliability must be maintained for the basic telephone service.

To be economic, the fullest use must be made of local network accessors. Fig. 1 shows that, if the accessor-to-customer distance could be increased to 1 km, then with 1000 customers, the average number of connexions per accessor would be about 17, which is reasonable.

Fig. 3 shows some statistics of the lengths of local connexions in the British local network and it can be seen that, if accessors are to be placed at an existing flexibility point, the primary cross-connexion point lies at approximately the right distance from the customer. Thus, the accessor position must no longer be thought of as the distribution point, suggested for the ring system, but as the cabinet.

Requirements (*b*) and (*c*) relate to the use of the existing network and the capability of a suitable transmission system. Only one pair is normally available between customer and cabinet, and duplex operation is required on this pair. Three ways of achieving this are under study in the BPO and elsewhere; a time-division duplex system, commonly known as *burst mode* or *ping-pong*; the classical duplex approach, using a hybrid with enhanced trans-hybrid loss using echo-cancelling techniques; and frequency separation for the two directions of transmission.

BURST MODE

In this technique, a burst of digits is transmitted from the cabinet to the customer, where it is received after a delay due to the finite transmission velocity (about 5 μs/km). The customer response causes a burst to be returned, which is received at the cabinet. This process is repeated, generally at a rate of 8000 bursts/s, because this corresponds with the normal speech sampling rate of PCM systems[5].

The choice of the instantaneous rate of transmission of the digits during the bursts is subject to opposing constraints. Firstly, with the instantaneous rate as high as possible, the greatest number of 64 kbit/s channels will be available to a customer. Also, the bursts will be shorter, and so more time is available for the cable transmission delays and the range is increased. On the other hand, high instantaneous rates imply more crosstalk between pairs, and higher attenuation giving lower-level received signals. This limits the range that can be reached.

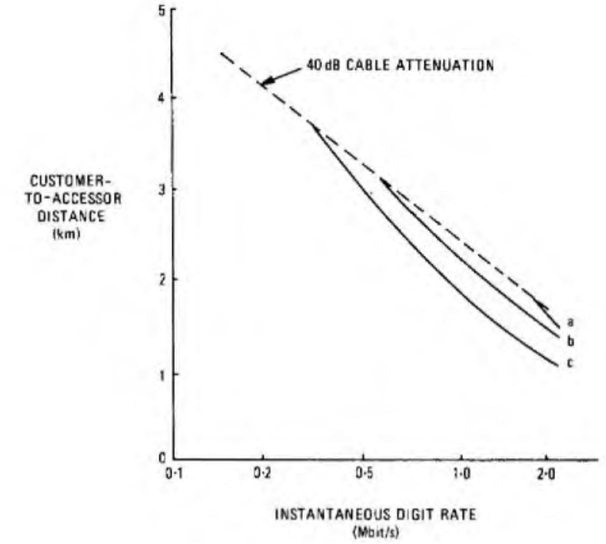
Fig. 4 shows the possible distances that can be achieved by systems working on local cables where the limit is imposed by attenuation and crosstalk. It can be seen that, if near-end crosstalk (NEXT) is the limiting factor, the required 1 km reach can be achieved with an instantaneous rate of 2 Mbit/s. At this instantaneous rate, bursts could contain sufficient digits to convey ten 64 kbit/s channels or, with fewer channels, the extra time between bursts could be used to segregate all the transmitted bursts in all pairs in a cable into separate time intervals from all the received bursts in that cable (Fig. 5). Then simultaneous transmission and reception will not occur and only far-end crosstalk (FEXT) needs to be considered. As can be seen from Fig. 4, curve *b*, this increases the range slightly.

Such a system has been demonstrated at the BPO Research Centre[8] using transmission equipment modified from that used on junction PCM systems. Fig. 6 shows typical waveforms on the line at the cabinet. A ternary code is used, the transmitted signal consisting of a header followed by a signalling bit and 8 data or speech bits, with the last bit added whenever necessary to give an equal number of positive and negative pulses; by this means, the low frequency content of the signal is reduced. Fig. 6 also shows the burst, distorted by the line, received from the customer.

From the cabinet to the exchange, it is proposed to use a fairly conventional PCM multiplexed link, working on 2 pairs. This link can be of considerable length as intermediate regenerators can be used.

When digital local working is first introduced, it may be more attractive to operate over even greater distances without intermediate electronics, and the requirement for several 64 kbit/s channels to each customer may be minimal. For this purpose, the instantaneous digit rate should be as low as possible, commensurate with providing sufficient time to allow for transmission delays between customer and accessor. For these lower speed systems, binary line codes, such as diphase or WAL2, may be more suitable than the ternary code proposed at higher rates. These binary codes are less sensitive to line distortion arising from the difficulty of equalizing the cable loss at lower frequencies because of the rapidly changing cable impedance.

To convey one 64 kbit/s channel at a rate of 8000 bursts/s implies bursts containing only 8 bits; in practice, the requirements of signalling and timing recovery increase this to 10 bits or more. Fig. 7 shows the instantaneous digit rates required to reach various distances with 10 bit and 16 bit bursts, when limited by transmission delays of 5 μs/km. Taking the transmission delay-limited characteristics, in conjunction with the limits imposed by attenuation and crosstalk (see Fig. 4), indicates an optimum instantaneous rate for maximum range of between 300 and 400 kbit/s, according to burst length; at these rates, a system reach of 3 or 4 km could be achieved. This means that 80–90% of customers could be reached with no intermediate regeneration between customer and exchange.



Curve a—Limited by NEXT with one interfering system
Curve b—Limited by NEXT with 50% cable fill
Curve c—Limited by NEXT with 50% cable fill

FIG. 4—Maximum distance possible with burst-mode system limited by attenuation and crosstalk

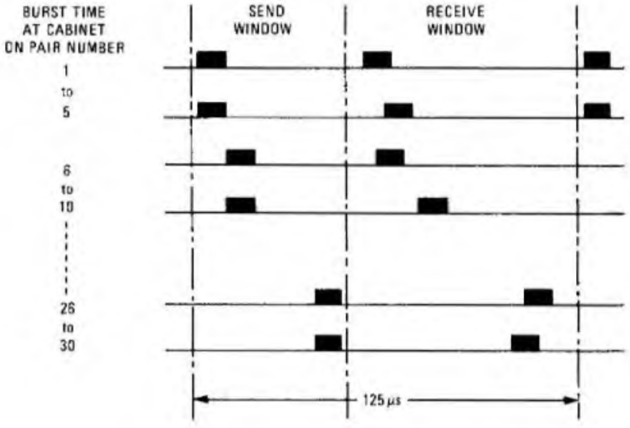


FIG. 5—Burst-mode windows at cabinet

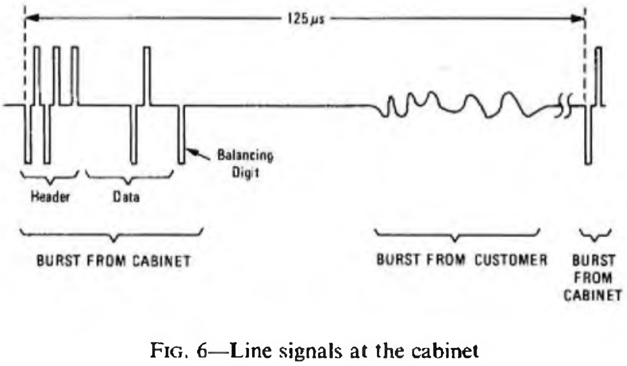


FIG. 6—Line signals at the cabinet

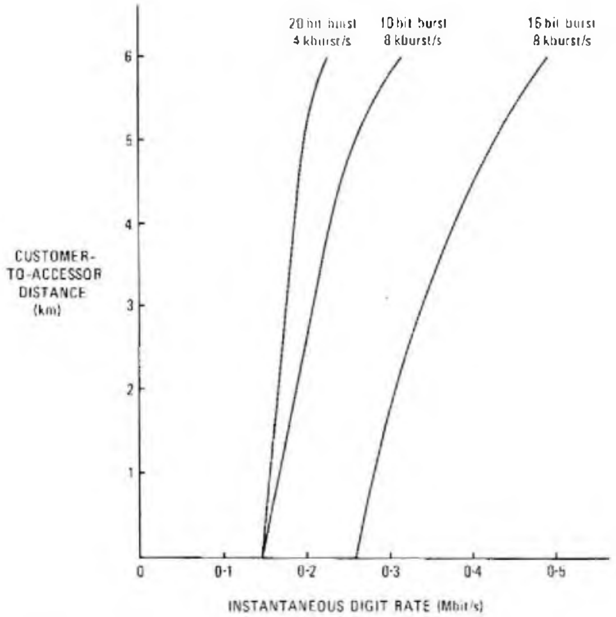


FIG. 7—Maximum distance possible with burst-mode system limited by transmission delay

In some proposals, even lower instantaneous bit rates are proposed to give even greater reach; to overcome propagation delay problems, several speech samples could be sent as one burst, the rate at which bursts are sent then being a sub-multiple of 8 kHz. Fig. 7 includes the reach available with 20 bit bursts sent at a rate of 4 kHz.

One requirement that still needs to be considered is that of maintaining the low cost and reliability of the basic telephony service; with burst-mode operation, advantage can be taken of the need to work at instantaneous digit rates considerably in excess of the basic information rate. Because of the high rates, and the line coding used to remove DC components from the signal, there is very little energy in the conventional 0·3–3·4 kHz speech band. Thus, by filtering, the physical baseband speech path can still be used, which retains the low cost and high reliability.

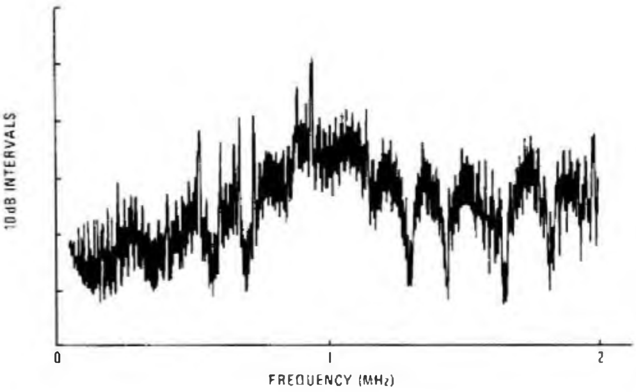
The spectrum of a system working at an instantaneous rate of 2·048 Mbit/s is shown in Fig. 8(*a*). Fig. 8(*b*) shows the low-frequency, speech-band part of the spectrum enlarged, after simple filtering. It can be seen that the digital signal is much lower in level than the speech. At lower instantaneous digit rates, the power in the speech band is higher and so the filtering problems are more severe.

The complete arrangement of such a system is shown in Fig. 9, where the physical and digital circuits are combined by filters at the customer's terminal. At an intermediate electronic unit at the cabinet, the physical and digital circuits are separated by filters and the digital circuits multiplexed into a standard 2·048 Mbit/s format. The physical connexion continues on a separate pair to a conventional analogue exchange termination.

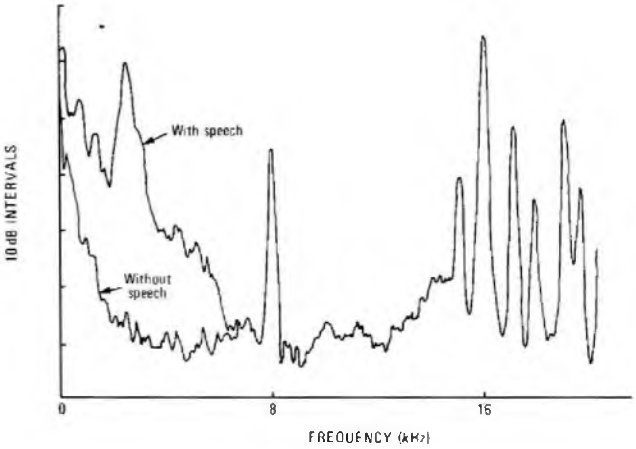
Although the cabinet is the most likely location for the equipment, it will probably be installed in a pressurized container in an adjacent footway box.

SIMULTANEOUS BI-DIRECTIONAL OPERATION

Burst-mode systems have a range limitation set by crosstalk, attenuation, cable delays and the need to avoid overlapping of bursts. To increase range further, either the crosstalk and attenuation must be changed, implying a new network, or simultaneous transmission and reception must be tolerated.



(a) Overall spectrum



(b) Low-frequency spectrum

FIG. 8—Frequency spectrum of burst-mode system

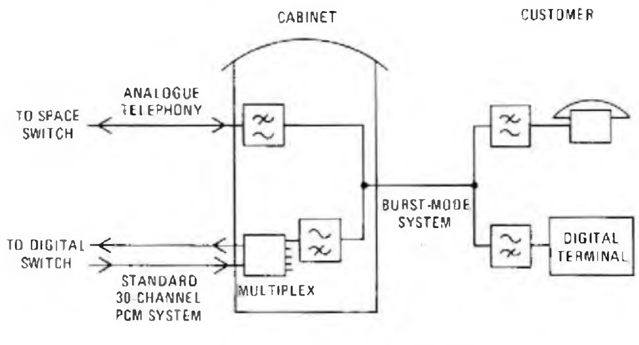


FIG. 9—Overall burst-mode system incorporating analogue telephony

For audio applications, hybrid circuits of various types are used, in which a bridge arrangement balances out transmitted signals from the input circuitry of the receiver operating in the other direction. However, in practice, this balancing can do little more than allow for the natural impedance of the cable to which the equipment is connected. For digital operation, echoes resulting from discontinuities in the transmission path (for example, changes of cable gauge) must be eliminated by some form of echo canceller[9]; in this, appropriately-delayed and attenuated parts of the transmitted signal are subtracted from the incoming wanted signal plus echo, as shown in Fig. 10.

As every path is different in the magnitude of these effects, the device must be made to adapt to the actual degradation and so becomes somewhat complex. Nevertheless, the availability of circuits using large-scale integration (LSI) means that this approach may be practical at reasonable cost. Thus, the transmission system will be able to operate at the basic information rate—rather than the higher rates required for burst mode—and attenuation and crosstalk will be reduced. A system reach of up to 8 km (limited by NEXT) may well then be practical and almost all customer-to-exchange connexions can be made without intermediate electronics.

One disadvantage arises from the low modulation rate: it is more difficult and expensive to superimpose such a system on a pair carrying conventional analogue telephony, because the requirements for the filter in terms of rejection and distortion become very severe.

FREQUENCY DIVISION

An alternative method of providing simultaneous bi-directional transmission uses different frequency bands for the 2 directions of transmission. One direction is a baseband digital signal and the other direction modulated on a carrier[10], as shown in Fig. 11. Because of the higher frequencies when modulated on the carrier, crosstalk between pairs is increased; however, because the transmitters and receivers at any point are operating in different frequency bands, only FEXT is of consequence. The FEXT path is usually of higher attenuation than the NEXT path, and so practical transmission distances may well approach that possible by echo-cancelling methods. However, retaining baseband telephony is just as difficult as for the echo-cancelling solution.

APPLICATION

So far, the means of providing a digital local network on existing pairs has primarily been considered. Its use can be divided into 2 broad applications: data and telephony. For data, it is a natural extension of the facilities offered today by modems and the analogue PSTN[11]. By choosing a digital local network, economies of scale reduce the cost of providing a data connexion so much that it comes within the range of domestic use.

The application for telephony is not so clear. Digital telephones, at present, do not appear to be cheaper than existing analogue versions, and the speech transmission advantages are small. However, the day is probably not far away when the evolution of technology will make the digital telephone competitive in price. This is particularly likely if the cost of the analogue exchange line unit is also considered; because of the power and signalling requirements, the use of semiconductor devices in analogue line units is difficult and expensive. Digital telephony also has the advantage of separate paths for each direction of transmission, and so loudspeaking telephones and conference calls[12] are simplified. On the other hand, it is not possible to provide extensions with digital telephones by using simple parallel operation, and a small conference unit will probably be needed. However, because of LSI technology, this may not be excessively expensive.

Although the penetration of digital telephony may be small, the very large number of telephones in use means that digital telephone connexions could outnumber the data connexions. One feature of digital operation that may make digital telephony attractive is the ease with which an additional low-speed data channel can also be added, so that viewdata[13], for example, could be accessed while a telephone call is in progress.

International discussions are taking place with a view to standardizing the parameters of local digital connexions. One proposal suggests an aggregate line capacity of 80 kbit/s[14], divided as shown in Table 1. It can be seen that 2 kbit/s signalling capacity is provided for each channel; thus, complex and rapid interactions will be possible between customer and network. For example, the routing and type of connexion could be changed during the call to give conference or data service.

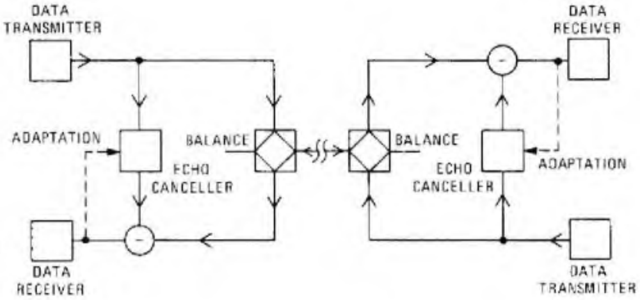


FIG. 10—Two-wire duplex system using echo cancellation

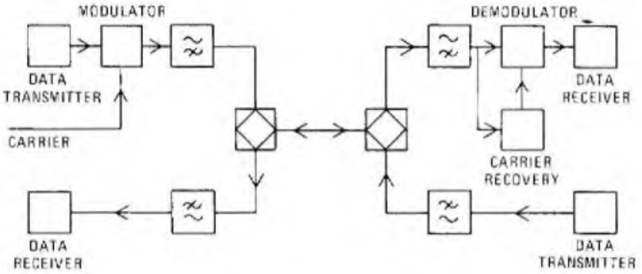


FIG. 11—Two-wire duplex system using frequency division

TABLE 1
Proposed Division of Line Digit Rate

Channel	Digit Rate (kbit/s)
Speech or Data Signalling	64 2
Data Signalling	8 2
Telemetry and Alarms	2
System Synchronization	2
TOTAL	80

SIGNALLING

The signalling capacity will probably be exploited by using a message-based system and, by the use of messages of various lengths, all types of terminals could be accommodated. A single button depression on a basic telephone might generate a short message carrying just one 8 bit character; an automatic data terminal would send the characters required for call set-up as one long message. These messages may include error-checking features, and automatic correction by retransmission may be provided. Such a signalling system operates both from and to the customer; in addition to conventional call set-up information, it could be used for alphanumeric displays at the customer's terminal and also for remote terminal testing.

Signals that are now provided by audible tones would be duplicated on the signalling channel so that electronic terminals could recognize network conditions. Even for basic telephones, the use of tones in the speech channel may be discontinued, and replaced by locally-generated tones or displays.

One particularly difficult area concerns the initial calling signal. It is undesirable to leave the terminal fully powered-up in the idle state, on grounds of economy of energy. However, it must be possible to power-up the terminal from the exchange for testing purposes, or to initiate a call. Similarly, the customer must be able to indicate to the exchange the wish to initiate a call.

FUTURE DEVELOPMENTS

One difficulty of digital operation on existing pairs in the local network arises from the high signal levels of practical digital systems, which will interfere excessively with analogue carrier systems (such as 1 + 1 carrier systems[15]) operating on other pairs in the same cable. For this reason, digital replacements for such systems will be required before any part of the local network can be converted to digital operation. Thus, the first systems to appear in Britain may well be digital 1 + 1 carrier systems and steps are already being taken to fully develop such systems. Although primarily for speech use, the digital capacity will be available for other applications.

Initial trials of digital equipment will take place in the laboratory, but such tests are by no means exhaustive and field trials usually reveal further problems. To attempt to eliminate these at the earliest possible stage, a local network test facility has been constructed at the BPO Research Centre. This is shown in Fig. 12, and consists of a small building connected to a cabinet 500 m away by overhead and underground cable of the type used between exchange and cabinet[16]. Several cables are provided and cross-connexions made so that the length can be increased to several kilometres. Cables of the fully-filled type, used in cabinet-to-customer connexions, are also provided from the cabinet back to the building and these can also be cross-connected to give longer transmission paths. Some of the pairs in these cables are terminated at a distribution point 200 m from the building, and the link to the building is made by drop-wire or underground distribution pairs. Thus, the building represents both the exchange and customer, and local network equipment can be thoroughly tested over real pairs, laid in a realistic manner.

It is difficult to estimate the rate of introduction of digital operation into the local network. Compared with the conversion of the main and junction network, about 10 times as many connexions are involved. In addition, suitable terminal equipment is necessary and this must be developed. In time, it may be attractive to install alternative transmission paths, offering wider bandwidths. To provide for this possibility, the local network facility has some spare capacity so that other transmission media, such as optical fibres[17], can be installed later.

CONCLUSIONS

It is possible to offer a 64 kbit/s digital voice-equivalent circuit with additional low-speed signalling and data channels on the existing network, with no cable re-arrangements except the introduction of electronics, probably at the cabinet. With fairly long system reach from cabinet to customer, the service could be economic with a small or a large demand for service. This can be achieved using only the technology of today, and could leave the existing physical connexion available for conventional analogue telephony with its existing reliability and cost. Such systems provide both a short-term solution for digital access and a long-term solution for an ISDN, until the demand for moving-picture services justifies the installation of suitable wideband paths.

FIG. 12—Local network facility

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Telegraph Time-Division Multiplex Systems

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UDC 621.394.42

This article briefly reviews the various methods used for multiplexing telegraph channels and describes three system designs, two of which accord with recent recommendations by the CCITT.*

INTRODUCTION

Several means are available for conveying a number of telegraph channels over a common route. Where the product of the number of channels and the distance is relatively small, and where cable pairs are available, DC transmission can give the most economical solution. Beyond this, the first order of multiplexing which is in common use is the frequency-division multiplexing of up to 24 telegraph channels on an audio bearer. This multi-channel voice-frequency telegraph (MCVFT) equipment produces an analogue output signal, although many present-day equipments use digital techniques to achieve this[1].

As digital equipment has become more economic, larger multiplexers using time-division multiplex (TDM) techniques have become increasingly attractive for use on routes of high telegraph-circuit density; for example, on high traffic-density routes that have to sustain traffic growth, and where it is not practical or economic to increase the number of bearers. At the present time this situation is evident on certain international routes, where bearer cost is a significant factor. Analogue audio bearers are used in this application; therefore, modems must be interposed between the digital TDM signal and the bearer. Another example of the use of TDM techniques occurs in the UK national network in situations where large concentrations of Telex customers' lines exist. In this case, however, 2 Mbit/s digital routes are used directly.

TELEGRAPH TDM SYSTEMS

Three types of telegraph TDM system are described in this article. For ease of identification within the British Post Office (BPO), each has been given a title which relates to the maximum number of 50 baud channels that can be accommodated; however they are all capable of carrying a lesser number of channels operating at a higher rate. In the BPO, the systems are known as *46 TDM*, *184 TDM* and *240 TDM* systems. It should be noted that they are invariably used in a bothway mode of working (4-wire) and so the number of channels quoted is the maximum number in each direction; that is, the channel capacity quoted can be read as the circuit capacity.

Telegraph TDM equipments are used to multiplex a number of anisochronous low-rate channels (Telex, or leased circuits at rates from 50–300 baud). The channels are combined into a single isochronous stream of bits by examining the state of each input channel in turn at a high rate. The resulting signal (the aggregate) then consists of the coded states of all channels in sequence. A complete set of samples from all channels constitutes a single aggregate frame. This system is called *bit interleaving* since, as with all the telegraph multiplexers described here, the input channels are sampled and assembled onto the aggregate on a bit-by-bit basis. Bit interleaving is used because it is important to minimize the signal transfer delay when TDM equipment is used in the Telex network. On the other hand, data multiplexers take in a complete character from each channel before assembling them, character by character, on the aggregate. Character interleaving is frequently used on data multiplexers because it can be more efficient in terms of channel capacity for a given bearer bandwidth.

Telegraph TDM multiplexers are divided into 2 distinct types: those which are code and speed dependent, and those which are code and speed independent.

Code-Dependent Multiplexers

In the case of code-dependent multiplexers, each frame is assembled in a time slightly less than the period of one bit on a basic low-rate channel. Code-dependent multiplexers are efficient in their usage of bearer bandwidth and are inherently regenerative. However, they tend to be complex and have the operational disadvantage that each channel has to be pre-set to the required modulation rate and code. Furthermore, for a Telex channel, the type of signalling to be used has to be pre-set. This arises from the fact that in order to achieve the maximum efficiency, only one aggregate bit is transmitted for each low-speed channel bit. Regeneration of the input characters is inherent in this approach and this can be an advantage on long routes having no other means of regeneration.

Code-Independent Multiplexers

In code-independent TDM systems the frame length is much less than the input data element length. This results in many samples of each input bit being transmitted in successive frames. Code-independent multiplexers are not as efficient as the code-dependent type, but fairly wide variations from the nominal modulation rate are tolerated. A small degree of telegraph distortion is introduced by the sampling process and its magnitude is determined by the sampling rate. The efficiency can be improved by reducing the sampling rate (which gives a corresponding increase in telegraph distortion) or by transition encoding, as in the case of the 240-channel TDM system.

The 46-Channel TDM System

The 46-channel TDM system uses code-dependent multiplexing designed to meet the requirements of CCITT* Recommendation R 101[2]. The system finds its widest application on international audio bearers, where it is a viable alternative to MCVFT.

A 2400 bit/s modem is normally used for connexion to audio bearers. The overall performance is very much dependent on the modem used, since a high bit-error-rate on the signal from the modem to the multiplexer would result in character errors and/or loss of frame synchronization. This highlights an important difference between an MCVFT system and this type of TDM system. With MCVFT, telegraph distortion tends to be proportional to bearer noise. With code-

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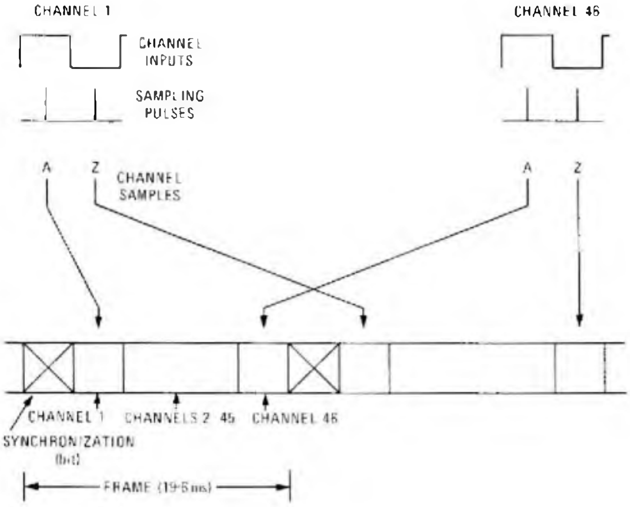


FIG. 1—Frame structure of a 46-channel telegraph TDM system

dependent TDM systems, an increase in bearer noise has no effect on telegraph distortion, but it does give rise to an increasing error-rate and, eventually, to system failure.

Each frame is assembled in a time approximately equal to the period of one bit on a basic low-rate channel (see Fig. 1). An allowance must be made for incoming data which is overspeed and, in the case of the 46-channel TDM multiplexer, this allowance is 2%. This results in a frame period of 20 ms less 2% = 19·6 ms. At an aggregate rate of 2400 bit/s, this results in a frame length of

$$2400 \times 19{\cdot}6 \times 10^{-3} = 47 \text{ bit}.$$

A synchronization bit is required to identify the start of each frame, leaving a channel capacity of 46.

There are 2 variants of synchronization method and frame structure defined in CCITT Recommendation R101, but many equipments now available are capable of being pre-set for either variant.

The first variant, termed *Alternative A*, enables one 75 baud channel to be accommodated in place of two 50 baud channels.

TABLE 1

Bit Rates and Available Channel-Capacity of a 46-Channel TDM System

CCITT Recommendation R101	Modulation Rate (bauds)	Character Structure		Maximum Number of Homogeneous Channels
		Character Length (bits)	Stop Element (bits)	
Alternative A	50	7·5	1·5	46
	75	7·5	1·5	22
Alternative B	50	7·5	1·5	46
	75	7·5	1·5	30
	100	7·5	1·5	22
	100	10	1	22
	110	11	2	22
	134·5	9	1	15
	150	10	1	15
	200	7·5	1·5	10
	200	10	1	10
	200	11	2	10
	300	10	1	7
	300	11	2	7

Note: At rates of 100, 200 and 300 baud, alternative character structures can be accommodated as indicated

The second variant, termed *Alternative B*, allows for the multiplexing of up to 8 different channel rates simultaneously. The channel rates are 50, 75, 100, 110, 134·5, 150, 200 and 300 baud. Channels operating at 100, 150, 200 and 300 baud replace two, three, four and six 50 baud channels respectively. Traffic at 110 baud is carried on a 100 baud channel by deletion of the second stop bit in each character. Traffic at 134·5 baud is carried on a 150 baud channel by adding a fill bit to each character. Channels operating at 75 baud are provided in pairs, each pair replacing three 50 baud channels. The channel rates and equipment channel capacity for a 46-channel TDM system are given in Table 1.

The Alternative-A system uses a handshaking synchronization procedure. This uses the whole of the aggregate bit stream in both directions, which results in loss of traffic in both directions following a loss of synchronization in one or both directions.

The Alternative-B system uses a search technique for synchronization, which does not necessarily involve loss of traffic in both directions since the equipment which is out of synchronism searches through the incoming aggregate looking for a predetermined synchronization pattern.

The 184-Channel TDM System

The 184-channel TDM system was designed to accommodate dense concentrations of Telex customers' lines in the UK; typically, these are to be found on routes radiating from towns that accommodate a Telex exchange.

The 1·536 Mbit/s or 2·408 Mbit/s digital links normally provided for pulse-code-modulation (PCM) circuits are used as bearers. Since the 184-channel TDM system has specialized application, it has not been made the subject of recommendation by the CCITT. However, it has been fully described in an earlier article[3].

Multiple sampling is used so that the system is fully code-and-speed independent (see Fig. 2). A 4 kHz clock is used to sample each channel at 250 μs intervals. Due to the short interval between samples, only a small additional distortion is introduced. For a 50 baud input channel, the 250 μs sampling interval results in 80 samples per bit. Thus, the distortion is

$$\frac{1}{80} \times 100\% = 1{\cdot}25\%.$$

Each sample is represented by 2 aggregate bits so that the 3 conditions used on UK Telex customers' lines can be transmitted. Dibits 10, 01, and 11 represent signal polarities A, Z and zero current respectively. Dibit 00 is not used.

A frame is assembled from each of the channel samples in

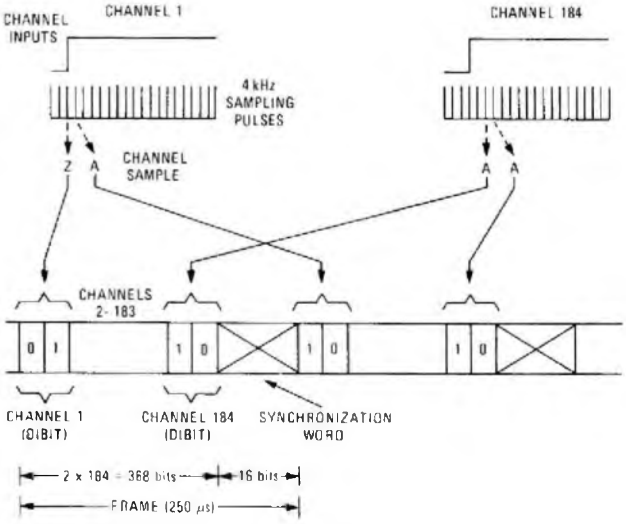


FIG. 2—Frame structure of a 184-channel telegraph TDM system

turn (in dibit form) and 16 bits are added for frame synchronization. This frame is transmitted every 250 μs so that, with an aggregate rate of 1·536 Mbit/s, the frame length is

$$1 \cdot 536 \times 10^6 \times 250 \times 10^{-6} = 384 \text{ bit.}$$

The channel capacity is

$$\frac{384 - 16}{2} = 184.$$

When 2·048 Mbit/s digital bearers intended for 30-channel PCM are used, there is a potential capacity for 248 channels. However, the additional channels are not normally provided due to the limitations of the physical layout of the equipment. The unused channel positions in the aggregate frame are set to transmit dibit 11.

The 240-Channel TDM System

The 240-channel TDM system is described in CCITT Recommendation R111[4]. The system is primarily intended for use on 64 kbit/s digital bearers, possibly in conjunction with PCM time-slot access. Like the 184-channel TDM system it is code-and-speed independent and introduces only a small sampling distortion.

The basic channel sampling is at 20 times the channel rate; that is, 1000 bit/s for a 50 baud channel (see Fig. 3). This results in a sampling distortion of 5%. These samples are not assembled directly into a frame, but a transition encoding process is used to reduce the aggregate rate. The sampling pulses are divided into groups of 4 and only one bit is transmitted for every 4 samples; therefore, the channel rate on the aggregate becomes

$$\frac{1000}{4} = 250 \text{ bit/s.}$$

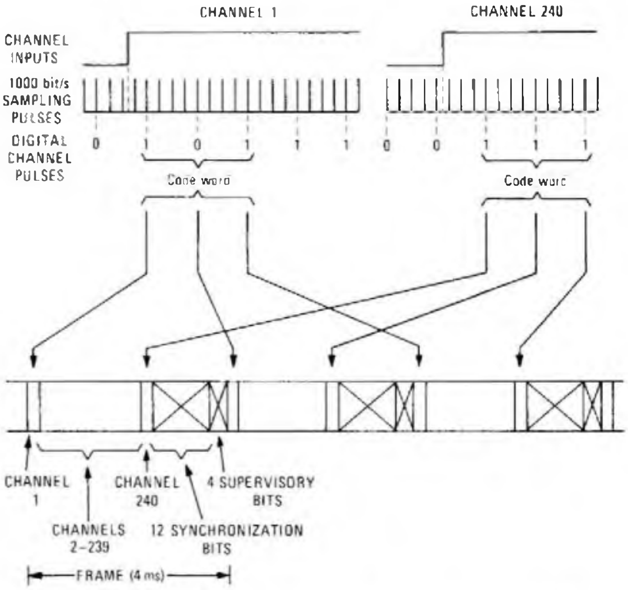
Whenever a transition occurs on the channel input signal, the next 3 bits transmitted form a code character that represents the sense and position of the transition. The first bit gives the sense, and the other two bits give the position relative to the group of 4 sample pulses during which the transition occurred. Since at least 3 bits must be transmitted for each input transition there is a restriction on the maximum input channel rate. This is

$$\frac{250}{3} = 83 \cdot 3 \text{ baud.}$$

If no further transition occurs during the fourth or subsequent 4 sample groups, additional bits are transmitted to confirm the polarity of the channel input signal.

The code elements are assembled from each channel in turn and synchronization and supervisory bits are added to form a frame of 4 ms. With an aggregate rate of 64 kbit/s, this gives a frame length of $64 \times 10^3 \times 4 \times 10^{-3} = 256$ bit. Twelve bits are used for synchronization and 4 for supervisory purposes; thus, the total channel capacity is $256 - 12 - 4 = 240$.

Higher channel modulation rates (mixed or homogeneous) are possible, as are alternative aggregate rates, see Table 2.



Code word for Z to A transition at the channel input	Code word for A to Z transition at the channel input	Position of the transition in a group of 4 sampling pulses
1 1 1	0 0 0	First quarter
1 1 0	0 0 1	Second quarter
1 0 1	0 1 0	Third quarter
1 0 0	0 1 1	Fourth quarter

FIG. 3—Frame structure of a 240-channel telegraph TDM system

SUMMARY

Three different types of telegraph TDM system have been briefly described. The code dependent 46-channel TDM system is beginning to be used as an alternative to VFT systems on international routes. It is likely that this trend will continue, possibly with the use of multiport modems to combine these TDM systems, thus giving even greater efficiency on these routes. In the UK inland Telex network, the code-independent 184-channel TDM system is now in widespread

TABLE 2

Channel Characteristics and System Capacities of a 240-Channel TDM System

Nominal modulation rate (bauds)	Maximum degree of isochronous distortion due to sampling (%)	Theoretical maximum modulation rate (bauds)	Channel rate on the aggregate (bit/s)	Maximum number of homogeneous channels for an aggregate rate of			
				64 kbit/s	9·6 kbit/s	4·8 kbit/s	2·4 kbit/s
50	5	83	250	240	32	16	8
	2·5	167	500	120	16	8	4
100	5	167	500	120	16	8	4
	2·5	333	1000	60	8	4	2
200	5	333	1000	60	8	4	2
300	7·5	333	1000	60	8	4	2

use on 1·536 Mbit/s digital links where this is an economic alternative to DC transmission or several VFT systems on the same route.

Greater capacity is expected to be required as high traffic-density routes result from the introduction of large stored-program-control Telex exchanges. The traffic capacity may be achieved by combining several 184-channel TDM systems onto one bearer and/or by reducing the sampling rate. The greater telegraph distortion thus produced being eliminated by the regenerative exchanges. Other means of gaining greater circuit capacity for customers' lines include concentrators of various types, but descriptions of these are outside the scope of this article.

The 240-channel TDM system has not yet found an application with the BPO but, with the advent of 64 kbit/s digital bearers (for example, time-slot access)[5], a TDM system of this type may become attractive in the future.

Whatever means of multiplexing is used, it must be remembered that a significant proportion of the cost of the terminal equipment is accounted for by the channel cards. Careful thought has to be given to the channel interfaces and to the means of providing transmission between the multiplexer and the customer or exchange—a subject outside the scope of this article.

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A Solution to Abnormal Telephone Exchange Congestion

J. P. DICKINSON †

Early last year, the Department of Health and Social Security (DHSS) Child Benefit Centre caused a severe service problem at Washington TXK1 telephone exchange. The distribution of child-benefit books was delayed and the centre was inundated with telephone calls from all over the country, resulting in severe congestion blocking the incoming network. Conventional approaches to solving the problem proved hopelessly inadequate, and discussions were speedily arranged with the DHSS.

In an attempt to quantify the level of traffic, additional meters were connected into the system. The 24-line group to the DHSS switchboard was fully occupied for over 8 h/d and call attempts at the junction-marker stage were running at 35 000/d; that is, over 1/s.

At meetings with the DHSS, it was obvious that they could not clear the cause of the problem for a variety of reasons, which led to the telephone area staff concluding that the only solution would be to reduce drastically the level of incoming traffic. To this end, a compromise scheme was worked out. This was to involve limiting the traffic to the DHSS centre to a specific level. When this level was reached, a verbal announcement was to be connected, advising callers of delay at the Child-Benefit Centre and instructing them to contact their local DHSS office. In addition, ex-directory out-of-area exchange lines were to be provided for the exclusive use of the local offices.

Details of the plan were worked out by telephone area staff, and included the direct connexion of the first 10 exchange lines of the original 24-line group to key-and-lamp units, already in use at the Child-Benefit Centre. The remaining 14 exchange lines were to be given a change of number and remain terminated on the customer's PABX3 switchboard.

At the local exchange, a non-standard method of connecting an announcement was devised. This employed a technique using a group-occupancy condition to give switching to an alternative routing. When all 10 lines were engaged, the announcement would be connected to subsequent calls. Various relay-sets and other items of equipment were urgently needed and a search for these was initiated immediately.

Within a week the DHSS confirmed acceptance of the plan and all urgency was given to its implementation. Telephone-area staff faced several difficulties, including shortage of vital equipment. The change-over took place over a weekend, with staff working under considerable pressure to meet their commitments. All work was completed by the Monday morning and nothing remained but to await the results.

These were dramatic. Within the first few days the traffic deluge subsided. Monitoring over the next few weeks showed a continuing drop, and it was apparent that the turn-back operation had proved successful. All congestion points were eased and the service to the other customers connected to the exchange rapidly improved. Satisfaction was felt in the telephone area that this combined exercise had achieved a pleasing result in that service to the customer had been returned to its normal high standard.

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INTELPOST

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A public trial of an international high-speed facsimile service is planned between the UK and several other countries. The service, known at this time as INTELPOST, provides the facility for members of the public to hand-in documents at nominated Post Offices for transmission by facsimile processes and for delivery. This article describes the service and the equipment used.

INTRODUCTION

During 1978, the USA postal administration invited a number of foreign postal administrations to participate in trials of an international facsimile service. The service, known at present as *INTELPOST*, has been designed to provide a high-speed document transmission service between the nations participating in the trial; the service is considered to be of particular interest to customers having insufficient traffic to justify their own facsimile equipment.

The British Post Office (BPO) made the decision to take part in the 12-month trial, as did the postal administrations of France, Germany, Netherlands, Argentina, Iran and Belgium. For the purpose of the trial, it was decided to provide an INTELPOST centre in a selected major city of each of the participating countries.

Each INTELPOST centre is to be equipped with facsimile equipment whose performance meets the requirements of the CCITT* draft Recommendation T4 for Group-3 facsimile equipment. Each centre will have one or more private circuits to other INTELPOST centres. The system operates on the store-and-forward principle; a minicomputer at each centre controls the operation of the facsimile equipment and the use of the transmission links.

The development of the hardware and software for the field trial has been carried out by contractors to the USA postal administration. All of the participating postal administrations are providing identical equipment at their INTELPOST centres and will use software supplied by the USA postal administration. Thus, complete compatibility of operations between INTELPOST centres is assured for the trial.

Wherever possible, the INTELPOST system is to be integrated with existing postal-delivery services. Documents for transmission by INTELPOST will be accepted at nominated Post Offices; after facsimile transmission to the destination country the document copies will be either delivered to the addressee or will be available for collection from designated INTELPOST offices.

In the UK, the London INTELPOST centre is situated at the Stock Exchange Branch Post Office. The equipment was installed during May 1979, and the system has been handling demonstration INTELPOST traffic to the USA since August 1979. At present, only two other centres are operational, these are located at Washington DC and New York city. However, several other countries are well advanced with their INTELPOST installation programme. At present, the USA postal administration is still awaiting the necessary regulatory authority to enable it to participate in commercial operation of the trial.

THE INTELPOST SERVICE

Documents to be sent via the INTELPOST service can comprise any number of separate pages of text, line drawings or diagrams. The facsimile equipment will handle pages up to a maximum size of 216 mm × 356 mm (8½ × 14 inches). Documents are transmitted in black and white only, but the facsimile scanner unit will tolerate originals bearing a wide range of colours and contrasts.

Use of the Service

Documents for INTELPOST will be accepted at the counters of the London Chief Office, Trafalgar Square Branch Post Office, or at the Stock Exchange Branch Post Office. Alternatively, customers in inner London will be able to telephone for an EXPRESSPOST messenger to collect their documents. The customer specifies which delivery method is required when the document arrives at the destination country and pays the appropriate fee. The charge for the INTELPOST service is to be determined by the number of pages in the document and whether collection or delivery by special messenger has been requested. The customer is also asked to specify the means of disposal of the original document after transmission to the destination INTELPOST centre. The original documents may either be returned to the sender or air-mailed to the addressee.

The Transmittal Sheet

A form, known as the *transmittal sheet*, is completed for each document to be sent via INTELPOST, using information supplied by the customer. The transmittal sheet records the various delivery options requested by the customer, addressee details and the number of pages which make up the document. The transmittal sheet forms the first page of the document to be subsequently scanned and transmitted. As document facsimiles are removed from the printer unit at the recipient INTELPOST centre they are placed in an envelope which has a transparent window section. The delivery option requested and addressee details, which were written on the original transmittal sheet, are visible through the envelope window.

Overseas Delivery Options

There will be slight variations in the delivery facilities provided by each of the overseas INTELPOST centres, but the main options are:

Special Delivery

Delivery is by special messenger direct to the addressee. Documents collected before noon in London will connect with same-day delivery services in the destination country.

Normal Delivery

Documents are distributed by the normal postal-delivery service. Delivery is normally made on the day after transmission.

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* CCITT—International Telegraph and Telephone Consultative Committee

Collection
Documents are collected personally by the addressee from the INTELPOST counter at designated Post Offices.

London Delivery Options

Documents transmitted to London by other INTELPOST centres will be either delivered by EXPRESSPOST messenger direct to the addressee, or will be available for personal collection from the INTELPOST counter at the Stock Exchange Post Office. For the duration of the trial, delivery will be restricted to the inner-London area.

INTELPOST-CENTRE OPERATIONS

The London INTELPOST centre occupies two adjoining rooms, one for the computer equipment, the other for the facsimile equipment and operator consoles. There will normally be two Postal Officers in attendance in the facsimile room; their duties will include operation of the facsimile equipment, enveloping and arranging delivery of incoming documents, and checking confirmation receipts for transmitted documents.

Outgoing Documents

Each document arriving at an INTELPOST centre is allocated a unique transaction number that identifies the document during its passage through the system to its final destination. The transaction number is written on the transmittal form, which was completed by the counter clerk who accepted the document.

The document to be transmitted, prefaced by the transmittal form, is placed in the automatic feed section of the scanner unit (see Fig. 1). The operator next completes the questionnaire displayed on the scanner terminal screen by keying the document transaction number, followed by simple codes to select the destination and delivery option required. The processor then activates the scanner unit, causing it to feed successive pages until the whole of the document has been scanned and stored. The operator, by pressing a SEND key on the scanner terminal, informs the processor that the electronic image of the document may be queued for transmission to the distant INTELPOST centre. Finally, the document originals are removed from the scanner outlet section and the unit is ready to deal with the next document. The document originals are retained in a file until the confirmation message from the destination processor has been received; the documents are then disposed of according to the sender's instructions.

FIG. 1—Facsimile scanner unit

Incoming Documents

Facsimile transmissions received at an INTELPOST centre are stored in a queue by the system processor. When the facsimile printer unit (Fig. 2) is free, the next document queued for printing causes an information block to appear on the printer terminal screen. The information consists of the document transaction number, the originating-centre code, the number of pages comprising the document and the delivery method requested.

The printer operator initiates printing by pressing the START key on the terminal keyboard. The printer unit, under the control of the processor, reproduces successive pages until the whole of the document, including the sender's transmittal form, has been printed. The processor then outputs a message to the terminal screen prompting the operator to check the quality of the document which is ready in the printer outlet tray.

Document Acceptance

Immediately after each document is printed at the destination INTELPOST centre, the printer operator at the receiving end is required to confirm acceptance of the document by pressing one of the 4 confirmation keys on the printer terminal keyboard. This causes a confirmation message to be transmitted back to the originating centre, where it is stored by the processor. The 4 confirmation key options available to the printer operator are: REQUEST RESCAN, WRONG CENTRE, REFUSE and CONFIRM OK. The function of these key actions is as follows.

Request Rescan
If it is evident from the printed document that an error or problem occurred during the scanning process, then the REQUEST-RESCAN confirmation option is used to direct the originating centre to rescan and retransmit the document.

Wrong Centre
This option is used to indicate that the document has been transmitted to the wrong INTELPOST centre by the origina-

FIG. 2—Facsimile printer and printer-operator's terminal

ting scanner operator.

Refuse
Documents are refused if the delivery address requested on the transmittal form is incomplete or illegal.

Confirm OK
This is the normal more usual method of confirmation, and indicates that the document has been received and printed, and that there are no problems associated with delivery.

Immediately after the document-acceptance option has been keyed, the printer terminal screen is updated to show details of the next document queued for printing.

Confirmations

The operators at each INTELPOST centre can interrogate their local processor at any time to obtain a list of confirmation reports for documents which they have previously transmitted. The confirmations are printed by a high-speed printer unit loaded with self-adhesive labels. Each label is printed with the following information concerning the document:

(*a*) document transaction-number,
(*b*) destination-centre code,
(*c*) number of pages,
(*d*) time and date scanned,
(*e*) time and date printed at the destination INTELPOST centre, and
(*f*) type of confirmation received.

After printing the confirmation labels, the operators deal with requests for rescanning and other forms of negative confirmation. The confirmation labels for accepted documents are peeled from the backing paper and transferred to the original transmittal form as a permanent receipt of the transaction.

THE SYSTEM-OPERATOR'S TERMINAL

The system-operator's terminal provides the means by which operators may acquire system and document-status information held by the processor. It also enables the operators to request various document control options provided in the system software.

By keying specific commands, the operators may request displays of status information that show

(*a*) the status of each of the remote INTELPOST centres,
(*b*) local status information, such as software queue sizes and disc occupancy, and
(*c*) the current status of any document held in the local system.

The operator can also key system-commands that

(*a*) delete specific documents from the local system,
(*b*) initiate an orderly shut-down of the system prior to carrying out equipment maintenance, and
(*c*) initiate printing and deletion of stored confirmation messages.

INTELPOST-CENTRE EQUIPMENT

A block diagram of the equipment arrangement at the London INTELPOST centre is shown in Fig. 3. The computer equipment (see Fig. 4) consists of a PDP11/34 processor with 128 K words of memory and a 67 Mbyte disc-memory unit. The disc memory is used as the buffer store for incoming and outgoing documents, and has a capacity of about 1000 A4-size pages of facsimile data.

A teletype unit prints error reports and transmission information during normal operation and provides a means of selecting and controlling hardware diagnostics in the event of a system fault.

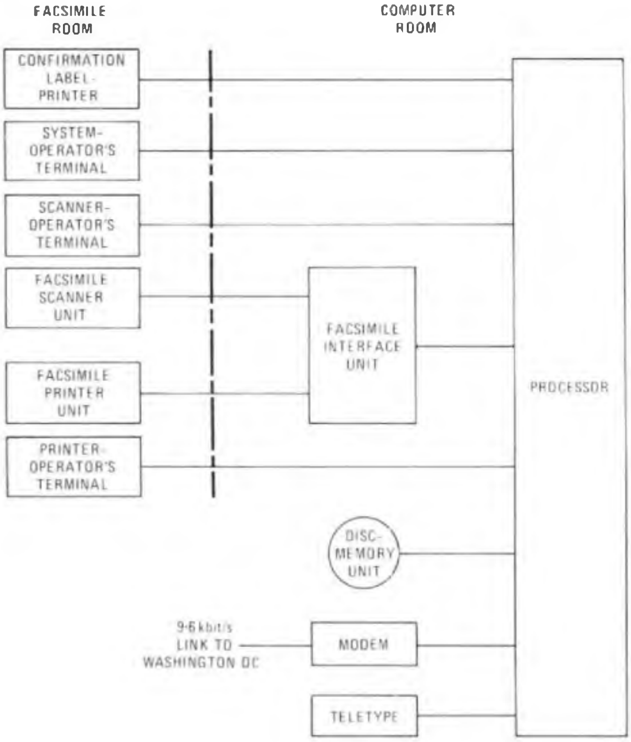

FIG. 3—Block diagram of the equipment arrangement at the London INTELPOST centre

FIG. 4—Computer room

Facsimile Interface Unit

The scanner and printer units have been designed to operate within a distance of 1 km from the computer equipment. To facilitate this, a facsimile interface unit (FIU), mounted in the processor rack, buffers the data and control signals from the facsimile units before connexion to the general-purpose processor interfaces.

A number of status indicators (light-emitting diodes) on the front panel of the FIU provide fault-localization assistance in the event of a scanner or printer malfunction. As a further engineering aid, a test switch is provided which, when operated, connects the scanner output signals direct to the printer input. This facility enables the two facsimile system elements to be operated and tested, totally independent of the processor.

The Scanner Unit

The scanner unit was designed specifically as a processor-controlled unit. It incorporates a page-feeding device that enables up to 50 pages to be scanned automatically without operator intervention. The scanner mechanism moves document pages over a narrow slit in steps of 0·127 mm; the image of the complete width of the illuminated page passing over the slit is focused on a cold-cathode discharge (CCD) photosensitive array. The CCD photo sites are very small and detect a height corresponding to only 0·165 mm of the document page. The horizontal resolution is 1728 picture elements; each element in the line scan is resolved as either black or white, and the resulting binary information is compressed into codes representing the length of black runs and white runs. The compression technique uses the CCITT-modified Huffman probablistic run-length code. The encoded line data is transmitted in serial form to the processor via the facsimile interface unit. The scanning process takes, on average, 15 s per page.

The Printer Unit

The printer unit receives compressed data from the processor and converts it into raster-scan information using data-reconstruction circuits. The printer uses electrostatic paper, which it cuts to length from a roll at the start of each page-printing cycle. During the page-printing cycle, the picture elements are transferred to the paper surface in the form of an electrostatic charge pattern; the page then passes through a liquid toner solution, a drying section, and is finally deposited in the outlet tray. The page-printing cycle takes approximately 20 s to complete.

TRANSMISSION NETWORK

Each INTELPOST centre is connected to the INTELPOST network by means of dedicated 4-wire circuits. The present London to Washington circuit is routed via a satellite link and operates at 9·6 kbit/s using a data modem at each end of the circuit. The data modems meet the performance requirements of CCITT Recommendation V29.

The data modem accepts serial, synchronous, binary data from the processor and transmits it to line at a signalling rate of 2400 baud. The time taken to transmit each page of facsimile data is 1·5–2 min.

The New York INTELPOST centre is connected to Washington DC by a 56 kbit/s circuit, which enables each document page to be transmitted in approximately 20 s.

The extent of the network configuration that will be used for the commercial field-trial has yet to be decided.

THE SOFTWARE

With the exception of local modification to accommodate particular equipment configurations, the software used at all INTELPOST centres is identical.

The transmission system and protocols used were largely determined by the work done for the ARPANET data network, which is currently in use in the USA.

The system software is divided into 3 main functions: the operating system, communications software, and application software.

The Operating System

The operating system provides the overall control of the many processes which are required to take place simultaneously; for example, one document may be in the process of being scanned, another being printed, and several other documents may be in the process of being transmitted or received. The operating system also provides the necessary management of the 128 Kword processor memory, using the PDP11 memory-mapping hardware.

Communications Software

All transmissions between INTELPOST processors are in the form of error-checked data packets. As packets are received, the transmission-control program issues acknowledgements and requests packet retransmissions as and when necessary. This avoids the need to retransmit a complete document page in the event of a minor data-corruption. The communications software also deals with retransmission of incoming packets that are destined for another INTELPOST centre in the network.

Each INTELPOST processor constantly checks the status of the other centres by sending and monitoring status transmissions. Thus, each processor is aware of which routes are available at any time.

Application Software

The application software is divided into a number of discrete processes, each having a particular, well-defined, task. The main processes are as follows:

Scanner

The scanner process reacts to commands from a scanner-operator's terminal, activates the scanner unit and stores the facsimile data on disc.

Printer

The printer process reads the facsimile data forming the next document for printing from the disc and interacts with the operator in controlling the printer unit. This software process also deals with document confirmations, which are keyed-in by the printer operator.

Co-ordinator

The co-ordinator is the process that controls the selection of documents for transmission and reception. Two queues are maintained by the co-ordinator: the first is a list of documents to be transmitted and the second is a list of documents to be received following requests from remote co-ordinators.

In scheduling documents for reception, the co-ordinator takes account of the available disc space before requesting the remote centre to start transmission. The co-ordinator software also handles the transmissions required for document confirmations.

CONCLUSIONS

After the first few months of the demonstration service, there have been virtually no problems with the INTELPOST equipment, and the initial demand for the service is encouraging. At least 6 more countries have decided to join the INTELPOST trial, and many others are showing a keen interest in the service.

Using the information gained during the trial, the design of future networks will take account of anticipated traffic between the various countries and will provide alternative data routes to ease congestion and route dependence; an internationally-agreed transmission protocol will be used. It is envisaged that each country will have a need to integrate the INTELPOST system with its own domestic facsimile network to provide a national service. Indeed, the INTELPOST systems may well become an integral part of an international electronic-mail system.

There is little doubt that there is a rapidly increasing need for an international electronic-mail system, and the BPO intends to make an important contribution towards its specification and implementation.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the work of his own staff and colleagues within the BPO in establishing the London INTELPOST centre. Credit is also due to the USA postal administration for their initiative in producing the INTELPOST system.

An IMPATT Diode Amplifier for 11 GHz Digital Radio-Relay Systems

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UDC 621.375.4: 621.371: 621.376.4

This article outlines the principle of operation of the IMPATT diode and discusses the materials, construction and packaging aspects. A description is then given of the design of an IMPATT diode amplifier capable of producing 10 W output power and intended as the replacement for the travelling-wave amplifier in 11 GHz digital radio-relay systems.

INTRODUCTION

Microwave radio-relay systems constitute a significant proportion of the main network transmission capacity, and must keep pace as digital working is introduced progressively during the 1980s[1]. This will be achieved initially by exploiting the 10·7–11·7 GHz frequency band[2], primarily as an overlay to the present 2, 4 and 6 GHz analogue radio network[3], using existing radio station sites and aerial support structures. The lengths of typical links, propagation effects at 11 GHz[4], and achievable noise figure of receivers combine to necessitate a transmitter output power of around 10 W to achieve the required main network transmission performance standards.

The first generation of 11 GHz digital radio equipment will produce this output power from a travelling-wave tube amplifier (TWTA). Recent advances in TWT construction have extended their operating lifetime, but even so, the limit is only some 3 years, representing a considerable maintenance and replacement cost during the life of the equipment. The TWTs also require high-voltage (several kilovolts) power supplies, which are heavy and bulky and have not always been very reliable.

This article describes an amplifier, incorporating high-efficiency impact avalanche transit-time (IMPATT) diodes, which is being developed for use in the output stage of an all-solid-state 11 GHz transmitter. This amplifier offers an economic advantage over the TWTA, because it is designed to last for the life of the system, without any routine maintenance or replacement of components.

SOLID-STATE POWER DEVICES

Of the possible alternative contenders for the active devices to be used in the amplifier, only the gallium arsenide (GaAs) IMPATT diode can provide the necessary power with the required reliability at present[5]. However, developments in GaAs field effect transistors (FETs) have been dramatic in the last few years, and it may not be long before commercially-available devices are challenging the GaAs IMPATT diodes developed for the present project.

Although IMPATT diodes can be fabricated from either silicon or GaAs, it is only in GaAs that the combination of high mobility and carrier velocity combine to produce the highest efficiency *hi-lo* Read-type[6] structure. The diodes are fabricated from suitably grown epitaxial layers, with titanium-platinum-gold Schottky barriers for both the active (N_1) and the back contacts[7, 8], as shown in the cross-section of a typical diode in Fig. 1. They use much of the basic IMPATT technology previously developed for the millimetric trunk waveguide project[9]; namely, proton isolation of the diode active areas and integral gold-plated heat sinks for good thermal heat sinking. Because of the extremely tight doping profile specification that is required for this *hi-lo* diode structure (Fig. 2), and the absence of a generally-accepted theory to explain the high-efficiency mode of operation, much effort was required in the British Post Office Research Department to optimize the structure for the 10·7–11·7 GHz band.

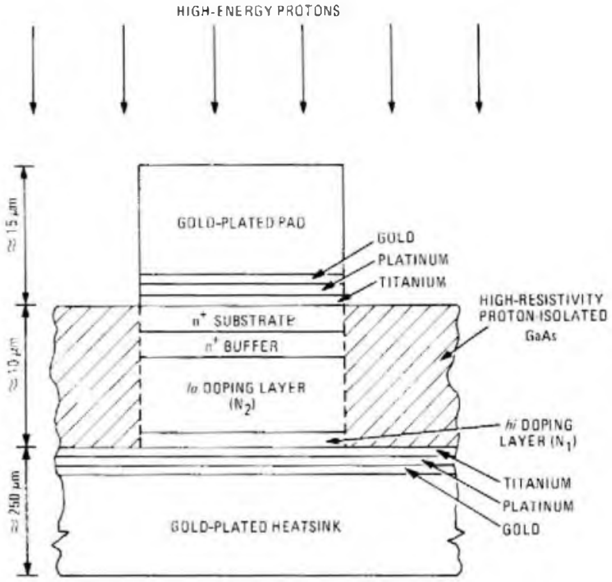

FIG. 1—Cross-section of typical diode

PRINCIPLES OF HI-LO READ-TYPE IMPATT DIODE OPERATION

The basic *hi-lo* diode derives its name from the shape of the doping profile required for its operation. A typical idealized and a practical profile for an 11 GHz GaAs diode are shown in Fig. 2. The junction of such a diode is formed by a metallic Schottky contact to the *hi* (N_1) region and, when the diode is sufficiently reverse biased, avalanche breakdown of this junction takes place; the resulting avalanche-zone is contained totally within a thin region (x_1) of approximately 0·4 µm, although the depletion region extends further into the N_2 drift region. To simplify the technology, a similar metal Schottky contact to the n^+ substrate is used in place of an ohmic back contact. (Since this diode is effectively forward biased during operation, its impedance is sufficiently low at the operating frequency.)

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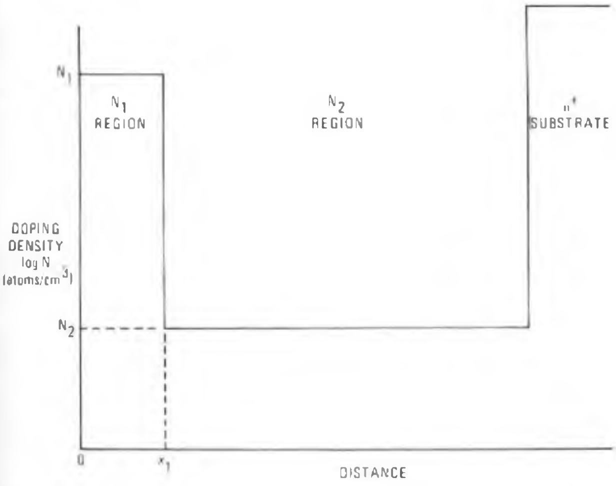
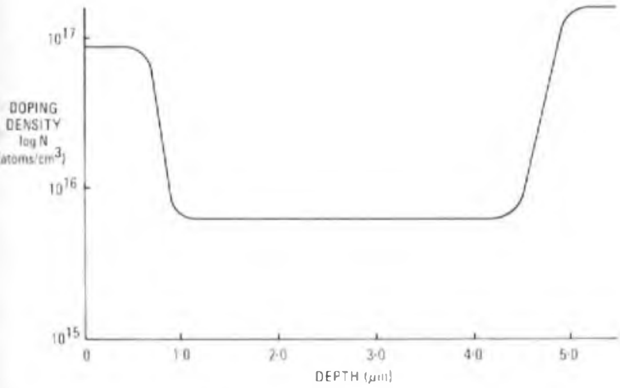
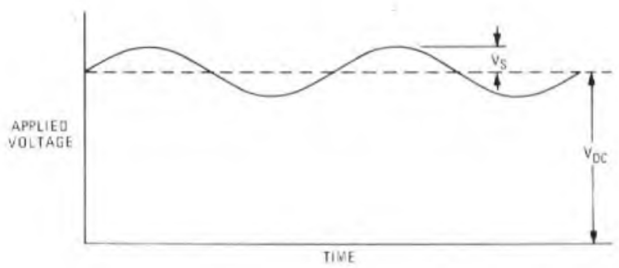


(*a*) Idealized profile



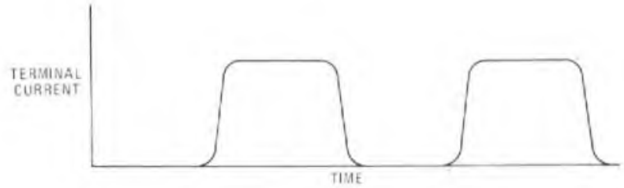
(*b*) Profile for practical grown epitaxial structure

FIG. 2—Doping profiles for 11 GHz GaAs *hi-lo* IMPATT diode



(*a*) Applied voltage

(*b*) Avalanche current



(*c*) Terminal current

FIG. 3—Diode operating principles

When a signal voltage (V_s) is superimposed on a DC voltage (V_{DC}) just below breakdown, Fig. 3(*a*), the peaks of the combined voltages generate avalanche pulses of charge carriers (electrons), Fig. 3(*b*), which then drift at the saturated drift velocity (approximately 6×10^6 cm/s at the operating temperature of about 200°C) through the *lo* doped N_2 region. Because there is a phase delay of approximately $\pi/2$ due to the build-up of the avalanche process, and a further delay due to the drifting carriers in N_2, it is possible, by appropriate choice of depletion-layer thickness (determined by the doping profile), to produce a total phase shift of π in the induced terminal current with respect to the applied voltage, Fig. 3(*c*); thus, a negative resistance is presented to the external circuit. Such a diode can then be used to generate power in an oscillator, or in a reflection amplifier.

This simplified theory of operation is equally applicable to the basic uniformly-doped IMPATT structure, but the particular properties of GaAs, used in conjunction with the *hi-lo* doping profile, enable a larger depletion layer swing to be obtained, which increases the normal efficiency of about 10% to greater than 20%. Powers greater than 2 W at 11 GHz have routinely been produced from a single diode, and the 5·3 W obtained from a single chip is probably the highest reported for a temperature rise of only 180°C.

Fig. 4 shows an example of a diode, mounted in a specially-designed package, consisting of 2 active areas bonded together with a thin gold tape to produce 4·5 W. Two diode chips, each in a separate package, are used in the amplifier power stage, as shown in Fig. 11.

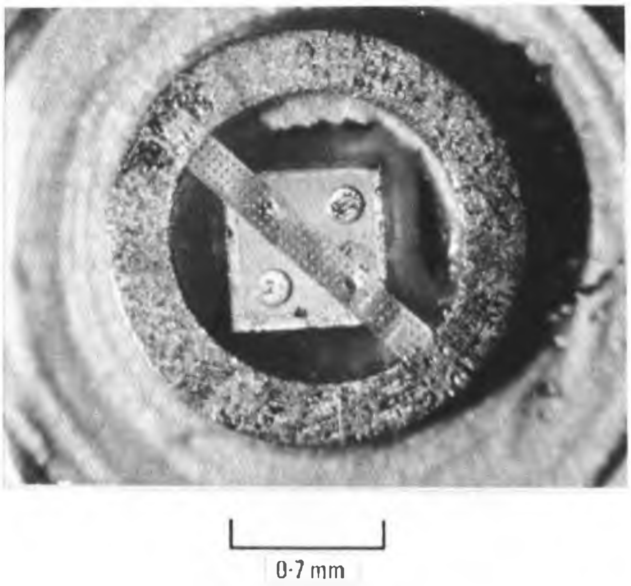


FIG. 4—Photograph of packaged diode—plan view showing 2 areas bonded

MATERIALS SPECIFICATION

Inevitably, the optimization of the structure[10] to obtain such improvement in performance places severe constraints on the basic semiconductor materials requirements, to such an extent that the specification is probably the most difficult to meet for any semiconductor device yet produced.

The most critical part of the epitaxial layer structure is the *lo* N_2 drift region, which is required to be $4 \cdot 0 \pm 0 \cdot 5\ \mu$m thick and of doping level $(6 \cdot 0 \pm 0 \cdot 5) \times 10^{15}$ atoms/cm^3. If this doping level drops to 3 × 10^{15} atoms/cm^3, the frequency of peak efficiency shifts from 11 GHz to 8·5 GHz; an increase to 8 × 10^{15} atoms/cm^3, however, reduces the efficiency to about 15% at 11 GHz.

The *hi* N_1 region has a more relaxed specification of (8·5 ± 1·5) × 10^{16} atoms/cm^3, with an initial thickness exceeding 0·5 μm. This is because the depletion-layer width, as deduced from the breakdown voltage, is the controlling factor in determining the correct operating frequency, and the layer thickness can be tailored appropriately to a particular doping by using an etch-to-voltage technique[11]. By successive anodic oxidation in a chemical solution, and removal by etching, thin layers of GaAs can be removed until a typical final thickness of 0·4 ± 0·02 μm is achieved. Careful monitoring of the removal of the layer is aided by the use of an ellipsometer, until the final breakdown voltage is reached.

Because of the very tight control required on the N_2 doping level, very stringent calibration and monitoring of the measuring techniques are required, particularly when material is obtained from more than one source of supply.

DEVICE TECHNOLOGY

The cross-section of a typical diode is shown diagrammatically in Fig. 1. From the basic GaAs slice, approximately 0·25 mm thick and containing the epitaxially grown *hi-lo* sequence of layers on a highly doped substrate, squares of side 8 mm are cleaved and thinned as described. When the correct breakdown voltage is reached, the slice is cleaned and the Schottky barrier of 0·1 μm of titanium is deposited by filament evaporation in a vacuum vessel. The slice is transferred to another vessel for radio-frequency (RF) plasma cleaning, and then layers of 0·3 μm platinum and 0·3 μm gold are deposited by DC triode sputtering.

A gold heatsink is electroplated onto the sputtered gold layer to produce a layer of gold 250 μm thick; the GaAs slice is then mechanically thinned from the back by lapping, followed by etching to remove work damage, until the final semiconductor thickness is approximately 10 μm. A similar titanium-platinum-gold metallization is then deposited on the n^+ substrate, and an array of gold pads, about 15 μm thick and with appropriate pad diameter (120–160 μm), is electroplated through a template produced by photolithographic techniques.

These pads not only provide contact areas, but also act as a mask to define the active diode areas during subsequent proton bombardment using a range of energies (200 keV to 1·4 MeV) from a high-energy accelerator. This bombardment converts the GaAs outside the masked areas into a semi-insulating form, which then isolates and separates the diodes and produces a buried device structure. Finally, the slice is sawn into about 70 chips, each 0·7 mm square, with 4 individual diode areas on each. The chips are then mounted, N_1 Schottky contact side downwards, into special packages, as described later.

LIFE TESTING

Packaged diodes are placed on accelerated life tests with junction temperatures up to 300°C. Preliminary burn-in tests eliminate premature failures caused by the alloying of gold from the contact metallization through flaws in the platinum and titanium films.

Three possible modes of eventual failure have been identified. The first is alloying of the Schottky contact metallization into the *hi* region, hence reducing the effective thickness and increasing the breakdown voltage. The second is indiffusion into the GaAs of an impurity such as chromium, which is present in the titanium at the parts-per-million level, lowering the effective doping level[12]. The third is catastrophic failure resulting from indiffusion of gold from the contact areas, leading to final alloying right through the semiconductor slice.

An encouraging feature of the tests so far is the stability of the breakdown voltage and the RF performance of the limited number of devices tested, which suggests that the titanium-platinum-gold metallization system adopted for the Schottky contact is capable of providing the required system life of greater than 10^5 hours[13].

ELECTRICAL ASSESSMENT

Although the diodes are intended for eventual application in an amplifier, initial assessment in terms of output power and optimum frequency is carried out using hybrid coaxial-waveguide oscillator circuits[14]. The results of such an assessment are shown in Fig. 5. Previous experiments have shown that the maximum added power obtainable from the diodes in an amplifier circuit is the same as that obtainable in an oscillator circuit. The choice of whether one, two or more diode areas are bonded, and what diameter these should be, is a complex interaction of thermal and reactive constraints imposed by the package, and will be discussed later.

An example of the trade-off between the number of diode areas bonded in parallel and the output power, for 2 different diameters, is shown in Fig. 6. Reactance considerations limit the total area, so that the optimum diameter depends on the number in the array. Within this constraint, 4 small diodes give more power than 2 large ones. Fig. 7 shows the output power at 11 GHz for four 120 μm diameter diodes connected in parallel and indicates that, for a junction temperature rise

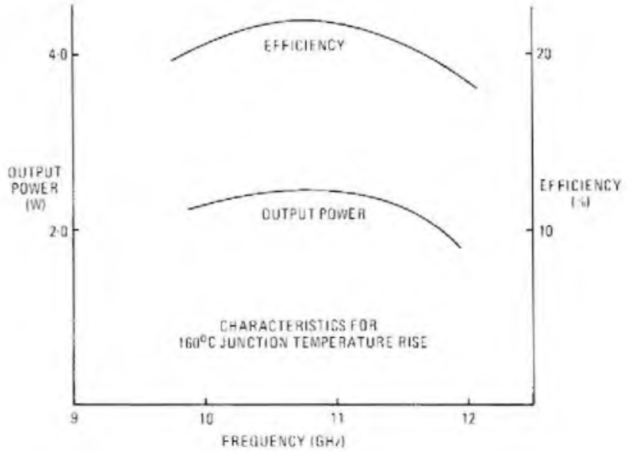


FIG. 5—Oscillator output power and efficiency as functions of frequency

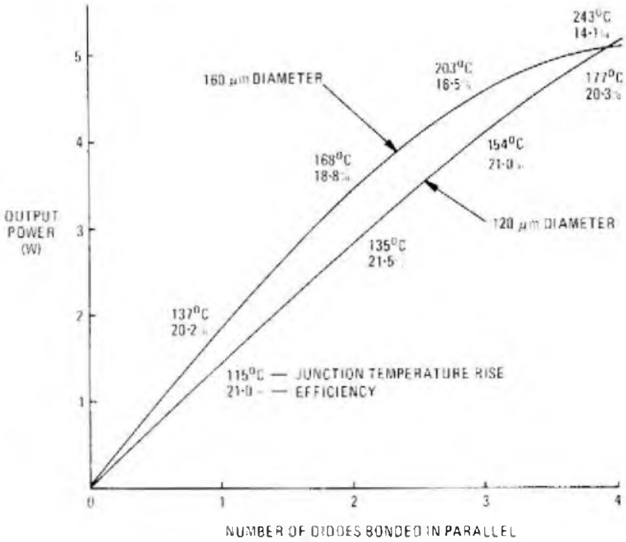


FIG. 6—Power related to diode diameter and number bonded in parallel

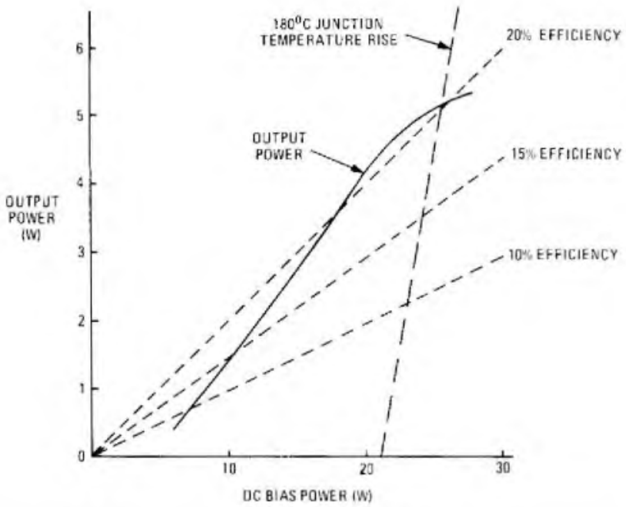


Fig. 7—Oscillator power and efficiency at 11 GHz for four 120 μm diodes

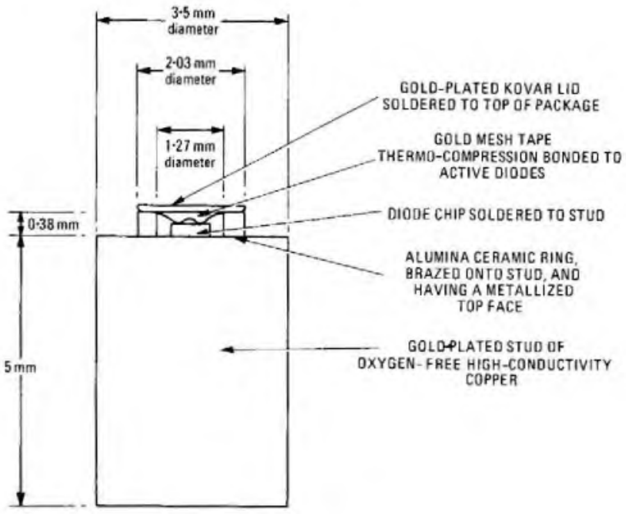


Fig. 8—Section through package containing diode

of 180°C, the peak efficiency and thermal limit are reached at nearly the same input power, thereby maximizing the output. However, larger diode areas bonded in arrays of only 2 or 3 are preferred on grounds of yield, and give sufficient power to be used singly in the amplifier driver stage, as described later.

DIODE PACKAGING

The diode chip is quite fragile, consisting of a thin brittle GaAs layer on top of the much thicker and comparatively plastic gold heatsink, and is insufficiently robust for mounting in an amplifier unless encapsulated in some way. Commercial packages are legion, but most of those intended for high-frequency use have inadequate heat-sinking properties. Most have threaded studs that result in poor thermal contact, except perhaps where a top flange of adequate diameter is provided, yet even this is in an area of low thermal flux. A special package was therefore developed, overcoming these problems and having better electrical properties than the alternatives; this is shown in Fig. 8.

The diode chip is soldered directly to the top of a relatively-massive gold-plated copper stud. The stud is mounted in a close-fitting collet (not shown in the diagram), its large diameter ensures adequate contact area at this first mechanical interface. The collet, in turn, is clamped in a conical seating in the amplifier body, so that it grips the stud tightly to provide good thermal and electrical contact. By this means, the contribution of the stud and its mounting collet to the thermal resistance is kept as low as 4°C/W.

Mechanical protection is provided by the alumina ceramic ring, which is brazed onto the stud. Flexible gold-mesh tape, attached by thermo-compression bonding, connects the active regions of the diode to a gold metallization on top of the ceramic ring. The tape is made by an electroplating process, and is 125 μm wide by a few micrometres thick. A gold-plated Kovar† lid can be soldered in place to complete the package and provide a closed environment for the diode.

The dimensions chosen determine the reactance of the packaged diode. Series inductance is associated with the bonding tape and with magnetic energy storage in the region of the package, while shunt capacitance is contributed by the lid, the ceramic ring and fringing effects. Low total reactance is necessary for wide bandwidth, and the balance between inductance and capacitance (that is, the series resonant frequency of the diode) must be compatible with the particular circuit environment. The amplifier configuration chosen contains quarter-wave matching transformers, and there is only limited scope for reducing their length to accommodate the low series resonant frequency that results from excess inductance, so it is this component that must be minimized in designing the package. Low inductance requires low total volume and a short bonding tape. Thus, the ring chosen has an inner diameter that just clears the corners of the chip and a height only slightly greater than the chip thickness. This choice of ceramic-ring height is an essential feature in achieving the maximum power output from the diodes.

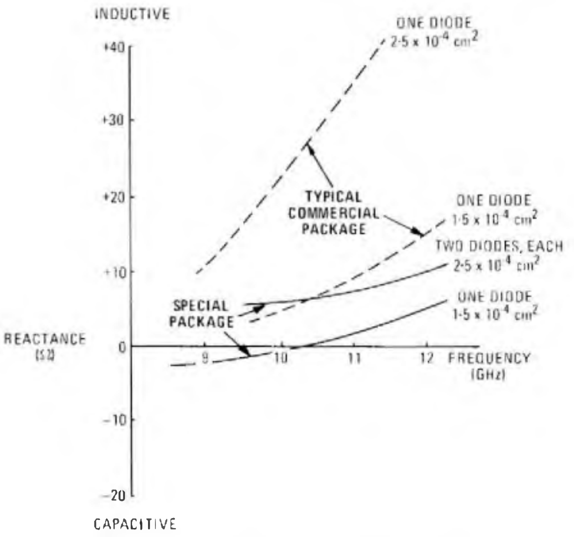


Fig. 9—Reactance of packaged diode

To increase power, the total active area of semiconductor must be increased by bonding together more diodes on one chip, or by increasing their diameter. However, the resonant frequency of the packaged device then falls and, for areas yielding the power needed in this application, is below the required operating frequency. The maximum inductive reactance that can be matched in the broadband amplifier is 10 Ω. The reactance curves of Fig. 9 show that, for operation in the 10·7–11·7 GHz band, a maximum area of about 5×10^{-4} cm² can be matched, giving about 5 W of added RF power. For this reason, the power from 2 packaged diodes is combined to obtain the required 10 W from the amplifier.

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† Kovar—Trade mark; a metal alloy having the same thermal expansion coefficient as alumina ceramic

THE 10 W OUTPUT STAGE

The IMPATT diodes are used in a reflection amplifier configuration. A signal incident on the diode is reflected with enhanced amplitude, and a simple amplifier could consist of an IMPATT diode, connected to a 3-port ferrite circulator to separate the input and output signals, as shown in Fig. 10. In practice, additional circuit elements are needed to provide an impedance transformation between diode and circulator, thereby controlling the gain and bandwidth; provision must also be made for application of DC bias. Furthermore, the impedance characteristics of the circuit must be such as to inhibit oscillation at unwanted frequencies.

The 10 W output stage, shown schematically in Fig. 11, uses a circuit structure first described by Rucker[15, 16] to combine the power from 2 packaged diodes. The diodes are mounted at the ends of quarter-wave transformers, which are connected together with a microwave absorber and capactively coupled to the input-output port; this, in turn, is connected to the circulator. At the operating frequency, there is a current node at the centre of the symmetrical circuit and, ideally, the absorber contributes no loss. In practice, there is a small loss if the characteristics of the 2 diodes are not perfectly matched. However, at other frequencies this condition does not apply and the presence of the absorber introduces considerable damping. This effectively inhibits the generation of harmonics, sub-harmonics and parametric products, which are so prevalent in more conventional circuits when IMPATT diodes are driven at high power levels.

The quarter-wave transformers are constructed in troughline, which is an open-sided U-shaped variant of coaxial transmission line. Adoption of this open structure eases the provision of bias and tuning arrangements. Constant-current bias is applied separately to each diode via a coaxial low-high-low filter section and a fine wire, which forms a quarter-wave choke (the absorber is non-conducting at DC). A nylon screw, with low-loss quartz tip, is inserted through the open side of the troughline to give a tuning adjustment range of a few-hundred megahertz.

The characteristic impedance, Z_0, of the transformers plays a major part in transforming the load resistance to the value into which the diode must work to give the gain required. The gain is given by

$$G = 10\log_{10}\left|\frac{Z_D - Z_s^*}{Z_D + Z_s}\right|^2 \text{ dB},$$

where Z_D is the diode impedance, Z_s the impedance presented to the diode by the circuit, and * denotes the complex conjugate.

At the centre frequency of the amplifier, the diode reactance is resonated, and the gain can be more simply expressed in terms of resistances as

$$G = 10\log_{10}\left(\frac{R_D - R_S}{R_D + R_S}\right)^2 \text{ dB}.$$

A typical diode has an RF resistance of $-2\ \Omega$; so, for a gain of 6 dB, the circuit must present a resistance of $R_S = 6\ \Omega$.

Fig. 12 shows how the RF equivalent circuit appears to each of the 2 packaged diodes. It can be shown that the impedance presented to the diode, when the transformer is one-quarter wavelength long, is

$$Z_s = \frac{2R_L Z_0^2}{4R_L^2 + \dfrac{1}{\omega^2 C^2}} + j\frac{Z_0^2/\omega C}{4R_L^2 + \dfrac{1}{\omega^2 C^2}}.$$

If the coupling capacitance is made large, then

$$Z_s \approx \frac{Z_0^2}{2R_L},$$

and a value of $Z_0 = 24{\cdot}5\ \Omega$ is required.

In practice, a lower value of coupling capacitance is chosen, so that the coupling can be adjusted easily to set the transformation ratio, and hence the gain, to the value required. This reduces the resistance presented to the diode and, to compensate for this, a higher value of Z_0 is required. A value

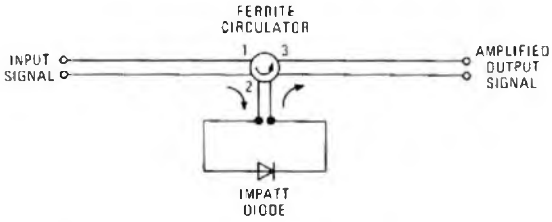

FIG. 10—Principle of circulator-coupled reflection amplifier

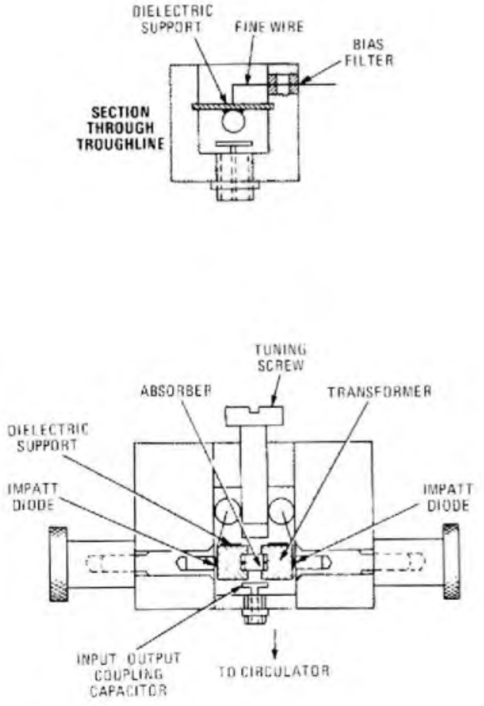

FIG. 11—Diagram of 10 W output stage

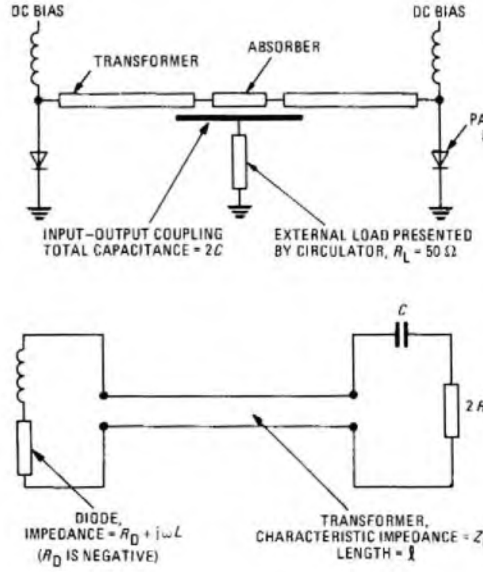

FIG. 12—RF equivalent circuit as seen by each diode

of 30 Ω is found convenient. Also, the transformers are made considerably shorter than the nominal quarter wavelength, in order to resonate the diode inductance. This factor, together with the stray capacitances associated with the transformer supports, and other minor fringing effects, contributes to the impedance transformation, which determines the gain and bandwidth of the amplifier.

It is characteristic of high-efficiency IMPATT diodes that their negative resistance increases markedly with reduction in RF signal level, especially towards the lower end of their operating frequency range. Consequently, an unconditionally stable amplifier (one that does not oscillate under any drive conditions) cannot be constructed with a gain greater than about 2 dB. Uncontrolled oscillations cannot be tolerated in an operational system, because they could cause interference to adjacent transmission channels. A squelch circuit must be provided to suppress the output when normal operating conditions are disturbed; for example, by a loss of input signal. In a conventional arrangement, the input power would be monitored with a directional coupler and diode detector. However, a novel and more all-embracing arrangement[17] is used, exploiting the change in diode DC operating voltage that results from any disturbance to the RF conditions. A temperature-compensated voltage-sensing circuit monitors the diode voltages, and removes the DC bias if these wander outside preset limits.

THE TWO-STAGE AMPLIFIER

The 10 W output stage requires just over 2·5 W of RF drive, taking into account the small losses in the circulator. Even this is greater than the power obtainable conveniently, and with reliability, by other means, and so a further stage employing high-efficiency IMPATT diodes is used as the driver. This also uses the Rucker structure to take advantage of its freedom from instabilities, and therefore incorporates many parts common to the output stage. Because power levels are lower, however, the heat sinks can be smaller, and within each diode package only a single active area is bonded. The consequent reduction in reactance improves the gain-bandwidth product, and the driver stage is operated at a gain in excess of 10 dB.

Fig. 13 is a functional diagram of the 2-stage amplifier, showing the third circulator that provides inter-stage isolation. The 3 low-loss stripline circulators† are constructed as a single 5-port module, reducing losses and reflections by elimination of redundant connector pairs. Bandwidth is reduced by cascading 2 stages, but remains well in excess of that required for an RF channel of the radio-relay system. Nevertheless, a tuning adjustment is provided on the driver stage. This allows a single amplifier to be used (or serve as a spare) for any of the 6 channels accommodated in a 500 MHz half-band for transmission in one direction. Another amplifier, having transformers and troughlines of slightly different length, accommodates the other half-band for the opposite direction.

The photograph of Fig. 14 shows a complete 2-stage amplifier. The driver and output stages are seen respectively below and above the rectangular circulator module, and surmounted by the heatsinks for the current regulator power

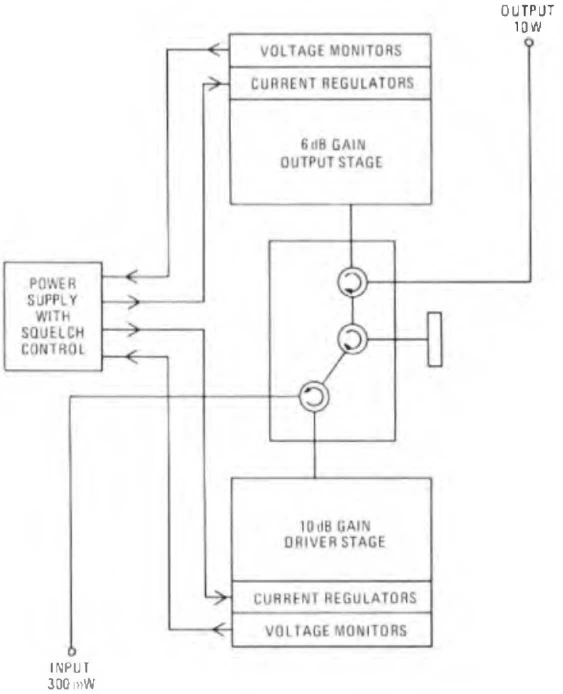

Fig. 13—Configuration of 2-stage amplifier

Fig. 14—Photograph of 2-stage amplifier

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† Developed at the Hirst Research Centre, GEC Telecommunications Ltd., Wembley

transistors. The unit is proportioned to fit into the slim-line equipment practice (SLEP) racks used for 11 GHz digital radio equipment, occupying a space similar to that required by a TWTA module. The separate low-voltage power supply can occupy less volume than the corresponding high-voltage unit used with the TWTA.

PERFORMANCE

Output powers of 10 W have been obtained from amplifiers in which the diodes are operated at junction temperatures compatible with long life. A typical transfer characteristic for an output stage is shown in Fig. 15, illustrating the relationships between gain, added power and output power. At a given bias current, the setting of the input-output coupling determines the input power at which the added power is at its peak value. In the example, this condition, corresponding to maximum *power-added efficiency*, is arranged to occur at the desired operating gain of 6 dB. At lower input powers the negative resistance of the diodes increases, resulting in higher gain but a reduction in both efficiency and added power; at higher input powers, the output power rises in step, with little change in diode negative resistance or added power, but the effective gain falls. Despite operating in an apparently saturated condition, the resultant signal distortion is not significantly greater than that produced by an equivalent TWTA.

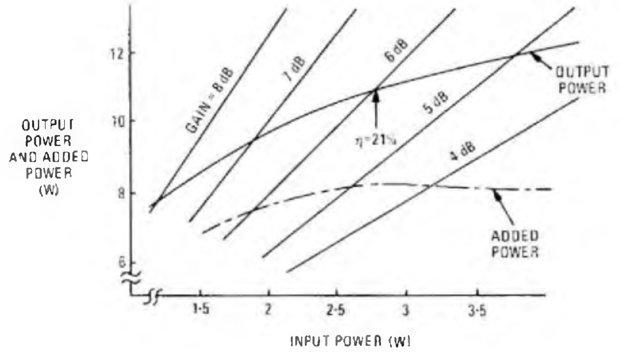

Fig. 15—Output stage transfer characteristic

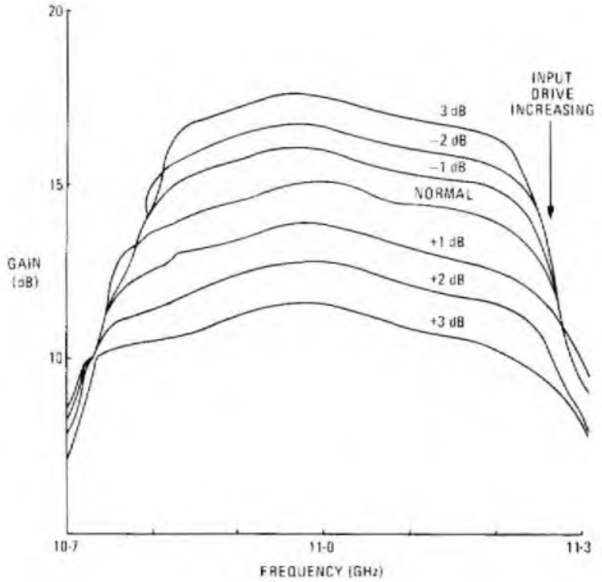

Fig. 16—Two-stage amplifier frequency response

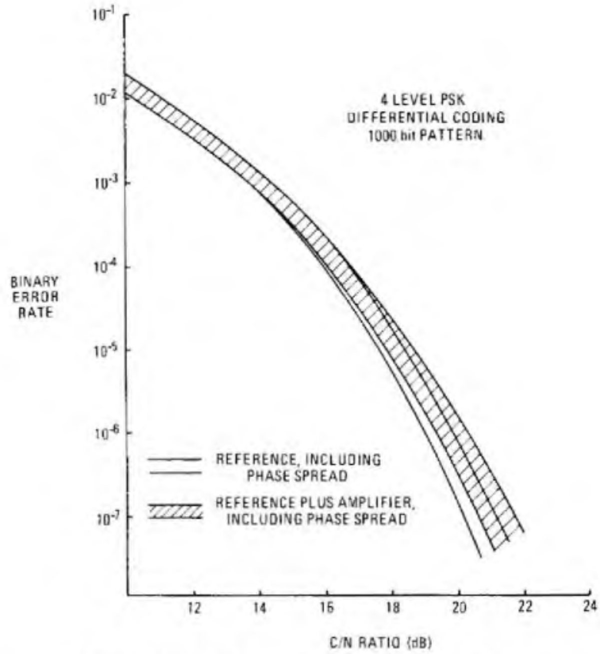

Fig. 17—Effect of amplifier on system error-rate

TABLE 1
Two-Stage Amplifier Performance

Frequency band	10·7–11·2 GHz or 11·2–11·7 GHz
Instantaneous 1 dB bandwidth	350 MHz
Tuning range	±100 MHz
Gain	15 dB
Output power	10 W
Input/Output impedance	50 Ω
VSWR (whole band) Input Output	 <1·2 <1·3
AM–PM conversion (typical)	3–5 degrees/dB
Overall power-added efficiency	14%
Power supply required	60 V rated at 1·5 A

The gain/frequency response of a 2-stage amplifier (see Fig. 16) shows that, as the input power is raised and the amplifier driven into compression, the bandwidth increases slightly. Other details of 2-stage amplifier performance are given in Table 1.

An important measure of performance for digital radio-relay system application is the amount by which the system signal-to-noise ratio must be increased, at a constant binary error rate, to overcome the degradation introduced by the amplifier. This is an acid test for high-efficiency IMPATT diodes, in view of former speculation that their unique properties might preclude their use with modulated signals. The results in Fig. 17, measured on an 11 GHz radio-relay system test-bed using 4-phase, phase-shift-keyed (PSK) signalling, show that less than 0·5 dB degradation is introduced by the amplifier, which is an acceptable amount.

CONCLUSIONS

Amplifiers have been built to prove the feasibility of obtaining sufficient power from solid-state devices to replace the TWTAs in 11 GHz digital radio-relay system transmitters.

A direct replacement of the 40 dB gain TWTA, around which the remainder of the system has evolved, can be achieved by making up the gain shortfall with an additional low-power driver stage. However, in an all-solid-state transmitter, it may be more appropriate to uprate the RF modulator to operate at higher power, thereby eliminating the need for additional gain at a bandwidth-conscious location in the system. Further investigation along these lines will determine the most appropriate manner for the demonstrated solid-state power capability to be used in the radio system.

ACKNOWLEDGEMENT

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Britain's Success at TELECOM 79

D. WILLSON†

Even Britain's competitors admitted that the British stole the show at TELECOM 79—the world's most prestigous international telecommunications exhibition, held in Geneva from 20th to 26th September 1979. In design, presentation and technical interest, Britain had the most successful stand.

It was a unique presentation of British equipment, expertise and endeavour in telecommunications. For the first time, the British Post Office (BPO) joined with the nation's top telecommunications firms—General Electric Company, Marconi Communication Systems, Plessey Telecommunications and Office Systems, Pye TMC and Standard Telephones and Cables—to present a co-ordinated display of British achievement and capability to the rest of the world.

Focal point of the display was a working System X local exchange—one of the integrated, modular 'family' of stored-program control (SPC) digital-electronic exchanges that will carry the British telecommunications network into the next century. The unveiling of System X at TELECOM 79 was a unique occasion. No comparable exchange system as advanced as System X was shown in operation at Geneva. Clearly, other systems with some of System X's features are being developed, but little of their hardware was in evidence, and none of it was working to the standard of the System X display.

Also making its first impact at Geneva was a new company, British Telecommunications Systems (BTS), which has been established by the BPO and its partners in System X—GEC, Plessey and STC—to promote the System's export. BTS undertook the presentation and demonstration of System X

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FIG. 1—System X demonstration stand

FIG. 2—The Monarch 120 demonstration stand

at Geneva, with engineers seconded to it from all 4 member organizations.

A major feature of that presentation was a kaleidoscope-type presentation in light and sound symbolizing the evolution of System X. Forty slide-projectors, linked and operated by microprocessor-control circuits, projected a striking multi-colour display, with an appropriately dramatic musical accompaniment, onto a 8 m × 2 m screen situated over the System X exchange; the screen presentation was of 5 min duration. A sound commentary in English, French, Spanish, Russian, Chinese and Arabic was available from telephones surrounding the exhibit. The arrangement of the System X stand is shown in Fig. 1.

What also came as a surprise to many users was the recorded-information facility of System X. This voice-guidance facility, designed to help customers understand and use the new facilities of System X (for example, short-code dialling), is a feature unique to the British development.

Supporting the System X exchange was a comprehensive display of digital transmission equipment (much of it functioning) linked to the System X exchange or to other working systems. All the present steps in the digital hierarchy were represented, from 30-channel pulse-code modulation systems to 140 Mbit/s line and radio systems, with optical-fibre transmission media well to the fore.

With these main switching and transmission exhibits was one of the most comprehensive displays of customer apparatus ever staged. Central to this display was a working Monarch 120 call-connect system (see Fig. 2)—the digital-electronic, SPC PABX based on the BPO Customer Digital Switching System No. 1. Connected to the Monarch 120 system were all 300 or so new generation telephones (the new range developed for use with System X), plus many other instruments; for example, telephone-user aids for the handicapped, and small business systems, the latter in proprietory versions as well as the version developed by Pye TMC for the BPO.

Prestel, the world-leading BPO viewdata service was on display, and it was demonstrated that it was the only service in public operation, putting rival systems in perspective. There was also a Confravision studio on the stand, linked to a mobile studio parked outside the exhibition hall to provide a continuous demonstration, in colour, of the system; working displays of Telex and data equipment were also on show.

The BPO launched its new Teleconsult service—an overseas consultancy service which, backed by the huge resources and expertise of BPO Telecommunications, has been established to advise on the modernization and expansion of other administrations' networks.

The BPO also had on display examples of the transmission media to be found in or planned for the UK telephone network: for example,

(*a*) 64 kbit/s customer-to-customer digital transmission, using, for local ends, the burst-mode technique for transmission over telephone pairs,

(*b*) slow-scan television, as an example of the high-information-content signals that can be transmitted using this digital capability,

(*c*) local wideband transmission, as developed for new towns in Britain,

(*d*) optical-fibre cable, produced by the double crucible technique, and newly developed components for 2 Mbit/s and 8 Mbit/s operation and a cost-reduced 2 Mbit/s system,

(*e*) automatic call-recording equipment (ACRE), showing how microprocessors can ease the workload of telephonists, and

(*f*) measurement and analysis centres, concerned with the improvement of network performance and quality of service.

The central area of the British stand was ringed by the stands of the 5 UK firms associated with the BPO in this venture. And to complete the British exhibits were displays by some 20 or so other UK companies who exhibited under the auspices of the Electronic Engineering Association and the British Overseas Trade Board (BOTB).

For the staff of the British stand, the week's highlight was September 25—British National Day—when HRH the Duke of Kent, Vice-Chairman of the BOTB, spent most of the morning touring the pavilion. That day, Britain also made telecommunications history when Europe's first, two-way, colour television conference link by satellite was established. For the entire day, the Confravision studio on the stand was linked to the Euston Tower studio in London via the orbital test satellite, and the link was used by BBC TV during its "Pebble Mill at One" programme for a live interview with the Director of BPO Research Department.

The occasion was a triumphant debut for Britain at the third ITU world forum and TELECOM exhibition. And by almost any criterion, the British performance was seen to be a success. On press preview day, September 19 (typically an occasion when journalists have to compete with workmen finishing the stands), the British pavilion was functioning, ready for business, at 0900 hours. Interest by visitors never slackened; the stand was always crowded and busy, with a daily average of more than 200 "serious" enquiries. The total of such enquiries by the end of the exhibition amounted to more than 1200, of which more than half were on System X.

System X: Design and Support

Part I—Information System

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UDC 621.395.34

The System X information system relates to the full range of activities which have to take place from the start of development of the System X project up to and including operational service. The system comprises the totality of the information involved, the processes that use and generate this information, and information management and control. The information encompasses both man-readable and machine-readable forms, and processes and control may be either manual or automated. This article describes the elements of the information system and the major features of its implementation.

INTRODUCTION

Previous articles[1–5] in this *Journal* and those scheduled for publication describe the various engineering and technical aspects of the family of digital-switched telephone exchanges, known collectively as *System X*. The development of System X has been a joint enterprise undertaken by the British Post Office (BPO) and 3 of the major UK telecommunications equipment manufacturers (GEC, PTL and STC).

In parallel with the development of the system itself, and within the same collaborative environment, a System X information system (SXIS) is being evolved to support the whole spectrum of activities from development, through individual exchange design, to operational use. Fig. 1 illustrates the type of activities covered. Such a system spans all of the interests encompassed by the developer, the manufacturer and the user administration; its realization necessitates, therefore, not only collaboration among the different interests but also the adoption of conventions or standards for the interchange of information.

Where the information is in the form of man-readable documents, nationally-agreed and, where possible, internationally-agreed standards have been adopted. However, the use of computers has become increasingly cost effective in many areas and, with the increasing pace of technological change, offers the only real prospect of being able to respond to changing circumstances in an acceptable timescale. Much of the information will therefore be held in machine-readable form, which dictates that standards for this type of information must be established. Again, where possible, international standards will be adopted.

HISTORY OF COMPUTER APPLICATIONS IN THE BPO

Before dealing specifically with the SXIS, a brief account of the growth of computing in the BPO is given.

The BPO and the UK telecommunications equipment manufacturers participating in the development of System X have made increasing use of computers since the introduction of batch-processing systems in the 1950s and the inception of time-sharing facilities in the 1960s. Initially, the tasks computerized were the traditional ones of payroll, billing and similar projects which could be justified because of the clerical staff they saved. As the power of the computing tools increased and the experience of computer personnel widened, the projects tackled also broadened into the more technical areas of BPO operations.

In addition to their use in the Research and Development field, which includes fundamental studies into teletraffic behaviour, computers found many applications in the operational switching field. Computer support was provided for many of the basic planning processes, for exchange dimensioning, exchange specification, circuit allocation and traffic-record analysis.

Throughout the early and middle stages of this evolutionary process, most of the developments were characterized by two fundamental attributes:

(*a*) each computer application was developed largely independently of any other application, and

(*b*) each application obtained its input data in a form that was not directly machine-readable.

During the more recent stages of development, there has been increasing emphasis on the closer integration of the various applications, particularly to make more efficient the handling and interchange of data, and on the direct capture of data in machine-readable form. An example of the first

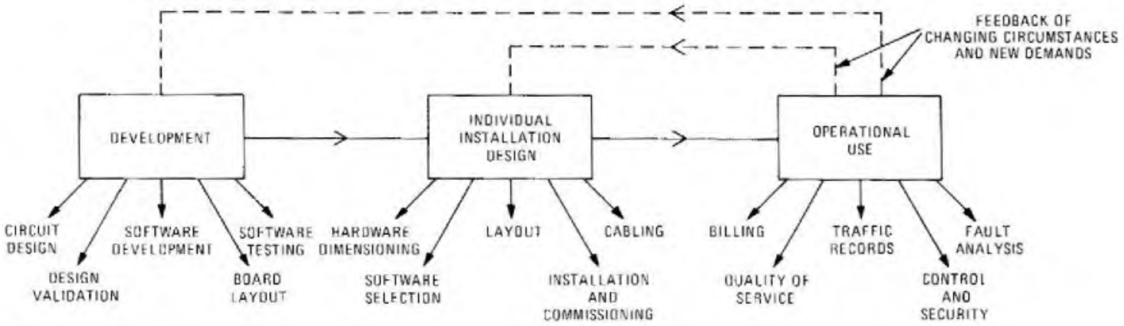

FIG. 1—Scope of the System X information system

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† System X Launch Department, Telecommunications Headquarters

type of development can be found in the telephone billing computer system, which now draws directly on another computer system for those details of a customer's installation needed to form the rental element of his charge account. Similarly, as an example of the second type of development concerning machine-readable data, microprocessor traffic recorders are being introduced into all existing exchanges (other than very small rural ones) so that the output can be written onto magnetic cartridges for direct input into the traffic-record computer-processing system.

Computer support is now evident in almost every sphere of BPO and UK telecommunications equipment manufacturers' activity. Much experience has been gained as advantage has been taken of technological developments to widen the scope of support, to integrate more closely the systems and to move towards input of data directly from exchanges. It is from this combined base of joint experience that the development of a comprehensive support capability for System X has been approached.

DEVELOPMENT PROCESSES

The development of System X is supported by a new design-documentation scheme and by a number of computerized aids for the designer, which are indicated in Fig. 2 and described briefly in the following paragraphs.

Design Documentation Scheme

As a fundamental step in the design of System X, a new documentation scheme has been adopted by the BPO and the System X manufacturers. This is based on a common identification scheme, a single configuration management system and common standards. The scheme is hierarchical, the total design information being progressively broken into more detailed component parts as one progresses down through the hierarchy. There are 3 separate but related hierarchies: one for a functional description of the system; one for the realization of hardware; and one for the realization of software.

The documentation is controlled by the configuration management scheme, through which a continuous record is maintained of the compatibility of documents describing any particular item, slide-in unit, shelf-group, module of software etc., and of the compatibility of one item with another. The rate of change in design through development and early trial of exchanges/models is high, and without complete control over the documentation, management of the project is impossible. At any one time, the design of System X is represented not only by the equipment that is available or the software running on the processor but, more importantly, it is represented by the documentation through which further equipment will be produced.

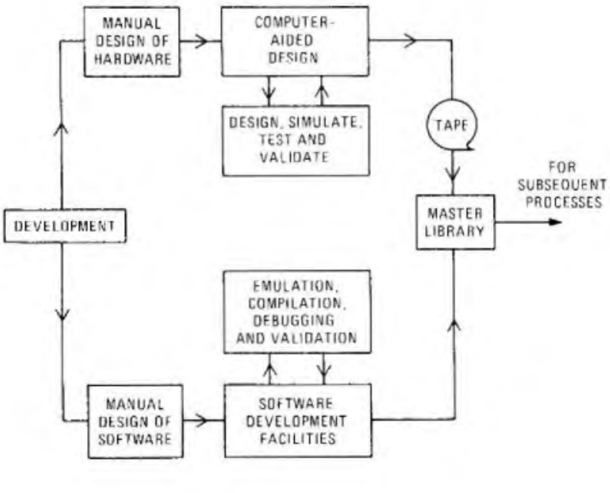

FIG. 2—Development processes

The complete documentation scheme encompasses both man-readable and machine-readable information. Indeed, a great deal of the man-readable documentation is derived from the appropriate computer-held documents. In this context, the word *document* is used to denote information in either form.

One of the difficulties in setting standards for documentation is that of meeting the requirements of all users without incurring the excessive cost of manual preparation, maintenance and control of additional documents. The availability of a computer-based information system provides an opportunity to derive different cost-effective presentations of the same information for these different users.

Documentation Database

The computerized documentation database holds the full set of compatibility documentation. It forms the support tool for configuration management activities and is maintained by inputs representing revised compatibility information resulting from design changes to any part of System X. The compatibility documentation provides essential information to designers, who have on-line access to the database, and is used to control the documentation to be used in manufacturing. Thus, although inputs are checked and processed by the BPO's master database, the resultant output information is made available to each of the System X manufacturers, who maintain their own copy of the database.

Computer-Aided Design

The BPO and each of the System X manufacturers have comprehensive computer-aided design (CAD) facilities for electronic designs. These systems take as input the engineers' sketch drawings of circuits, simulate their operation to provide early verification of designs, and translate the circuits into physical designs. The output—which describes boards, slide-in-units and shelf designs as well as test programs—is in machine-readable form for input to automated manufacturing processes.

Although the total design has been divided among the 4 parties, a design requirement for System X is that each manufacturer will manufacture complete systems using, where appropriate, designs from the other 3 parties. A further design requirement is that, for operational purposes, the product from all 3 manufacturers will be identical.

These requirements result in an effective multi-supply situation for the BPO, but emphasize the separation of the development and manufacturing activities. This gives rise to the adoption of common hardware design standards and, perhaps more importantly, the adoption of defined documentation between the two functions. Thus, the computer facilities of all 4 parties are to be linked through standardized machine-readable documentation for printed-wiring boards, slide-in units, shelf design and automatic testing programmes, at the point in the design process between design and manufacture.

The CAD system, and the method of interworking, are described in more detail in a companion article in this issue of the *Journal*.

Software Development Facility

The processors to be used within each System X exchange are being developed as part of the System X programme. However, much useful software development has been, and is being, undertaken on computers other than those to be used in System X. This is being done by the use of a software development facility (SDF), which will be described in detail in a future article in this *Journal*.

Software Master Library

The software master library (SML) provides secure library facilities to hold all machine-readable documentation for System X. It was provided originally solely for software files and, in its present form, is closely associated with the software development facilities.

The above paragraphs describe the major systems which support development and form a part of the continuous design process. Other computerized aids are in use to assist in the preparation of man-readable documents. Each of the 4 parties makes use of word-processing equipment, and a facility (known as *SX1*) is available for the automatic preparation and revision of progression and flow charts. However, in these cases, little advantage is seen in the control and interchange of such information in machine-readable form and the documentation is controlled in its man-readable form.

Thus, the full set of design documentation, managed as a coherent whole, consists of machine-readable documents (for hardware design, software design and configuration management information) and man-readable specification and descriptive documents.

INDIVIDUAL INSTALLATION DESIGN PROCESSES

A number of processes are being developed to support the design of individual exchange installations. The problems here are somewhat different from those of development, in that the interfaces are only between the BPO and the manufacturer. However, as the BPO has to interface separately with each of the 3 manufacturers, there is still a need to maintain standard formats for individual installation documentation. In addition, there is a need to retain flexibility in the division of responsibilities between the BPO and the manufacturers for the various activities involved. Hence, the various facilities need to be established for use by either the manufacturers or the BPO.

The major processes related to the design of individual installations are illustrated in Fig. 3 and are described briefly in the following paragraphs.

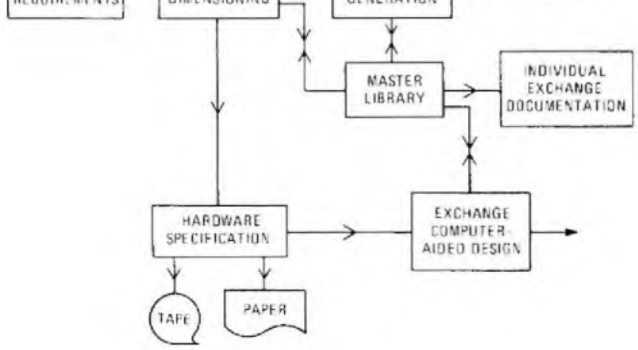

FIG. 3—Individual installation design processes

Hardware and Software Dimensioning

Hardware and software dimensioning for individual installations is performed by a program called *SIFTER*. Dimensioning is based on individual installation design data (derived from planning), dimensioning rules for the System X equipment (generated as part of the development documentation) and compatibility information from the documentation data base. A design feature of SIFTER is that dimensioning rules can be changed readily to reflect the particular requirements of the BPO, or of any other administration.

Both the software and hardware for System X is modular, each module perhaps being realized in more than one form to meet different individual installation design parameters. The criteria for a choice between these options are contained within the dimensioning rules, enabling SIFTER to select from the different options automatically. Whilst such selection is essential for optimized designs of hardware covering the full range of installation sizes and facilities, there are doubts about the need for a similar approach with software generation. However, the automated tools to provide the facility do not present a particular difficulty. They will, in any case, be of great value through later stages of development and into early production models, by quickly providing updates of software as required, following changes or enhancement to design.

The dimensioning of hardware is complicated by two further needs:

(*a*) to take into account existing equipment and the design of that equipment (both in terms of design compatibility and individual installation design) when designing exchange extensions, and

(*b*) to take into account predicted requirements of future extensions for optimization of design throughout the life of the installation.

The output from SIFTER represents a full specification of the hardware and software for an installation. In the present method of working between the BPO and its suppliers this specification forms the basis of a supply contract and is made available in both man-readable form (required for legal reasons) and in machine-readable form (for interfacing with the computer systems in use within the manufacturer's organization). The software part of the specification is used as input to the exchange software generator (ESG); the hardware part is used as input to the exchange-name CAD system.

Exchange Software Generator

As stated above, part of the output from SIFTER identifies the software to be generated in terms of software parts lists (SPLs), which reflect the design documentation structure for software; the SPLs define the source code, the compilers, linkers and the lower-order modules in the software structure, necessary to generate the object code. In addition, they identify any individual exchange man-readable documents which are required and which may be generated automatically.

The ESG acts on the instructions contained in these SPLs and, making use of the language system of the SDF as necessary, generates files in the SML for each element of the software; these are retained for use on subsequent regenerations of the software or for possible use on other similar installations.

Substantial parts of the ESG have been operational since early 1978 and have been in use since that time in support of development.

Exchange-Name Computer-Aided Design

The principal function of the exchange-name CAD system is that of producing manufacturing information for hardware, including the laying out of the equipment specified by SIFTER, designing the overhead ironwork, cabling and cable layout etc. and running checks on power requirements, ventilation and so on. This system, as for SIFTER, has to take into account existing equipment when handling extensions (to avoid costly re-arrangements) and to prepare some preliminary picture of later growth to minimize difficulties at later extensions. The system must, necessarily, be iterative to enable practical constraints, such as timing tolerances in cables, to be satisfied.

At present, work on this system is at an early specification stage, particular priority is being given to those modules of the system which are most cost effective in the manual effort saved by automation. However, the system is, as far as possible, based on past developments for existing systems.

Initial Operating Data

Before an exchange can be brought into service the processor must be loaded with relevant details of the subscribers, circuits, code translations, etc. To alleviate the large workload that would fall on the local exchange operating staff, a facility is being developed to enable this data to be assembled on a computer file and associated with the exchange software before loading onto the installation just prior to final testing. This facility is known as the *data area initializer and verifier* (DAIV). Once the data has been loaded in this way, further updates to maintain the data are made through normal man-machine interfaces to the processor.

Individual Exchange-Name Documentation

Individual exchange-name documentation for System X will be based on the scheme already in use for existing exchange systems. Some enhancements will be required to interface this scheme with that for System X development documentation and to introduce additional configuration management facilities to cover the wider use of machine-readable documents in an automated system.

As for development information, the machine-readable files generated by the automated processes will be used to generate the bulk of the man-readable documentation required. Again, it will be possible to format the information in different ways to serve the requirements of different users (for example, installation, commissioning and maintenance), without significantly increasing either the effort required for preparation or the information management problems associated with a variety of presentations of the same information.

This information also provides an input to a database that describes each exchange and contains details of the hardware, software, circuit allocations and other key parameters. This database will be kept up to date to reflect the operational activities of the administration. Thus, for any particular exchange, the data held will relate to each of the following phases as the exchange moves through the various stages of its life:

(*a*) original details of hardware and software specifications for a new exchange,

(*b*) actual details of hardware and software at date of opening service,

(*c*) details of exchange module interconnexions and circuit allocations at the date of opening of service,

(*d*) predicted and, subsequently, actual state of hardware, software and allocations at the date of opening of each exchange extension, and

(*e*) day-to-day changes of hardware, software, circuit allocations, etc.

The above data will be held to a level of detail sufficient to provide the following functions:

(*a*) a record of where hardware and software is used, so that the sites affected by new releases or retrospective changes can be quickly identified and the scale and cost of the work assessed,

(*b*) a direct feedback of details of the existing state of an exchange to the procurement system, so that extensions can be correctly dimensioned and specified,

(*c*) automatic production and updating of the interconnexion and allocation documentation, thus avoiding large volumes of tedious error-prone manual work, and

(*d*) a fixed-asset register for valuing the state of investment and calculating appropriate depreciation provisions.

OPERATIONAL PROCESSING

The family of System X exchanges contains software that monitors and reports on the events happening within the exchange. Apart from the fault alarms and the communications via the man-machine interface (MMI), all of the data will initially be produced on magnetic cartridges, either at the exchange site or, via data links, at the local administration centre (LAC) site. Subsequently, data links may be provided direct from the LAC to the computing centre. The output data falls into the following broad categories:

(*a*) security records,
(*b*) call-accounting records,
(*c*) traffic records,
(*d*) quality of service and other statistics, and
(*e*) fault history records.

The System X information system provides facilities to process each of these categories of data. The processes are illustrated in Fig. 4 and each is described briefly in the following paragraphs.

Security Records

The security log contains a record of all the transactions made via the MMI, together with a record of other key events of potential importance. The security log cannot be read or altered at either an exchange or an LAC, and therefore provides management with an independent record, to audit standards, of the significant operational parameters of each exchange.

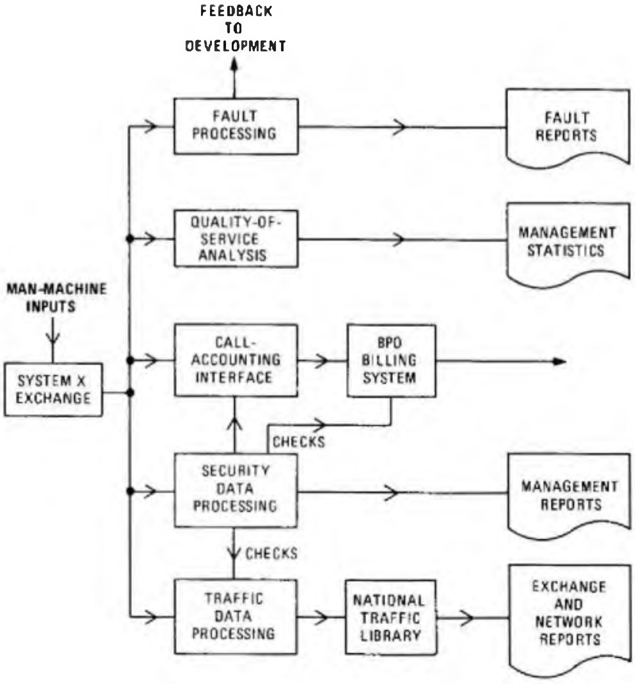

FIG. 4—Operational processing

The information system provides for the processing of this log to fulfil the following major aims:

(*a*) confirmation that important changes have been executed correctly (for example, that billing tariffs have been appropriately changed);

(*b*) confirmation that routings, translations, etc. are maintained correctly;

(*c*) detection of changes-of-state of important parameters; and

(*d*) detection and tracing of potential or actual abuse of the exchange or network.

Call-Accounting Records

Within an exchange processor, all calls are monitored and the data is written onto magnetic cartridges, which are processed subsequently within the information system. Some of the major types of data are

(*a*) individual charge units (for ordinary, coin-collecting box, PBX lines, etc.),

(*b*) block charge units (for routine billing),

(*c*) itemized calls (to enable detailed charge accounts to be provided), and

(*d*) itemized supplementary service usage records.

This data will be used to calculate the customers' accounts, to provide detailed statements of calls made, and to provide a wide range of statistics concerning usage of the system in general.

The specific requirements for billing arising from the additional facilities provided by System X, and the interfacing of System X call-account records with the existing computerized billing system have been specified and are under development.

Traffic Records

Each System X exchange offers the capability of taking a wide range of traffic records, and the results of these are again written onto magnetic cartridge at either the exchange itself or, more usually, at its associated LAC. The major types of record are:

(*a*) traffic intensity for subscriber, junction, tandem and automatic-alternative-routing traffic,

(*b*) destination traffic intensity,

(*c*) call counts (for subscriber, junction route and ineffective calls),

(*d*) congestion counts (for destination route), and

(*e*) common-equipment traffic intensity, including measurements of each subsystem within the exchange.

These records will be processed as appropriate by the information system and many parameters will be retained in the central library in the form of a computer database. This database provides a very valuable basis for both forecasting work and planning work. Moreover, it provides a number of management statistics which show, for example, the efficiency of operation of each part of the network. The requirements arising from the need to interface this output data from System X with existing computerized systems for traffic records have been specified and the necessary interfaces are under development.

Quality of Service and other Statistics

A large number of other parameters are monitored and recorded by System X exchanges, and are processed to provide management information concerning the state of the network. Some of the more important ones are

(*a*) service-based call count,
(*b*) charge-related call count,
(*c*) charge-units count,
(*d*) set-up analysis,
(*e*) tariff analysis,
(*f*) failure analysis,
(*g*) supplementary service analysis, and
(*h*) 1-in-N call sample.

These parameters, when processed in a suitable manner, provide information to help in assessing the quality of service being given and the type of usage being made of the system by customers. This information is used for a variety of purposes including quality-of-service control, determination of market trends, market stimulation campaigns, and planning and budgeting.

Fault History Records

Both System X exchanges and LACs contain diagnostic software and fault-processing software to enable adequate maintenance to be given without further assistance. Nevertheless, as with any complex system, situations may arise for which no specific cause can be readily identified.

The System X information system will provide assistance in the detection of elusive or intermittent faults by processing fault/clear data over a longer timespan than is possible within the local processor. The principal technique used is one of pattern recognition, which draws on the larger volume of data to localize probable causes of difficulty. This enables a variety of information to be gleaned to assist in fault detection, as well as providing advance warning of potential trouble spots due perhaps to component weaknesses.

CONCLUSION

The development of the various procedures and processes supporting all aspects of telecommunication switching systems is as essential to the overall management of telecommunication networks as the development of the switching systems to be provided in those networks.

This article has described the components of the information system that supports the development, and will support the application, of System X. It has also attempted to highlight the need to base these on the coherent management of all items of information in both man-readable and machine-readable forms.

This article is the first of a series which will examine the separate elements of SXIS in further detail.

ACKNOWLEDGEMENT

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System X: Design and Support

Part 2—Computer-Aided Design

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UDC 621.395.34: 681.31

Computer-aided design (CAD) has been used widely in the System X development. This article explains the principle of the CAD systems used and explains how different CAD facilities operate as an integrated system.

INTRODUCTION

Computer aids have been widely used and have played an important role in the design of System X hardware. The use of computer aids for hardware design is generally called computer-aided design (CAD). Most manual design processes can be automated to a greater or lesser degree; the degree of automation generally depends on economic factors. Although the initial cost of purchasing or developing CAD systems is high, operating costs are not high and saving can be achieved over manual methods. The time to produce a reliable design is reduced, and throughput for a given number of staff is increased. Additional benefits gained are:

(*a*) greater accuracy of the output (in fact, the accuracy required to produce some printed wiring board (PWB) designs cannot be achieved by manual means),

(*b*) repeatable output, if it has to be regenerated,

(*c*) ease of updating,

(*d*) reliable storage of information, and

(*e*) greater ability to control the design process.

It was realised very early in the System X development that CAD would play a vital role in the development, and a CAD system was being defined at the same time as the early System X system and subsystem definitions. The definition of a hardware design process and a CAD system to support it was largely completed by the end of 1975. Since then, hardware development aids have been designed and provided within the developing companies and the British Post Office (BPO), in line with this CAD system definition. The aim within each company has been to integrate different design aids to produce an overall system, allowing information to be passed from one aid to another with the minimum of manual intervention.

CAD is, however, only part of an overall scheme, described in this series of articles, for use of the computer aids in the development, realization, and operation of System X exchange systems.

One of the main aims of the System X developments is to produce switching systems that are modular, the designs being such that a subsystem designed by one company is capable of being manufactured by any one of the companies involved in the System X development. It will be seen in this article how integrated CAD systems have been developed to achieve this aim, while allowing a great deal of flexibility in the choice of particular CAD facilities, both in terms of computers and the programs run on them, while allowing companies to adopt their own design philosophies and manufacturing processes.

INTEGRATED CAD SYSTEMS

In the past, each CAD facility has been justified on its individual merit. There are additional benefits to be gained, where several computer aids are used in a design process, by integrating the facilities; that is, passing the information from one CAD facility to another directly, without human transcription. It has been the aim in the System X project to integrate CAD facilities as far as possible, not only within one company but also between the design processes of different companies involved in the System X project.

CAD Database

One of the principles adopted to aid this integration has been the use of a CAD database. In the past, CAD facilities have been provided in isolation, with a manual input and an output in readable form. For the results to be input to a further CAD facility, the information had to be manually transcribed. This task is laborious and very error prone and can be improved by outputting the information in computer-readable form so that the information can be transferred automatically to the next CAD facility. Thus, manual transcription is avoided. A further improvement is to put all the information onto a common CAD database. A process will extract the relevant input information from the database, manipulate it, and pass the resultant information into the same database. The design information is gradually built up in one database, instead of being contained in several different computer files. Each type of program can have standard interfaces with the database defined, thus allowing ease of modification of programs. The final result is a record of the design, in computer storage, from which manufacturing information may be produced by further computer processing.

Provision of Common Facilities

Complete integration could mean having common CAD programs, on common computers, at a central site. All the information produced would be immediately usable by all the other companies, and the common facilities would simplify the transfer of design information between companies for manufacture or further development. However, there were several reasons why this was not considered the best approach:

(*a*) Such a CAD system would have taken time to develop, and System X design could not start in earnest until the facility was ready. This would have resulted in an unacceptably long timescale for the overall development.

(*b*) Computing power provided at a central site would pose problems of security.

(*c*) The management of such a major resource shared between four independent companies, could be difficult.

(*d*) New common software would need to be agreed and implemented, much of it duplicating software already operated by each manufacturer.

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Another approach considered was to provide common programs on different computers. This solution has in fact been adopted for the provision of design verification facilities. For this approach to be attractive, the advantages of using a common tool—such as shared development costs and direct interchangeability of results—must be seen to outweigh the overheads and limitations inherent in maintaining a large software suite to a common specification on several computers.

The Solution Adopted

Each of the companies had some design facilities available at the beginning of the project, and these were required to enable design work to get underway as early as possible. The approach adopted, except in design verification, has been for the companies to have different programs and facilities to carry out each of the functions in the CAD process, and for these facilities to be enhanced as necessary, to bring them into line with the agreed CAD system requirements. This approach has meant the definition and adherence to fairly strict common standards for System X hardware design and documentation to ensure that hardware designed by one company can be produced by another. Companies must produce common documentation for use by the BPO and other companies. It has also meant the definition of interfaces between the companies, so that CAD information can be interchanged between companies, via the BPO, in computer-readable form.

DESIGN PROCESS

To see how computer aids have been used, it is necessary to have an understanding of the hardware design process. The process is shown in outline in Fig. 1. In order to achieve benefits from CAD, it is necessary to look beyond the design function itself; many of the savings come from producing manufacturing information by computer. Thus, in Fig. 1, the actual design and the checking of the design is all shown in the first box. This is an iterative process, with the engineer creating an initial design, which is then refined following verification by computer programs or by manual methods. When the design is satisfactory a permanent record needs to be kept, from which manufacturing information can be derived and documentation produced for manufacturing and maintenance. This permanent record is required by the BPO for maintenance purposes, and by other companies for them to manufacture the items. CAD facilities have been used in System X hardware development for the following functions:

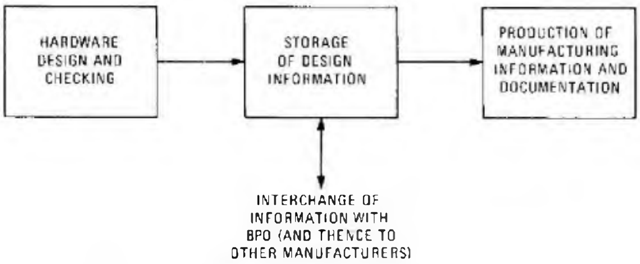

Fig. 1—Simplified hardware design process

(*a*) designing logic circuits and draughting of circuit diagrams,
(*b*) verification of designs,
(*c*) laying out PWBs,
(*d*) design of shelf wiring,
(*e*) production of design and maintenance documentation from the above processes,
(*f*) production of manufacturing information from the above processes, and
(*g*) production of standard files for the interchange of information between companies.

A more detailed design process showing these functions is given in Fig. 2. CAD facilities can be provided either using specifically-designed minicomputer systems (for example, an automated draughting system (ADS)) or by using application programs on a mainframe computer (for example, on the BPO IBM computer at Harmondsworth).

AUTOMATED DRAUGHTING SYSTEMS

An automated draughting system (ADS) is a set of equipment, controlled by a computer, which helps a Drawing Office to process drawings and the information on them. An ADS is particularly useful for modifying or updating drawings.

There are many types of ADS control consoles, known as *workstations*. All provide ways in which drawings, and associ-

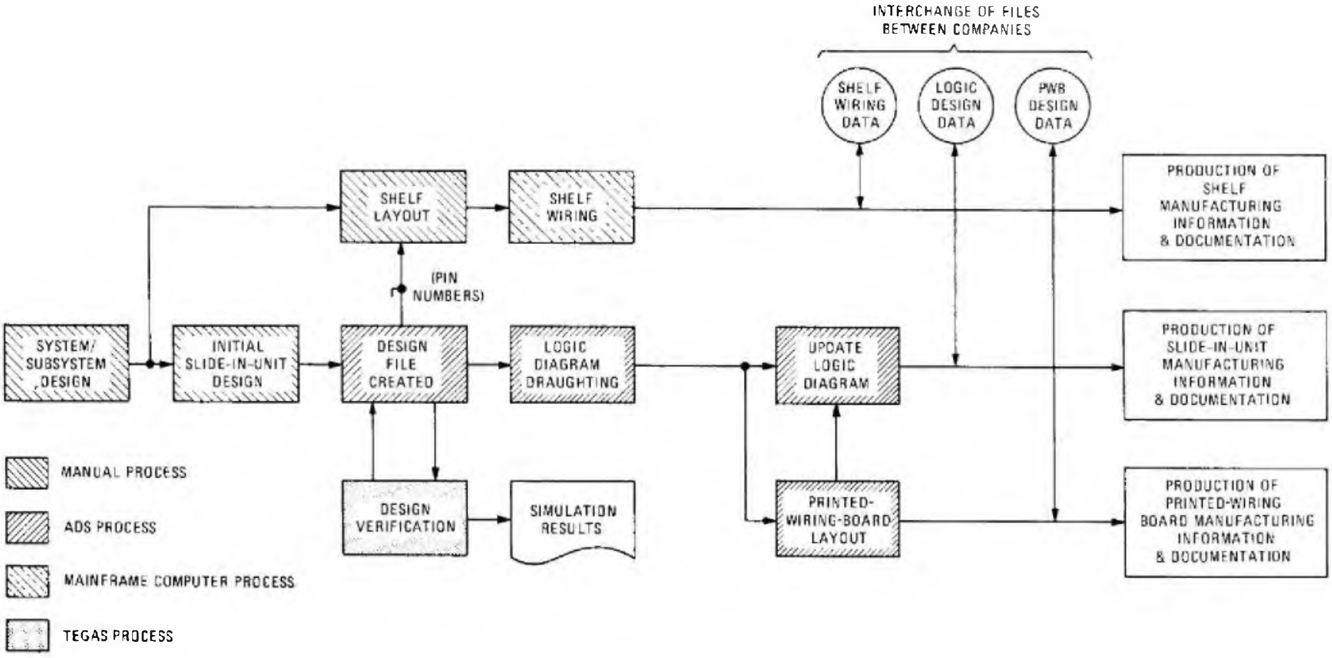

Fig. 2—Hardware design process

FIG. 3—Automated draughting system

ated text, can be described to the draughting system; most also provide ways of feeding back such information to the user.

Outputs of the system can include drawings (produced via plotters or on microfilm) and control instructions for automatic manufacturing aids (produced on paper or magnetic tape). Each output is produced by taking appropriate information from the computer memory and reformatting it, using a program called a *postprocessor*, to suit the particular output device to be used.

Automated draughting systems may be dedicated minicomputer systems, such as the commercially available CALMA and REDAC systems, or may be application programs on mainframe computers such as The General Electric Company's (GEC) LINDA program. In both cases they operate in a similar fashion. A typical minicomputer system is shown in Fig. 3.

ADS Operation

Digitizer workstations are often used for data input. A rough copy of the diagram or PWB layout to be produced is placed on the drawing board of the digitizer and the lines of the drawing are traced with a cursor. The cursor is placed on each significant co-ordinate point on the diagram (for example, on ends or bends in interconnecting lines), a button is pressed on the cursor and the co-ordinates are stored. From the preceding sequence of operations, the ADS may be able to interpret the digitized point: if not, its human partner can add information in a variety of ways; for example, by using the cursor to select a function from a list attached to the drawing board. Often there is a visual display unit (VDU) adjacent to the digitizer, on which the operator can see a picture of the diagram as it is built up from the digitizer information. This enables mistakes to be identified and rectified more readily by the operator.

To speed up the digitizing task, a symbol needs to be digitized once only and stored in a library of symbols. Each time a symbol is required, it is called up by name from the library by means of the keyboard, and the co-ordinates of its reference point on the diagram are input using the cursor. When the diagram is drawn in full, the whole symbol will appear at the specified point, complete with any text associated with it. Some sophisticated processes are incorporated in the ADS such as the ability for the "intelligent" completion of an activity initiated by the operator. For instance, a connexion line, if quickly and approximately placed, will connect itself to the nearest interconnection point on a symbol. This, and other similar facilities, allow the operator to speed up digitization considerably.

Another type of workstation uses a VDU for modifying a design once it has been stored on the ADS. The VDU can be used to input drawing information by using a location mark or cursor displayed on the screen and controlled by a light pen or by hand-held controls. A digitizer, however, is often a faster means of initial data capture if a rough diagram already exists.

Automated Draughting System Output

When a drawing is satisfactory, it can be stored by the ADS and used to produce hard-copy outputs for use in design and manufacture. A number of output facilities are available, either directly or via another medium such as magnetic or paper tape. The directly-connected facilities may include a terminal from which lists can be obtained, and a penplotter to obtain a high quality drawing. If the ADS is linked to or implemented on a mainframe computer, then all the mainframe computer output facilities available can be used.

The facilities which may be driven via magnetic or paper tape include:

(*a*) a photoplotter, for producing a diagram on a stable photographic film media; for example, a PWB artwork master for production purposes,
(*b*) numerically-controlled drilling machines,
(*c*) automatic component insertion machines, and
(*d*) computer output on microfilm (COM) system, producing a diagram on microfilm without the intermediate step of producing it on paper.

Sometimes a quick plotter is associated directly with the ADS. This enables the drawing to be checked before commiting it to a penplotter or a photoplotter, both relatively slow and expensive to run.

Use of ADSs for System X

Automated draughting systems perform a key role in the System X CAD systems, being used for both slide-in-unit (SIU) and PWB design functions shown in Fig. 2. Although the PWB is an integral part of a SIU, for System X it is considered separately as one of the components since it could be used in several different SIUs or in several variants of one SIU.

When an untried design of a SIU has been produced, the drawings are used as input to the ADS, which produces a logic circuit diagram and stores the design information. A postprocessing program can be run to produce a circuit description for input to the design verification package. When the engineer is satisfied with the performance of the design, PWB layout can commence.

The slide-in-unit interconnexion information is used to provide initial data for layout and tracking processes and, if necessary, this interconnexion information can later be checked automatically against the pattern of tracks produced during layout. Some ADS facilities are able to lay out and track a board automatically; on others, layout and tracking is done interactively by the ADS and its operator. After layout and tracking, postprocessors can be used to derive printed-wiring-board documentation and manufacturing information, such as:

(*a*) master artwork, produced on a photoplotter,
(*b*) conductive pattern diagrams (a paper drawing of the board tracking),
(*c*) paper tape to control a drilling machine,
(*d*) a drilling drawing (as an alternative to (*c*)), and
(*e*) any other manufacturing instructions.

When the PWB design is complete the logic circuit diagram can be updated with component placement information and the ADS will, if programmed to do so, produce a layout diagram showing the position of all electrical components within the SIU. Other SIU design and manufacturing information can then be produced by the postprocessors, including the parts list and a paper tape to drive automatic component insertion machines.

On completion of the designs of the SIU and PWB the stored information is passed to a CAD database where a permanent record of the design is kept. From this database, CAD interchange files (described later) are produced to send to the BPO master library and to the other manufacturers.

Manufacturers' ADS Facilities for System X

All the manufacturers hold their CAD databases on mainframe computers and, wherever possible, produce documentation and manufacturing information on the mainframe computer using postprocessors. This avoids tying-up minicomputer-draughting systems on tasks that can be handled more efficiently on a larger computer. However, if the mainframe computer does not have a draughting program, it cannot interpret all the CAD database information and there is a need for the ADS to produce diagrams and artwork.

Both the Plessey Company and Standard Telephones and Cables have minicomputer-based ADSs interfacing with mainframe computers. The GEC has its ADS on its mainframe computer; thus, all output information can be postprocessed directly from its CAD database.

BPO ADS Facilities

The BPO has no direct need for a large-volume design facility for System X SIUs and PWBs, as most of the System X development work is carried out by the manufacturers. However, there is a need for the BPO to have facilities to match those of the companies. The BPO needs to receive and produce documentation from the CAD interchange files, to provide back-up for the manufacturers' facilities and to produce maintenance documents in forms other than those defined for System X development purposes. Documents may eventually be produced directly on microfilm using a BPO COM facility. A BPO CAD system is being developed using minicomputer-based ADSs, for use not only on System X but for other development work.

DESIGN VERIFICATION

The design verification process, as the name suggests, verifies the correctness of a SIU design. A model of the SIU, or any other conveniently sized block of logic, is built in software by describing the electronic devices (for example, integrated circuits) used and the way in which they are interconnected. Once this software model has been correctly produced, sequences of logic signals are applied to it as data. Designated outputs of the model are monitored, and information about their performance is stored. The designer can request some, or all, of this information to be supplied to him.

Because applications vary widely in their demands for precision, simulation can be done at different levels of detail. The simplest form of simulation establishes the logical behaviour of a circuit, completely ignoring timing details associated with the propagation of signals through components. A more complex technique takes nominal pin-to-pin propagation delays and other timing data into account, allowing a check to be carried out equivalent to building one prototype of a circuit. Further sophistication in the simulator allows the full range of SIU performance variations, caused by component timing tolerances, to be demonstrated.

TEGAS (*TE*st *G*eneration *A*nd *S*imulation), the simulator used in System X CAD systems for design verification, was chosen after an extensive evaluation of similar tools. It was developed by Comprehensive Computing Systems and Services (CCSS) Inc, a company based in Austin, Texas, USA, and is used by many organizations in North America, Japan and Europe. TEGAS, like most similar products, is under continuous development, made necessary by changes in technology. Development is done locally within the BPO, as well as by CCSS Inc. Copies of the program are maintained on mainframe computers within each System X participating company. Fig. 4 illustrates the main features of the TEGAS system, as used for design verification.

The basic building block in TEGAS is an *element* which can range in complexity from an inverter to a programmable logic array. System designers, however, use packages selected out of an approved range of medium-scale and large-scale integrated circuits. Models of these devices are constructed from TEGAS elements and assembled in a System X device library. Pin configurations and the timing performance of these models are based on the device manufacturers' published information. The designer chooses the required device models and describes their interconnexion. Usually, the interconnexion data is generated automatically from a CAD database by the auxiliary programs in the integrated CAD systems. Test waveforms are then specified by the designer to check the logical functioning as well as the design integrity of the proposed circuit.

TEGAS has 3 principal modes of operation. Two are used for design verification and the other can be used to support fault finding on a SIU using automatic test equipment. The first verification mode performs a simulation which takes into account the nominal delays associated with each of the devices used in the SIU. Simulation results are examined to establish

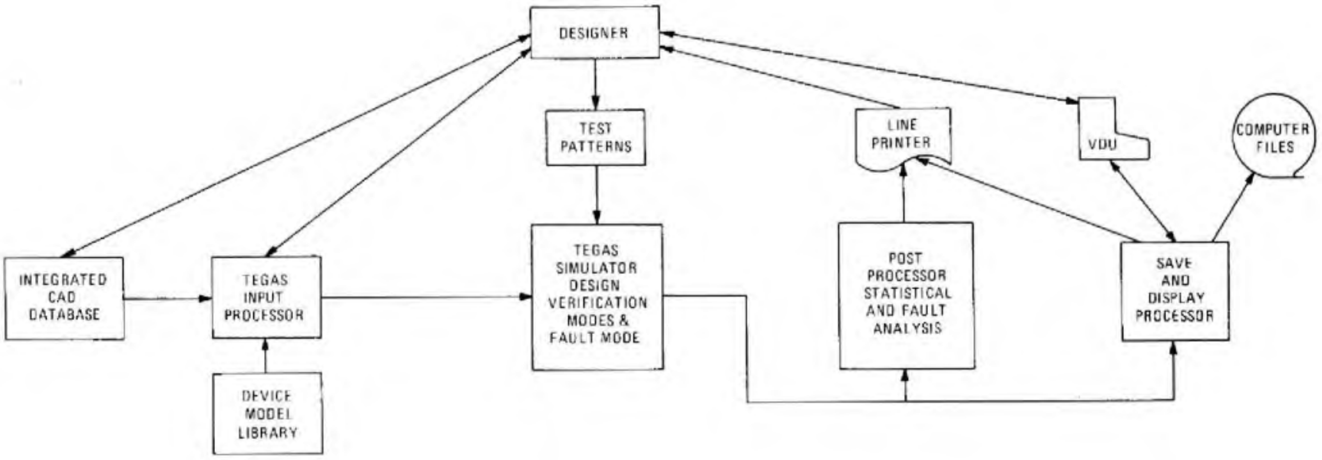

FIG. 4—Design verification process

the correct functioning of the logic of the SIU, to detect any gross errors of timing. If these results are satisfactory, worst-case timing analysis may be performed using the other design verification mode of TEGAS to investigate the effects of the worst combinations of maximum and minimum delays through the network. Such a timing analysis ensures that the circuit will operate satisfactorily when assembled using commercially available components, each having delay values which fall within a specified range. This mode of simulation does not work in terms of instantaneous logic state changes, but works instead in terms of intervals of time during which a change of state will occur.

If a design has been thoroughly proven using both TEGAS design-verification modes, a high degree of confidence can be placed in its logic, even before construction. At this stage, the test patterns and simulation results as well as the SIU design information may be stored on computer files for future consultation.

Current development work on TEGAS for design verification is directed towards the simulation of larger, more complex circuits, so that more interfaces between different blocks of logic can be brought within one verification exercise. A range of very efficient device models for existing medium-scale and some large-scale integrated components is being developed as an alternative to the existing models of these devices. Models of programmable devices, implemented as elements within TEGAS, are also planned.

The use of TEGAS and other simulation tools for fault simulation and test generation will be covered in a future article in this *Journal.*

SHELF WIRING

The design of the shelf wiring takes place after the design of the SIUs and their PWBs. *Signal names* for each of the SIU pins can be obtained from the SIU information; however, for shelf wiring, this is not all the information required. Although a signal name may identify a signal uniquely within a SIU, if there are several SIUs of the same type, the same signal name will appear several times, perhaps connected to different places. Connexions within a shelf are therefore identified by a *net name* which uniquely identifies all the posts from different SIUs that are to be connected together on the shelf. It is difficult to derive these net names automatically, particularly where a shelf may have several different uses.

The SIUs are laid out manually in the shelf and the net names derived. The signal names and net names for each of the connector posts on the shelf are fed into the shelf-wiring program together with other information such as wire type. The shelf-wiring program designs the wiring between posts with the same net name using the most economical routes. This replaces what used to be a laborious and error prone manual task of routing thousands of connexions. The *noise group*, part of the input information, imposes restrictions on wire routing as it will specify the maximum length and the other wires which may be run in the same channel so that excessive noise is not picked up. Account must be taken in the program of these restrictions, and the physical restrictions imposed by such parameters as channel sizes. The more sophisticated programs take account of channels that are full and reroute the wiring to remove the blockage. Reports are produced at the end of the program run which identify wires that cannot be routed by the program, and these are added manually. After any manual changes have been made the information is stored in the CAD database. From this information in the database, postprocessing programs can be run to produce documentation, manufacturing information and interchange files.

The shelf wiring postprocessors produce wiring lists, net lists, and posts lists, the latter two being subsets of the wiring-list information for maintenance purposes. The postprocessors also provide the link to the manufacturing process. They produce parts lists and assembly information, and paper tapes to drive automatic or semi-automatic wiring machines. Where an automatic wiring machine is not available, wiring schedules for manual wiring are produced.

Each of the manufacturers has developed interim shelf-wiring programs to run on their mainframe computers. Shelf wiring programs are not as complex as ADS programs, so there is scope for them to be fully developed by one of the manufacturers and to be used by all companies. The BPO is not involved in shelf design so does not need a shelf-wiring program. However there is a need for the BPO to be able to receive the CAD interchange files and produce documentation from them.

CAD INTERCHANGE

The minimum requirement for the interchange of CAD information is to allow manufacturing information to be transferred such that any suitably equipped company can manufacture any item. In addition, the interface files have been defined such that the relevant common documentation can also be produced from the files. The files also contain enough information for the receiving company to add the transferred design to its design database, and do additional design work on the item without going back to the originating company. This facility may be required if a company has an export contract which needs special facilities not provided by the original design.

CAD files are produced on the sending CAD system and sent to the BPO using the System X interchange mechanism. In the BPO, the file is stored on the master library, a secure library of all System X computer files, and copies of this master file are sent to all the companies automatically as part of normal updating procedure of the companies' slave libraries. Thus, the CAD files are treated in the same way as any of the System X software and other files. Fig. 5 illustrates the processes required for interchange.

The interchange of CAD information is carried out at three different levels in the design hierarchy: at the PWB level; at the SIU level; and at the wired-shelf level. The information has been partitioned such that the file at each level has all the information required to produce the item at that level.

The PWB Design Data File

This file contains all the information required to produce an etched PWB. It shows the position and sizes of lands and holes, text and track work on all the layers of the board, and defines the outline of the board. Drilling tapes, artwork and conductive-pattern diagrams can be produced from the information contained in the file.

The Logic Design Data File

This file describes the circuit design of a SIU and from this file can be derived basic component and interconnexion information, circuit diagrams, layout diagrams, a port-to-pins list, an external interface list and other manufacturing and design information. In addition, the file contains enough information for a receiving company to reconstitute CAD files to enable design work to be continued on their own CAD system, if desired. The file can contain all the information on any SIU and its variants, where these have a common circuit diagram, and can cater for multi-board as well as single-board SIUs.

The Shelf Wiring Data File

There are two types of shelf wiring files: one type contains the complete information for the current issues of the wired-shelf group (the *base* information); the other type contains information for producing documentation to modify existing versions of the wired-shelf group, (the *modification* information). The two types of file will be interchanged separately. The

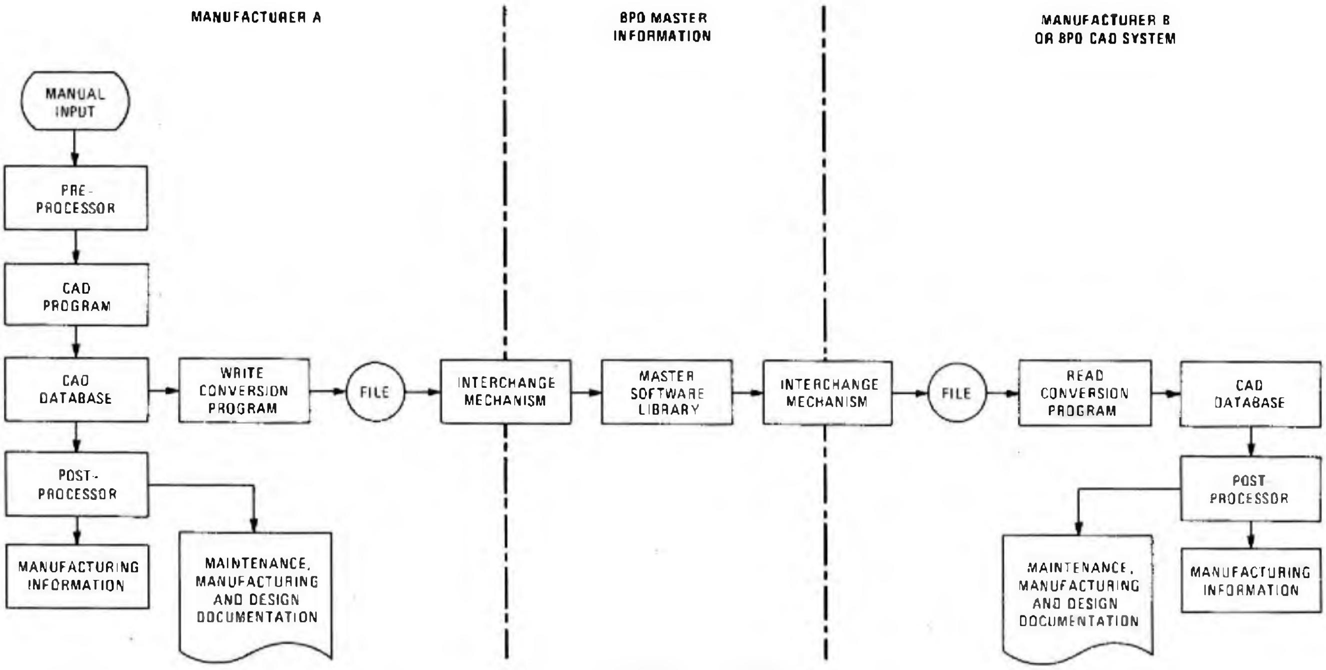

Fig. 5—CAD interchange

shelf-wiring base file will hold all the information to derive documents and manufacturing information to allow all current issues of a wired-shelf group and its variants to be assembled and wired. Wiring lists, net lists, post lists and parts lists can be produced from the base file.

The shelf-wiring modification file will hold the information to derive modification instructions.

CONCLUSION

CAD systems are being provided that achieve the aim of enabling any suitably equipped manufacturer to make any item in the System X family of designs. These CAD systems are integrated within each company and are integrated with the other companies by the use of common design standards, common documentation, and a rigid definition of the interface files. The approach adopted allows flexibility in the choice of particular CAD facilities and allows companies to adopt their own design philosophies and manufacturing processes within the constraints imposed by the design standards.

System X Software Engineering

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System X is a computer-controlled switching system. The computer software forming part of the switching system introduces a new class of technology to the UK telecommunications network. This article outlines the software engineering techniques employed in the development.

INTRODUCTION

The System X family of switching systems, local, main and tandem, are computer-controlled. The control of the switching, signalling, supervisory and auxiliary elements is vested largely (but not wholly) in a central computer: the small processor utility in the case of local exchanges, and the large processor utility in the case of main network and tandem exchanges. A proportion of the control is also vested in microprocessors external to the processor utilities. For simplicity, this article refers mainly to the processor utilities but, in general, the software principles described apply also to the microprocessors. The principles of System X have been more fully outlined in a previous article[1].

The processor utilities are special-purpose computer systems, which employ similar principles to commercial computers, but which have a number of additional attributes to make them suitable for the exchange control application; that is, the ability to

(*a*) provide continuous service even in the presence of faults,

(*b*) operate in a normal exchange environment,

(*c*) be extended without interrupting service,

(*d*) operate from the exchange −50 V battery, and

(*e*) use an equipment practice compatible with the rest of the exchange system.

The software (or computer programs together with their associated data), which is the subject of this article, forms an important part of the computer control.

SOFTWARE

Definition of Software

The major components of a computer system are set out in Fig. 1. The two principal components are known as *hardware* and *software*, but the term *liveware* is often used in the computer industry to refer to a third important component: the people who will program, operate, and maintain the system.

The computer hardware is a general-purpose digital machine capable of obeying the instructions given to it. In addition, it is capable of storing a whole sequence of instructions and the results arising from their execution, and of making reference to stored information relevant to the job in hand. The range of instructions that can be employed depends on the type of machine but, in general, it comprises a selection of elemental data-manipulation steps; for example, ADD, SUBTRACT, COMPARE, etc. The hardware of the System X processors will be described in a later issue of this *Journal*.

The software in a computer system is the series of instructions given to the machine, together with any essential information necessary to carry out a particular job. The instructions are referred to as the *program* and the other information is known as *data*. Thus, the software comprises program and data. In a System X exchange there will be several hundred thousand instructions and a similar number of items of data.

This article deals with the engineering principles applied to the creation of the System X software and indicates that such software needs to be carefully engineered to ensure that it has the characteristics necessary for its particular application.

System X Software

System X software is divided into a number of classes (see Fig. 1), but similar software engineering principles are applicable to each class.

Operating System

The operating system (OS) is that software which converts the hardware into a system which is more convenient for other programs to use. The OS performs a variety of functions essential to the operation of all other software; for example,

(*a*) the allocation of resources (such as processing time and storage) to the various programs on the system,

(*b*) the transfer of messages between the various programs, and

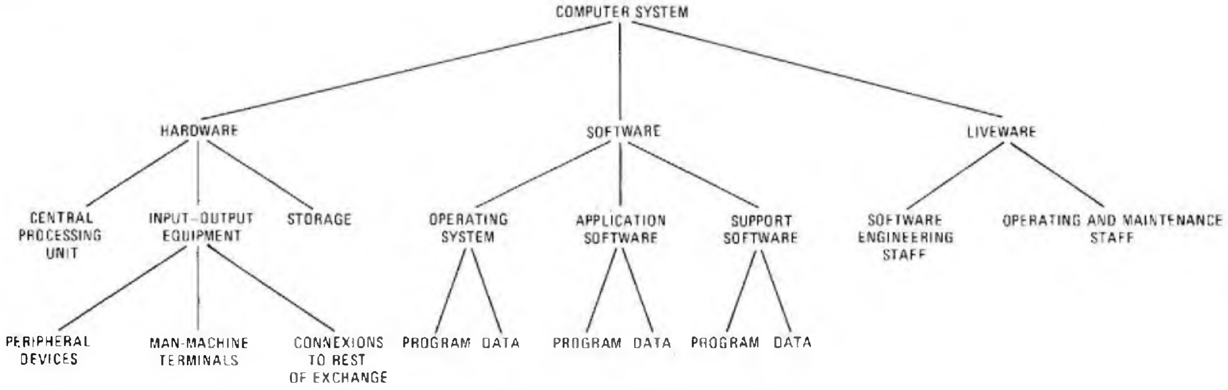

FIG. 1—Major computer-system components

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(*c*) the handling of signals and information going to, or coming from, the rest of the exchange, including man-machine terminals.

The OS also ensures that the processor utility continues to operate in an error-free manner, even in the presence of hardware faults (by putting faulty units out of service), and provides a number of facilities used by the software engineer during program development and testing. The OS will be described in more detail in a later issue of this *Journal*.

Applications Software
In System X, the various exchange functions are divided between a number of subsystems. Some of these subsystems consist of software only; for example, the call-processing and management-statistics subsystems: others comprise both hardware (external to the processor utility hardware) and software; for example, the digital-switching and message transmission subsystems.

The software associated with subsystems is known as *applications software* (AS). The AS runs on the processor hardware in the environment created by the operating system. The various subsystems will be described in more detail in articles to be published in later issues of this *Journal*.

Support Software
Many of the tools used in the development and management of software are themselves software. Some of this so-called *support software* (for example, the software development facility, described in a later article) runs on large commercial computers, and some runs on the System X processor utilities (for example, processor-utility hardware test programs). The term *support software* may also be taken to embrace the software required to deal with the billing and traffic data produced by the System X exchanges. This aspect, however, is not considered further in this article.

Quality Criteria

Correctness
The software produced for a telephone switching application must clearly, first and foremost, work correctly. This is, however, only the first of a number of criteria that must be met in order for the software to be regarded as being of a sufficiently high standard. Correctness can be achieved only by careful design, meticulous implementation and extensive testing. Even so, it may be the case that a few design deficiencies (known as *bugs*) lurk undetected for months or years after a piece of software has entered service. The procedures adopted aim to reduce this remnant bug-count to an insignificant level.

Other quality criteria are discussed below, and are given in order of importance.

High Reliability
Software can be faulty in two ways: it may contain design deficiencies (that is, it has always been wrong), or the copy of the software being used is corrupted in some way (that is, a fault has occurred). Once discovered, the two types of fault require different treatments. The first must be dealt with by having a software engineer redesign the software to remove the deficiency, and the second type of fault is dealt with by throwing the old, corrupted copy away and using a fresh one. This latter action is usually taken automatically by the exchange system.

The reliability requirements for telephone exchanges are particularly stringent, varying from tens to hundreds of years between complete failures, depending on the size of the exchanges. It is necessary therefore to design software to ensure that the effects of software faults are minimized. In general, this means carrying out checks to reduce the probability of the effects of incorrect data, resulting from a software fault, propagating through the system. The techniques employed are discussed in more detail later in this article.

Maintainability
Maintenance of software is the process of correcting design deficiencies (bugs). A particular piece of System X software may have a service life of up to 20 years or more and, hence, must remain maintainable throughout this period to ensure rapid and inexpensive removal of bugs. Since the engineers who designed the software will not necessarily be the ones who carry out the maintenance, high maintainability is essential; this is achieved by adequately documenting the product so that it is fully understandable to the maintenance engineer, and by structuring the design of the software to minimize the likelihood of a correction made in one place causing a fault in some other place.

Flexibility
Two types of flexibility are required. Firstly, the software product must have the ability to operate as a telephone exchange component in a wide variety of size and network environments. Secondly, the product must be capable of evolution and enhancement throughout its life in order to cope with new requirements or provide new facilities. It is desirable therefore to ensure that, as far as is possible, these changes do not necessitate a complete rewrite of the software, but that they can be introduced with the minimum of disruption to the existing product.

Performance
An exchange system has a wide variety of performance targets to meet. Many of these (for example, the average time to receive dial tone, or throughput measured in terms of the maximum number of busy-hour call attempts which can be serviced) depend to a large extent on the runtime performance of the software. Therefore, it is necessary to ensure that the time taken to run the most frequently used parts of the software is minimized. This has to be done, however, in a way that does not conflict with the other performance criteria. For example, care has to be taken not to use clever tricks that may shorten the run-time, but which make the software unmaintainable.

Cost
In order for the exchange system to be commercially competitive, engineering of software products must involve the minimization of a number of costs as follows:

(*a*) Cost of development—a well-ordered well-controlled development process is essential.

(*b*) Cost of storage—the larger the program the greater the storage required within the processor system.

(*c*) Cost of running—the larger the program the higher the processing power required to meet a given traffic performance.

(*d*) Cost of maintenance—without careful engineering the cost of software maintenance can be high compared with the original development costs.

SOFTWARE ENGINEERING FOR SYSTEM X

Strategy

To achieve the stringent objectives discussed above, a very careful approach to System X software development has been adopted. The discipline of software engineering, which has been emerging within the computer industry since the mid-1960s, has been embraced. A large number of procedures, tools and techniques have been introduced in the last decade which have helped to move software development from the status of a "black art" to an engineering discipline[2]. Particular aspects of the discipline employed in System X are

(*a*) top-down design,
(*b*) modular structure,
(*c*) use of high-level language,
(*d*) bottom-up integration and testing,

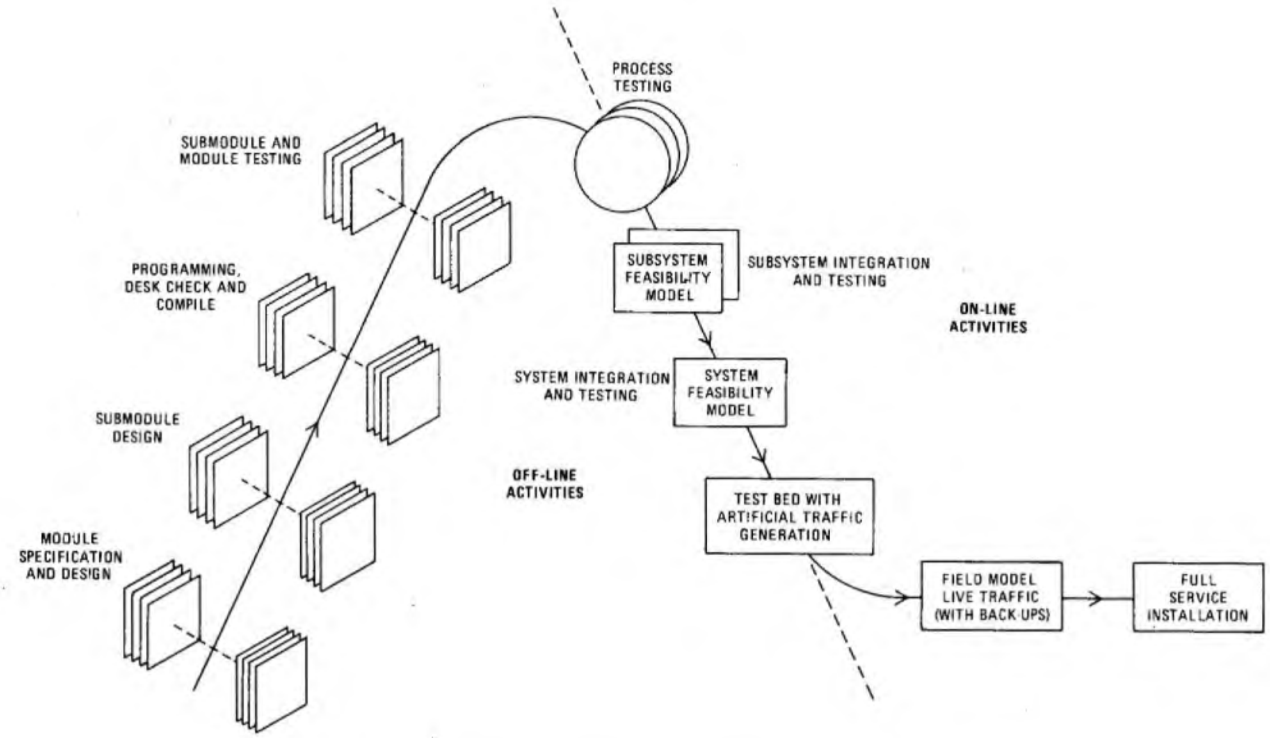

FIG. 2—System X software development strategy

(*e*) standards for design, programming, testing and documentation,

(*f*) quality assurance procedures,

(*g*) comprehensive software development facilities,

(*h*) modelling to support design and implementation, and

(*i*) management aids for planning coordination, monitoring and development.

Each of these aspects is dealt with in more detail below under the appropriate phase of the software life cycle. The cost of each phase varies from development to development but, as a general guide, the analysis and specification might cost up to 15% of the total, and maintenance up to 45% of the total. The System X software development strategy is illustrated in Fig. 2.

Much of what follows in this article is applicable to software in general. However, it should be noted that System X software run on the processor utilities has an added complication compared to, say, the software that processes payrolls or telephone accounts in that it is *real-time* software; this means that the software must take account of the passage of time, and must recognize and respond to external events within given time constraints. This factor increases the importance of following rigid software engineering disciplines.

Requirements Analysis and Specification

In the System X development, the specification of the major elements of software and hardware has been a function of subsystem design and, below subsystem level, the design of one level results in the specification for the next level down. The importance of having properly prepared specifications has been fully recognized.

Design

Top-Down Design

The approach used in *top-down design* is to divide a complex problem into a set of smaller problems. This process is repeated until each resultant problem is of manageable proportions and of a suitable size to be handled by a small team of engineers. Previous articles in this series have indicated how a complete System X exchange is divided into a set of subsystems. Each subsystem is then further divided into smaller units which, for subsystems implemented partially or entirely in software, are termed *processes, modules* and *submodules*. The decomposition into these smaller units has to be carried out with the following criteria in mind:

(*a*) clear separation of functions;

(*b*) clearly defined ownership (control) of data; and

(*c*) simple interfaces between units, involving a small number of messages.

Thus, the top-down design hinges on the definition of a modular structure of units which isolate a set of data, and contain a cohesive set of functions which operate on that data. The interaction or coupling between these units is minimized, so that changes to one unit are unlikely to result in changes to other units.

This is a highly-skilled procedure that cannot be fully standardized. Iteration around the problem must be undertaken to ensure that a reasonable balance between such factors as maintainability and performance is obtained.

Modular Structure

System X software is broken down into a hierarchy of units, as illustrated in Fig. 3.

The software of a subsystem is separated into a number of processes. These processes represent a large functional unit, such as the call-control functions within the call-processing subsystem. They also represent the scheduling unit in the software; that is, that program which is allowed to run on the processor utility at any one time. Thus, at the highest level in the software of both the AS and the OS, the logic is performed by a large number of functionally separate, asynchronous processes. Each process is made up of an integral number of modules; usually, modules are formed by identical functions and by the data which is operated on by the functions. In this way, the detail of the data in a module is effectively hidden from other modules and can be readily altered with minimal impact on the other parts of the program.

Each module is composed of a number of submodules

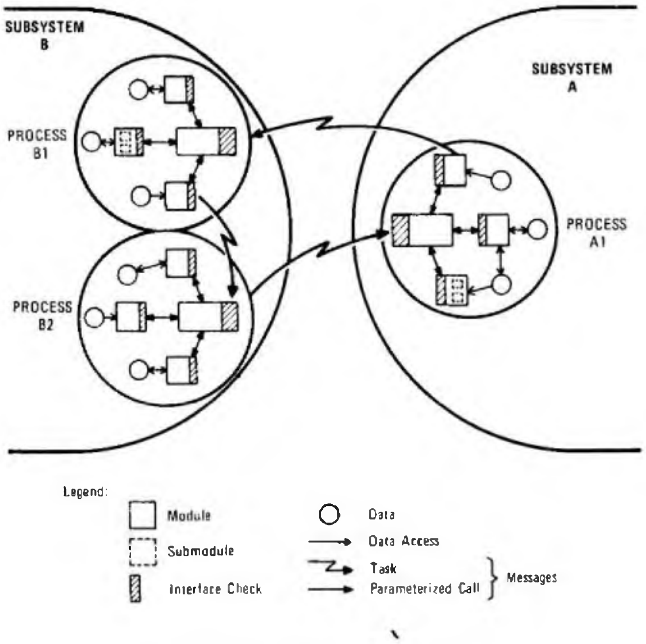

FIG. 3—System X software structure

which form the functions operating on the data within that module. These submodules are of such a size that they are easily definable, and can be readily implemented by one engineer. To give some appreciation of the size of the software units being discussed, the following are approximate values for each of the constituent units of the application software in a large exchange; a high-level language (HLL) program is used.

(*a*) subsystem	10 K HLL statements.
(*b*) process	1–5 K HLL statements.
(*c*) module	50–500 HLL statements.
(*d*) sub-module	10–50 HLL statements.

The main object of aiming for maximum cohesion of functions in units and minimum coupling between units is to simplify their interfaces. This includes both the explicit interfaces, made up of defined sequences of data flows, and the implied interfaces related to the internal operation of each of the interacting units. In practice, in System X, this results in the explicit interfaces being made up, in general, of messages of 120 bits in length. At the process level, these messages appear as *tasks* in the processor utility which are handed around the network of processes by the OS. At the module and submodule levels, the same message appears as a set of parameters of the procedure or macro.

As with the overall program, the data is structured to provide clarity and flexibility. Data structure design is a vital element in the design process, and has significant consequences on maintainability, storage requirements and run-times. It is obvious that, where exchanges can be equipped with, say, 50 000 circuits, then the way that circuit data is represented and packed in storage is extremely important. Dense packing saves storage, but is costly in run-time because processing the data is more complex, and changing software facilities becomes more difficult. This type of design trade-off must be exercised for each set of data individually, based for example on its size, frequency of use, and potential for change. The sharing of complex sets of data between processes or modules has been greatly restricted in order to increase significantly the reliability and maintainability.

Implementation

After a design has been obtained, the next step is to implement the logic. This is achieved by putting together a sequence, or program, of computer instructions, as opposed to wiring logical elements together as in the case of hardware. Such a program can be formed in various ways, just as gates can be linked in many configurations, and different languages can be used to express the instructions. These languages extend from the basic form understood by the computer hardware, known as the *machine code*, to more sophisticated HLLs, which are somewhat equivalent to the use of integrated circuits in hardware.

Languages

Primarily to pursue the goal of clarity, bringing with it improved reliability and development and maintenance timescales, a decision was taken very early in the System X project to use a problem-orientated HLL for the majority of System X software implementation. A problem-oriented HLL is a computer language that has sufficient textual English content to enable it to be readily understood by programmers and which additionally has facilities which make it suitable for the problem being tackled. Software written in HLL has to be translated into machine code, for execution by the computer, using a support program called a *compiler*. The language chosen as the basis for this work was CORAL 66 which, in the early 1970s, was adopted as a Ministry of Defence standard. This was modified, in line with work carried out by the University of Essex and the BPO Research Department to produce the POCORAL language.

The main alternative to HLL is assembly language (AL), which is little more than machine coding in a clothing of mnemonics. Using this type of language, the programmer has to be intimately aware of the operation of the computer and has little intrinsic assistance from the language in terms of producing good quality software for the job in hand.

A simplified example is shown in Fig. 4, which illustrates some of the basic clarity of HLL. This shows a submodule, implemented as a procedure, which deals with the abbreviated-dialling facility. If two "star" digits are received from a caller's telephone then this facility is required and the program checks if this is allowed—an element related to the subscriber's number in a set of data is accessed and its value equated to the NOT ALLOWED value. If the subscriber is not allowed to use the facility then, by accessing another procedure (not shown in detail in Fig. 4), he is connected to a *fail* tone. Provided the facility can be used, the called number is obtained by accessing another set of data (DIRECTORY) with the third digit input. The routing digits are then obtained by using another procedure (TRANSLATE) to manipulate the called number and, finally, the routing is used by a further procedure to make the required connexion.

```
'PROCEDURE' ABBREVDIALLING;
'BEGIN'
  'IF' DIGIT1 = STAR 'AND' DIGIT2 = STAR
  'THEN'
  'BEGIN'
    'IF' SERVICEMARK (SUBSCRIBER) =
    NOT ALLOWED
    'THEN'
      CONNECTFAILTONE
    'ELSE'
    'BEGIN'
      CALLEDNUMBER: = DIRECTORY (DIGIT3);
      ROUTING: = TRANSLATE (CALLEDNUMBER);
      SWITCHCALL (ROUTING)
    'END'
  'END'
  'ELSE'
    OTHERFACILITIES
'END' ABBREVDIALLING;
```

FIG. 4—Example of POCORAL language

The main technical features of POCORAL are as follows:

(*a*) Block Structure—each separate logical piece of program, represented by a group of statements (high-level instructions), is bracketed by BEGIN and END instructions. This provides a good clear layout and improved protection on the use of the data elements and labels within the various blocks; this arrangement is called *scoping*.

(*b*) Data Flexibility—telephony processing is concerned with handling small pieces of data very frequently and efficiently. The POCORAL language provides features for structuring data well and for accessing this data economically; data packing and bit-manipulation features are available.

(*c*) Logic and arithmetic operations are provided.

(*d*) Procedures and Macros—facilities are provided for producing submodules with defined interfaces. Both types provide a simple function acting on a set of parameters which are handed over when the submodule is used; CALLED NUMBER is a parameter given to the procedure TRANSLATE in the example given in Fig. 4.

(*e*) Security—sets of data can be identified by a reference *pointer*, which checks the types of data being accessed. This ensures that all use of data is clearly defined and that bugs relating to data access can be detected.

(*f*) Communicators—to support modular programs, a method of defining interactions between the parts must be available. A set of communicators has been provided to enable messages to be passed and for the synchronization of processes to be achieved.

The International Telegraph and Telephone Consultative Committee (CCITT) is currently investigating the use of a standard high-level language for stored-program control (SPC) called *CHILL* (*CCITT HI*gh *L*evel *L*anguage). This language has been defined, and its implementation problems are now being investigated by a number of teams in the world with a view to obtaining final agreement in 1981. The key features of CHILL are similar to those of POCORAL with the added advantage of being an internationally-agreed standard; it is proposed to adopt CHILL for System X in due course.

With assembly language, an understanding of the instruction set and the working storage (registers) of the computer's central processing unit is necessary. Good programming can be done with AL, but considerably more expertise and discipline is required if a product is to be obtained that is both reliable and maintainable. A very brief example for comparison with the POCORAL example is shown in Fig. 5.

```
INSERT:  LDB3 (B2, LKHDP);
         RCPY (G7, B3);
         LDB3 (B3, 0);          (First cell in list)
         JZ (END);              (optional test for empty
                                  list to save SCL setup)
         LOR (G0, 15);          (set mask in G0 to
                                  FFFF)
         LCPY (G1, n);          (Displacement of
                                  priority word in cell)
         LDAC (B1, n);          (Prority word of new
                                  cell)
         ILIX (xy);             (Number of cells in list)
         SCLNP (AC);            (Stops when priority
                                  position, or end,
                                  reached)
END:     ST (B3, B1, 0);        (Link remainder of list
                                  on to new cell)
         RCPY (B3, G7);         (Previous cell address)
         ST (B1, B3, 0);        (Link new cell on to
                                  previous cell)
```

Note: This piece of assembly program inserts an element in a list in its correct priority position

FIG. 5—Example of assembler program

The level of self documentation and clarity of logic of the two should be noted; the fact that the HLL allows the problem to be expressed in a more understandable fashion is a significant advantage.

Defensive Programming

There are many techniques for implementing code and data which minimize the potential for leaving design errors and which make the software more robust in terms of being able to continue functioning in the face of corruption due to hardware problems. These techniques are broadly called *defensive programming*. In simple terms, the approach is to assume that anything can and will go wrong, and to implement against these worst-case circumstances. The following are some of the techniques used in System X:

(*a*) all incoming messages to a process are checked for validity before being processed;

(*b*) all interactions between asynchronous units, whether software only, or software and hardware, are covered by timeouts, which produce a software alarm if the response is not received within the specified guard period;

(*c*) data structures, accessing and recovery routines are organized in such a way that failures will not cause the loss or corruption of important data;

(*d*) structured programming, using the following classical elements:

(*i*) sequence—component A is a sequence of components B, C, D in that order;

(*ii*) iteration—component K is made up of a number of identical components which are cycled through in order;

(*iii*) selection—component W is a selection of any one of components X, Y or Z; and

(*e*) the use of block structured high level language provides clarity and scope checking.

Testing

It is important that testing, particularly of software, should be carried out in a systematic and carefully controlled manner. In System X, the approach again hinges on the modular structure, with testing and integration being carried out in what is termed a *bottom-up* fashion. In simple terms, this means that the smallest units, submodules, are first tested individually, and then integrated into larger units in simple steps; a set of tests must be specified and carried out successfully at each step before proceeding to the next. Thus, submodules are integrated into modules; modules into processes; processes into subsystems; and finally subsystems into the complete system. Since implementation starts with the submodules, this approach enables testing to begin at the earliest possible time. Like all methods, it relies on well documented test schedules, which are as important to the development of a good product as are the design and implementation documents.

With modules and submodules, the approach is to test every path through the program and to ensure that fault conditions are dealt with adequately. At process and higher levels, because the amount of logic involved is large, and the interactions are asynchronous, testing becomes non-deterministic—it is impossible to test every possible case. Thus, sensible samples of the total set of test cases are chosen, based on exercising all standard functions and all functions involved in recovery from faults. At this stage, a balance has to be carefully drawn between the level of confidence required and the length of time available for testing.

Software Development Management

Having discussed the outline of the technical approach, it is worth briefly considering the management aspects that support and control the development. In general terms, a common management approach has been adopted throughout System X, for both hardware and software.

Standards
All key elements of System X software development are embodied in a minimum set of contractual standards: these are

(*a*) structural design,
(*b*) programming (coding) practice,
(*c*) testing,
(*d*) documentation of all stages of development,
(*e*) planning, and
(*f*) quality assurance.

Documentation
It is fundamental to the production of a good software product that it is supported by clear, comprehensive documentation. The System X documentation scheme will be discussed in more detail in a later issue of this *Journal*; suffice to record here that both hardware and software are covered by the same hierarchical scheme, which enables all significant aspects to be recorded, including test results and exchange-dependent features.

Planning and Progress Monitoring
Within the general scheme, the plans are firmly linked with the production of documentation at each stage. Progress monitoring is then achieved relatively accurately by carefully reviewing the documents produced during one activity before allowing the next activity to proceed. Thus, there is a clear linkage through the documentation and plans to the quality assurance procedures. Specific guidance on estimating software development times has been produced and is being refined in the light of experience to enable the amount of work, and thus the duration of the activities, to be calculated in a consistent manner.

Quality Assurance
Quality assurance of software takes the form of various types of review of the documentation appropriate at each stage of development, including test specifications and results. For instance, on completion of the design of a process, the subsystem designer will ensure that the design explained in the design-description documents for that process meets its specification and that it provides specifications for the constituent modules that can be understood easily. All problems identified are recorded and are dealt with before the module designs are started. Similarly, checking of the program implementation documents (source code) is carried out by an experienced programmer in the team in co-operation with the implementor.

Development Facilities

A number of tools and support computers have been provided to assist with the software development. These will be discussed in a later article, but it is worthwhile here to consider briefly the need for such facilities.

It has been noted that the HLL statements have to be translated into computer instructions, groups of these instructions have to be linked together to form the complete program to run an exchange, and that the whole has to be loaded onto the processor utility so that the instructions can be executed. This gives rise to the need for a *compiler* (to do the translation), a *linker* and a *loader*. A range of tools is also provided to enable testing to be carried out effectively; *de-bug* packages are available to allow modules and submodules to be tested, instruction by instruction. A *software message generator* is able to generate and check messages going to and from a process under test.

To enable the developments to proceed without the need for a very large number of the exchange-control processors, off-line computers (for example, an ICL 2960) have been made available with emulators, which make the ICL machine appear to operate like the processor utility. The final major facility is the *software master library*. This allows copies of program source code, together with their development status, to be stored on an off-line computer. Thus, programs still under development can be worked upon by their development teams separated by the library control mechanisms from fully accepted software that is being used to build suites of exchange software.

Processor Utilities

The exchange processor utilities are mentioned here with the emphasis on the viewpoint of the program writer—the overall picture of their architecture and features will be discussed in a subsequent article. The large processor utility (LPU) is used as the example.

(*a*) The LPU encourages the separation of software into processes. It allows multi-processing to occur; that is, a number of processes can be executed in parallel, which requires that the programmers must be aware of the opportunities provided by parallel processing, and associated problems of synchronization and clash resolution for common resources.

(*b*) A facility for making the software aware of external events is provided through the interrupt mechanism and peripheral controllers.

(*c*) There are a number of storage media within the structure of the processor utility; this storage hierarchy is hidden from the programmer by a virtual memory scheme. This operating-system (OS) facility moves the program from one storage medium to another without the programmer having to produce special control programs to achieve this.

(*d*) The OS passes messages between processes in the form of tasks.

(*e*) The LPU provides a rollback facility, which refreshes a corrupted piece of the program by replacing it with a copy from a secured disc backing-store.

The small processor utility (SPU) presents a very similar set of facilities to the programmer. The main differences involve the handling of the storage hierarchy and recovery from faults. These differences arise because of the reduced size and the worker–standby configuration.

Performance Assessment

Some of the engineering approaches discussed above, particularly the use of HLL, can have an adverse affect on performance. A careful trade-off must be exercised and, therefore, at significant points during the development, the performance of the software is monitored. This performance includes its ability to meet response-time requirements (for example, time to receive dial tone) and the number of busy-hour call attempts that can be handled.

During the design stages, performance is predicted by the use of modelling techniques. A number of models are being used for System X, the major one being a simulator, built by the BPO Teletraffic Division. This, as its name implies, simulates the processor with its OS and AS. Data is fed into the model to represent call flows through the software, and the model predicts throughput and response times. Obviously, the results are only as accurate as the quality of the input data; therefore, at the design stage this can be used only as a broad indicator for design decision making. Once the real software is available, not only can accurate information be fed into the simulator, but also the programs can be run and timed in a realistic environment. Testing is carried out using traffic generators and timing tools on both the system feasibility models and the System X test bed to provide firm performance information. These results, whether from modelling or testing, are fed back into the development to allow subsequent developments to be improved. This normally requires a careful trade-off between possible improvements to any number of the areas: processor utility hardware, OS, AS, and compiler.

Building and Maintaining Software

Having completed the development, accepted the software, and approved the exchange, it is necessary to cope with the in-service period of the life cycle. It should be recognized that several thousand exchanges have to be produced, each with its unique set of network requirements, subscribers, facilities, etc. It is necessary to produce a suite of programs for each exchange, complete with all the data relevant to that exchange. It must then be possible to introduce improved, maintained, programs (ones which have had bugs removed or contain new facilities) onto a working exchange.

Building Software

It is intended that a small number of standard program suites will be produced. In each standard suite, the same functions will be provided and the same ultimate equipment sizes will be available. These suites are assembled from the appropriate software units in the software master library, as defined by that standard suite's software parts list.

The majority of data in the software is specific to a particular exchange, its position in the network and its connexions and facilities. The data structures can be complex and large in number, but mechanisms are provided to load the specific data into these structures in a simple well-defined manner. These shield the operator from the inner complexity, and reduce the task from an error-prone assembly of fragmented binary information to a relatively simple set of sequential, repetitive instructions in an understandable form.

The basic outline of the software building system is illustrated in Fig. 6.

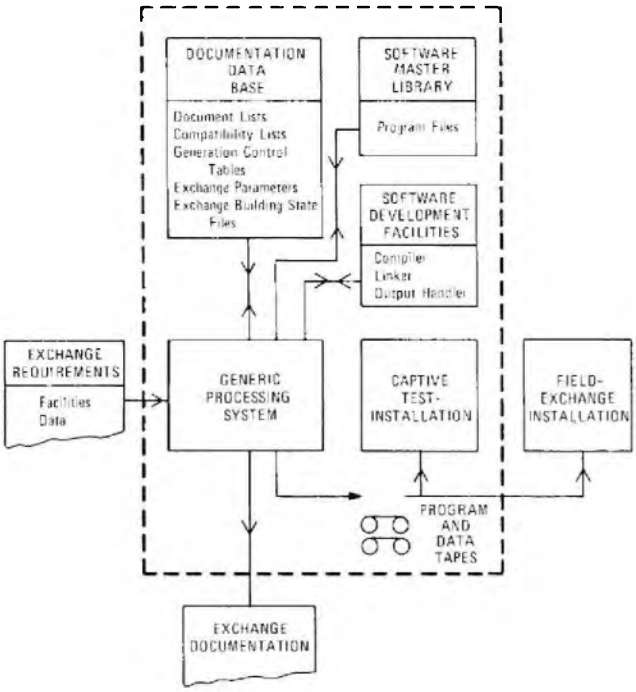

FIG. 6—Software-building system

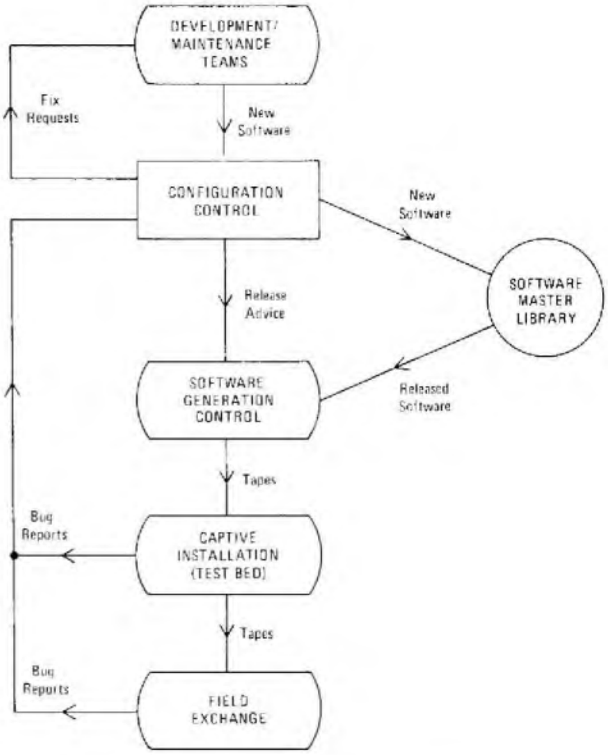

FIG. 7—Software release and maintenance

Release and Maintenance

Once software is accepted and is resident in the software master library, it is made available for release to the field. Standard suites of software are generated for exchanges, against orders from operational departments. Before copies are used on field exchanges, each standard suite is tested on a captive installation (the test bed) with live traffic tests.

Any bugs which are detected during in-service operation, or during testing at the captive installation, are reported through fault-escalation procedures to a configuration-control function, which is responsible for controlling the status of all software and hardware. The bug is eliminated by a central maintenance team, and the software is retested thoroughly before it is registered in the software master library. Release of the amended software to appropriate exchanges then follows the earlier procedure, under the control of the operational department; the approach is illustrated in Fig. 7.

CONCLUSION

The software for the System X family of exchanges has to meet very exacting requirements. To meet these requirements, rigid software engineering disciplines, as outlined in this article, have been applied to the development. The results to date indicate that this approach is successful, in that software products of sufficiently high quality for use in both home and overseas networks are being produced by the UK telecommunications industry.

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DC Power Supplies to Telecommunications Equipment: Distribution, Earthing and Protection against Induced Transient Voltages

Part 2—A New Method

P. C. WILSON†

UDC 621.311.6: 621.3.024: 621.39

The second part of this article describes the philosophy, development and realization of the radial-cable, single-earthing system, which is to be used for distribution of power in all System X exchanges.

INTRODUCTION

An electronic system using the earthed pole of a conventional power-distribution system as a reference and signal return path cannot tolerate differences of potential approaching the voltages used for signalling along that path. For System X, the limit is 3 V. Higher potentials are liable to cause equipment misoperation and even damage. Moreover, electronic equipment is vulnerable to misoperation due to depression of supply voltage, and damage from transient overvoltages appearing across the power supply coincident with distribution faults.

The original intention for System X was to use a conventional bar distribution and an electrically separate electronic earthing system, similar to that used for TXE4 and TXE4A, described in Part 1. However, the fault liability of such a system, adapted to TEP-1(H) hardware, was considered to be unacceptable because of the high probability of the bare metal shelf backplanes coming into contact with rack frames and power circuits. It was therefore decided to investigate the already known principle of using a radially cabled power distribution from a single distribution common point (DCP), associated with a single earthing system of defined quality.

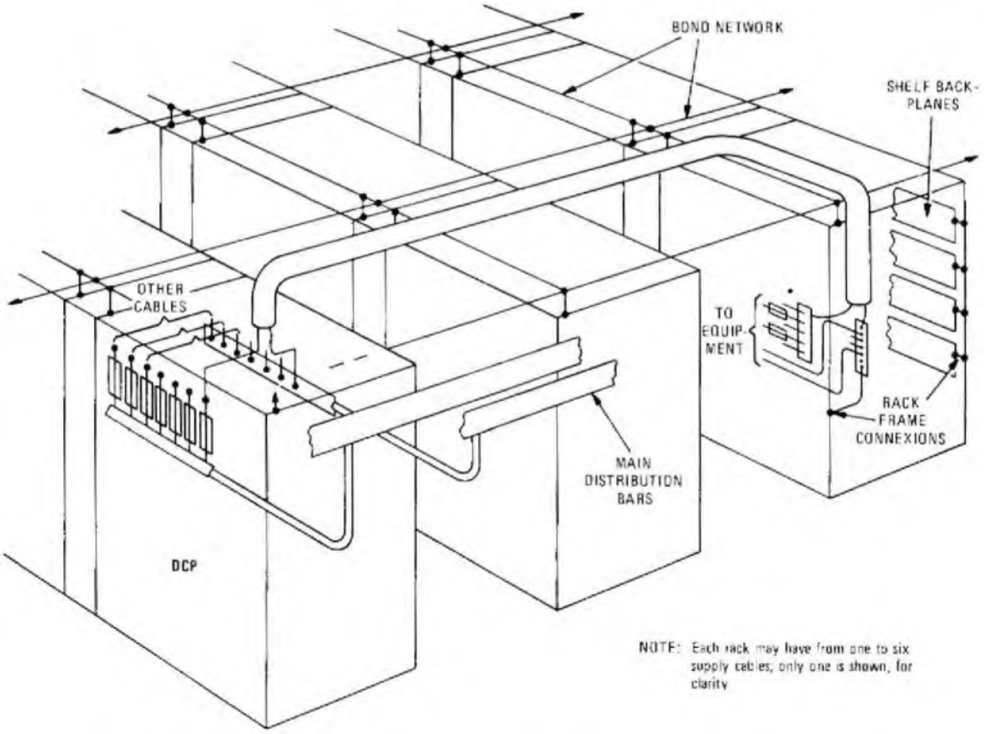
In such a system, the fault liability arising from contact between different earthed members is eliminated because all parts of nominal earth potential, except the earthing conductors associated with mains distribution, are bonded together into a single massive system; by design, this can carry the largest likely fault current without undue voltage disturbance. Fault currents are inherently limited by the small-sized conductors and fast-acting fuses used. This contrasts with the high fault currents that can be drawn from an unfused bar system of relatively large cross-sectional area. Transient voltages across poles of a radial cable system are limited by the heavy damping effect of the many healthy loads remaining across the supply when a fault occurs on a particular circuit.

OUTLINE OF SYSTEM

Fig. 1 shows a simple radial-cable, single-earthing system. The essential features are:

(*a*) The conductors from the power plant to the DCP are unfused and have good mechanical protection, so that the supply, at this point, is secure and substantially free from disturbances.

(*b*) A large proportion of the total supply impedance is between the DCP and equipment racks, with the result that, if a fault occurs to rupture the DCP fuse of one circuit, other healthy circuits suffer only a small, tolerable disturbance.



NOTE: Each rack may have from one to six supply cables; only one is shown, for clarity

FIG. 1—Mechanical arrangement of radial-cable, single-earthing distribution system

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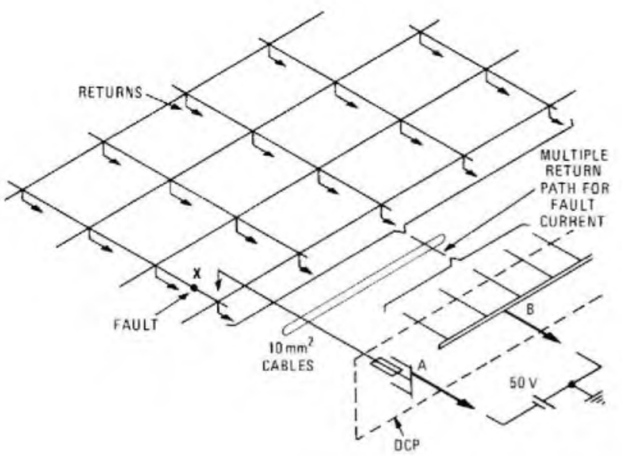


FIG. 2—Electrical arrangement of radial-cable, single-earth distribution system

(*c*) Under normal working conditions, the supply is taken to each shelf fuse-mounting, and returns to the DCP via the return conductor of its own twin cable. The bonding network ensures potential equilibrium between all earthed points, and acts as a return path and voltage reference for all electronic circuits. (It does, however, carry some out-of-balance current due to differing voltage drop in the various cables.)

(*d*) In the event of a fault, the fault current has only a single supply path, but has a multiple return path of low impedance, over the return conductors of many other cables, accessed via rack frames and the bonding network. Consequently, potential disturbance is effectively confined to the single supply pole.

THE PRINCIPLE

The essential philosophy of the single earthing system in limiting earthed-pole disturbances is illustrated in Fig. 2. Assuming that the source impedance of the −50 V supply is very low, and that a short circuit occurs at any point X, the fault current passes via its fuse and the single path A–X to the fault at X, then back to the DCP via the multiple return path X–B. Theoretically, provided that the impedence of the return path does not exceed 6% of that of the supply path, the highest potential possible between X and B is 6% of 50 V; that is, 3 V. In practice, an impedance ratio of better than 6% is needed to cope with transient voltages.

The amplitude of voltage transients generated in a conductor when a fault current in that conductor is interrupted depends on the inductance and dissipation of the conductor paths, and the rate of change of current. Any transient generated in the multiple conductor path between the DCP earthed bar and the earthed network can be impressed across the network because, if the latter is large, some parts of it will remain at or near DCP potential. Hence:

(*a*) the inductance of both the multiple return path and the network (through which it is accessed) must be kept as low as possible;

(*b*) the rate of change of fault current must be controlled;

(*c*) the network and return paths should themselves be capable of dissipating most of the energy contained in the transient.

The return path comprises many conductors of differing length, in parallel, via the bonding network. The inductance of such a path is inherently very low. Since the path is loaded electrically at the DCP end by the earthed main distribution, and by the mass of rack-frames and ironwork at the other, a network is created that will dissipate most of the energy in the transient. Control over the rate of change of current is exercised by the design of fuse used; this is explained later.

PRACTICAL DEVELOPMENT

Preliminary studies of this philosophy produced an outline design of a practical system. This was first tested on a small-scale model in various forms; then a full-size model of a large exchange of 130 racks, built at the British Post Office (BPO) Research Centre at Martlesham Heath, enabled the paper design to be developed into a practical reality.

The model was constructed to the following provisional set of standards and these remain substantially unchanged:

(*a*) The overall voltage drop from battery to equipment input would be up to 2 V.

(*b*) The radial cables would be standardized, using 10 mm^2 twin PVC-insulated copper cable, and the minimum number of cables would be provided per rack, depending on loading and security requirements.

(*c*) Each cable would be limited to a maximum current of 15 A and a maximum drop of 1 V. On this basis, the maximum cable length could range from 17 m at 15 A to 65 m at 4 A.

(*d*) The fuse would be standardized with a 16 A or 20 A rating and specified characteristics.

(*e*) The bonding network conductors would be standardized, using 10 mm^2 single-core copper cable.

(*f*) There would be no major design changes to the TEP-1(H) hardware system.

At this stage, the design work was based on assumed floor layout standards, since these had not been settled. However, the main principle of operation embodies a ratio of impedances, rather than discrete impedance values. The system is therefore, to a considerable degree, independent of the layout standards adopted.

The model represented a large exchange, but was divisible into smaller units to test the validity of the devlopment in all sizes of exchange. While intended to develop the radial-cable, single-earthing system, the model included facilities to simulate the originally-intended bus-bar system with separate electronic earthing, for comparison purposes.

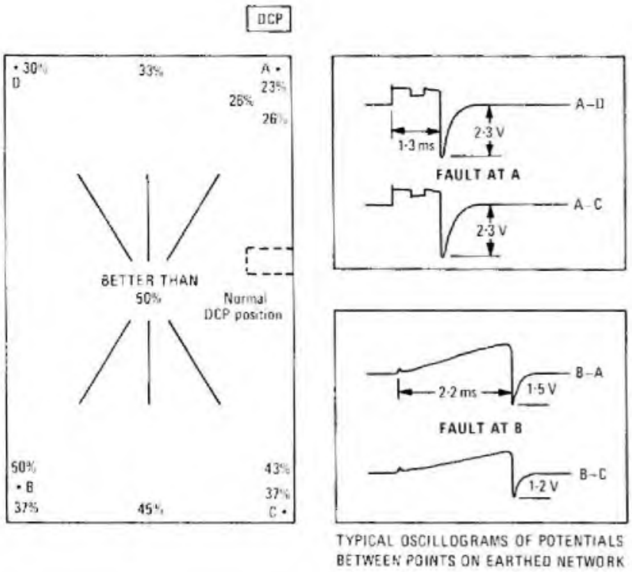
Overhead and rack ironwork was minimal to ensure worst-case conditions, but facilities were included to vary the extent of the electrical loading of the earthed network by the ironwork. By this means, the effects of more typical ironwork and rack structures were assessed by extrapolation.

The worst fault that can occur within a radial cabled system is one that ruptures a DCP fuse. Such faults, and minor wiring faults which ruptured standard 5 A alarm-type fuses, were applied at various points on the system by a remotely-controlled contactor. A signal from this was used to trigger storage oscilloscopes connected between various points in the system to monitor the transient voltage disturbances that were produced as faults were applied. In some tests, fault currents were also monitored. Photographic records of all displays enabled easy comparison of earlier and later results, and enabled weaknesses of the system to be designed out as they were identified. As the library of information was built up, the planning rules and practical features of the system were developed.

The tests on a series of representative unit sizes showed that the fully developed model was quite capable of containing earthed network potential disturbances to within the System X limit of 3 V between any 2 backplanes in a floor area. Tests on a TEP-1(H) rack confirmed that, with suitable bonding, the additional system limit of not more than 0·4 V between any 2 backplanes of a 2 or 3 shelf group could be met.

Voltage disturbance to other healthy loads in the same area was also easily contained; at worst, the supply voltage fell to −15 V for 1 ms, followed by a very short transient reaching −70 V. The equipment can tolerate a fall to zero volts for up to 4 ms, and a transient of up to −100 V. The highest fault current recorded was nearly 1000 A; generally, the current was around 700 A. Fig. 3 shows some typical test results.

Tests on the model adapted to bar distribution with separated electronic earthing showed a marked contrast. Fault currents of well over 5000 A were shown to be possible if a live bar was earthed. Provided that electrical separation between



Notes: 1 The DCP was adversely located to create worst-case conditions
2 The percentage safety margins shown in the sketch were observed when faults occurred in those areas; for example, a 33% safety margin indicates that the highest transient voltage was 2 V, against a limit of 3 V.

FIG. 3—Earthed network performance on full-size model

all structural metalwork (racks etc.) and the electronic earth network was maintained, only induced disturbances were observed in the latter. Even so, these sometimes exceeded the 3 V limit with severe faults. However, when the 2 earthing systems were placed in fault contact (for example, a backplane to a rack frame), some severe disturbances exceeding 5 V were recorded. Finally, it was shown that, with small wiring faults, whereby a −50 V supply fused at 5 A contacted a backplane, disturbances of over 10 V could occur. Thus, the predictions of a high fault liability if a separate electronic earthing system had been used for System X were confirmed.

Both systems proved susceptible to disturbance when small AC mains fuses were ruptured by contact of a mains lead to rack frames. Whilst there were some indications that these would be brought within the 3 V limit by the full rack frame and overhead structure in a practical situation, the need for special precautions was confirmed.

MECHANICAL DESIGN FEATURES OF THE SYSTEM

Distribution Common Point

The DCP is being developed as a system of fuse shelves, built into a standard TEP-1(H) rack frame. Each shelf will hold either 48 or 90 fuses in fully enclosed carriers, according to type, and will have a drilled earthed distribution bar at the rear, on which the return conductors of the radial cable system terminate. An alarm facility will indicate failure of any one or more fuses to a centralized automatic fault-reporting system.

The 50 V supply to the DCP will use conventional practice, in either bar or cable, according to size of the installation. In larger exchanges, the DCP will be on the periphery of the equipment area and may occupy more than one rack. Power will be fed to each fuse-shelf in cable, or in bar via a pair of standard cable links, each shelf forming a nominal 300 A load section. In small exchanges, the DCP will usually be remote from the equipment, preferably in the power area.

Fuses

Fuses will be in standard cartridge form to allow use of commercially-available fuse carriers and bases, but of a form not used by the BPO in mains circuits, to avoid mis-use. The rating will be 20 A, but the design of fuse is subject to certain critical limits; it must withstand insertion into a circuit containing up to 12 000 μF of discharged capacitance, yet must clear a fault in less than the 4 ms limit for voltage depression.

FIG. 4—Typical fuse elements

These 2 requirements can be met by proprietary fuses, but System X usage also requires a slow interruption characteristic not found in such fuses. This is because the proprietary fuses are intended to interrupt AC mains circuits at up to 600 V and have internal elements designed to break into a number of series-connected areas, which is essential for use at this voltage. Unfortunately, the same element used in a 50 V DC circuit produces a virtually instantaneous interruption of fault current, generating high transient voltages in the conductors.

A specialized design of element is therefore needed to satisfy the fuse specifications. This should form a single arc, which increases in physical length as the ends of the element melt, thereby reducing the current. When the arc becomes too long to be sustained by the available voltage across the fuse, extinction occurs. The 2 types of element discussed are illustrated in Fig. 4.

Cable

Cable used on the earliest installations will be a commercial twin PVC-insulated and sheathed type of 10 mm^2 core area. Development of a special cable for subsequent installations is in hand. This cable will have similar sized conductors, but of flexible make-up, with an extruded sheath of figure-of-eight section in an abrasion-resistant PVC material. This will occupy considerably less space and be much easier to install than the semi-rigid earlier type of cable. Cross linking treatment of the PVC insulation will reduce the likelihood of distribution faults due to cable insulation damage.

For both power-distribution and bonding purposes, all connexions must have a high order of reliability, and so crimped terminations have been specified for all connexions. These are more reliable and consistent in performance than soldered lugs, which depend substantially upon the skill of the craftsmen employed.

Relatively little stray magnetic field surrounds a twin cable, compared with that surrounding a pair of single cables. This allows relaxation of the usual 200 mm separation rule between power and equipment cables, enabling the same trays to accomodate both.

Bond Network

Bond network conductors will be in bare copper. Tests on the model, which used insulated bond conductors, showed that the bond network, comprising a network of identical inductive loops, was itself responsible for generating small transients.

Such inductive loops will be broken up into very small, random, heavily-damped components by the high degree of incidental contact of bare conductors with the overhead structure. To assist in securing good contact with the bond network, and between the various members, a passivated zinc-plated finish has been chosen for rack frames and the overhead structure.

Mains Supplies

Mains supplies can deliver fault currents which, while of very short duration, can reach very high levels. Both single- and dual-earthing systems can suffer earth-plane disturbance from mains faults, so the best possible precautions must be taken against them. All mains wiring and points will be in insulated conduit and enclosures, while lighting equipment will be insulated from the overhead structure. In both cases, separate earth-continuity conductors will be provided, connected to the mains switchboard and fully insulated from rack frames.

The above precautions are already standard for TXE4 and TXE4A exchanges; in System X areas, all portable tools and equipment, and rack-mounted mains equipment, will either be of double-insulated construction, or supplied via isolating transformers.

ECONOMICS OF THE SYSTEM

The radial-cable single-earthing system was developed primarily to meet the needs of the equipment. Nevertheless, it offers several important economic advantages, which help to offset the high cost of copper conductors and the use of a higher overall voltage drop than the normal economic ideal of 1 V.

The most important savings accrue from the deferment of capital provision against growth; no distribution of this type need at any time be larger than is actually required, since fuse shelves and cables can readily be added, with negligible risk to the safety of personnel or to service. This is in sharp contrast with an equivalent bar system, which must be fully provided initially because the risks of extending live unfused bars cannot be tolerated.

The only skills required to install the power cables are likely to be already on hand for equipment cabling, whereas installation and joint testing of bars requires specialized skills. Minimal planning effort is needed for the cable system, piece-parts ordering and stocking becomes a simple matter, involving only cable and crimp terminations, and detailed draughting work is almost eliminated because the cable trays are a standard part of the overhead structure.

THE FUTURE

Although there are limitations to the range of possible problems that can be identified, even with a sophisticated model, a great deal of information has been built up during the course of this development. A considerable number of fault configurations were investigated and the corresponding transients recorded. These records have provided the evidence to prove that an efficient design of radical cable distribution and a single earthing matrix will meet the known stringent requirements of modern switching systems.

It is expected that the Radial-Cable Single-Earthing system now adopted for System X will become standard practice not only for all new equipment systems, but for the extension of existing ones.

Post Office Press Notice

CONFRAVISION BY SATELLITE

More telecommunications history was made by Britain recently with the setting up of Europe's first two-way colour Confravision link by satellite.

Confravision is a high-quality conference-by-television system enabling people, hundreds or thousands of kilometres apart, to see and talk to each other over special inter-city closed-circuit television links.

Invented in Britain, the system has been operated by the British Post Office (BPO) since 1971, based on studios in London, Bristol, Birmingham, Manchester and Glasgow. It saves time, money and fatigue, so often associated with long-distance travel. Mobile studios are now being used to bring added benefits. They can be taken to a customer's premises so that the conference participants do not even have to travel to a BPO studio.

The satellite link was set up between London and a special studio in the British Pavilion at Telecom 79—the international telecommunications exhibition held in Geneva. The link was set up to show the world's 2000 top telecommunications specialists attending Telecom 79 how advanced services of this kind can play a significant part in the future by improving industrial efficiency and by saving the world's non-renewable resources.

The link was used for a series of conferences between London and Geneva, forming part of the activities of British National Day at the exhibition—held to highlight British achievements, equipment and services. The exhibition studio was visited by the Duke of Kent during his tour of the pavilion.

The Confravision satellite link resulted from joint British endeavour by four organizations: the BPO, the Independent Broadcasting Authority, Ferranti Electronics Microwave Division and British Aerospace Dynamics Group—with the co-operation of the European Space Agency and Interim Eutelsat (the international organization formed to run Europe's future communications satellite).

From the BPO's Confravision studio on the stand, television pictures and sound went by underground cable to a transportable earth station set up in a car park about 500 m from the exhibition hall. A small dish aerial at the station beamed the pictures and sound to the orbital test satellite (OTS), in geo-stationary orbit over equatorial Africa.

The OTS beamed the signal to the BPO's 11/14 GHz earth station on Goonhilly Downs, Cornwall, from where it travelled by microwave link to the Post Office tower in London and then to the Euston Confravision studio.

There was also a mobile Confravision studio in Geneva, in a car park adjoining the exhibition hall, linked to the studio on the stand, to provide further demonstrations of Confravision, which attracted hundreds of visitors during the show.

Britain was the first country in the world to have Confravision—a time-saving alternative to meetings, which demand many man-kilometres of travel. Groups of executives or businessmen use the service to set up conferences from Confravision studios in the UK. The system is also used for staff training, direct customer selling, market research and client presentation, as well as conferences.

The studio privacy is one of its features. Once the studio is "live" and on the air, there are no BPO staff present. Complete confidentiality is maintained.

Display cameras are available in the studios to transmit pictures of graphs, maps, charts, documents and small objects. Early next year the BPO plans to have a colour Confravision service available at two of the permanent studios.

Main Transmission Network: Optimization Methods in Planning

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UDC 621.394.4: 681.327.8

The planning of the British Post Office main transmission network is a complicated and difficult task. This article discusses the problems and considerations related to the decision-making process and to the techniques that may be invoked to optimize that process; in particular, the use of computers.

INTRODUCTION

Forming an optimal plan for the future of the British Post Office (BPO) main transmission network has long been the objective of telecommunications planners. Until recently, the size and difficulty of the problem have caused the optimization to depend upon the intuitive skill and experience of the planner. New mathematical techniques, implemented on powerful computers, should soon allow automatic optimization of a comprehensive range of transmission network strategies.

This article surveys the fundamental decision-making problems at the heart of main transmission network planning. It discusses optimization techniques in general, and shows how they are being applied to the development of an experimental, practical system. The system is designed to facilitate the optimal medium-range to long-range planning of the BPO main transmission network.

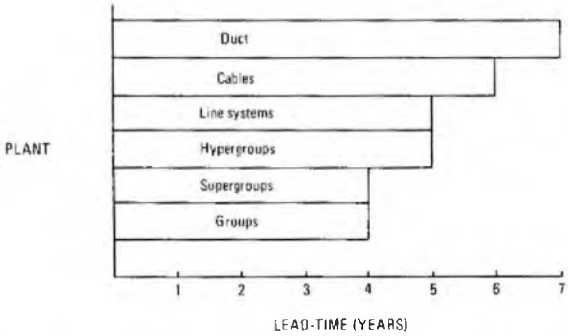
The main transmission network[1] is essentially the inter-city transmission network; it is heavily interconnected and has a complex multiplexing hierarchy. This part of the network provides a wide range of alternatives to the planner and is therefore an obvious candidate for optimization.

THE PLANNING PROBLEM

Planning is making decisions at appropriate times. The basic problem in telecommunications network planning is that of satisfying the customer's demand at minimum cost, subject to various constraints. The decisions to be made can be described as either *tactical* or *strategic*. Tactical decisions are short-term and are essentially irrevocable. They are concerned with questions of *what*?, *where*?, *when*?, and *how much*? Strategic decisions are longer term and usually subject to modification. They are made in order to co-ordinate individual short-term decisions so as to achieve an overall or long-term aim; they are concerned with questions of *whether*?

Tactical Planning Problems

The rapidly advancing technology of telecommunications gives the planner a wide choice of equipment which may be used to meet the demand for traffic capacity. Provided that alternative types of equipment meet the standards for factors such as performance and reliability, then the cheapest will be chosen. This may not be a simple choice because the cost over the life of an equipment must be considered. A type of equipment that is more expensive initially may be cheaper in the long run. There are problems of compatibility between different types; an obvious example of this is between analogue and digital transmission. The equipment installed on a particular link[*] should be appropriate to the equipment installed on adjacent links. The size of the demand to be met will also affect the choice; the law of the economies of scale applies well to telecommunications.



Note: The lead-times for groups and supergroups are for bulk quantities at a station

FIG. 1—Examples of equipment lead-time

In general, there is a selection of possible paths over which capacity may be provided to meet a given point-to-point demand. The superficially obvious choice is the shortest geographical path; however, this may not necessarily be the best. The cost of a transmission link is a function of the sum of all point-to-point demands that are routed over it. Accordingly, the cost of a path for a particular point-to-point demand cannot be determined in isolation. In addition to economic considerations, there are diversity requirements to be met. For example, in the BPO main transmission network, there is the restriction that no more than two-thirds of the total of any point-to-point circuit demand may be routed on the same cable path.

The telecommunications network planner has to make decisions based on forecasts of demand in the future. How far into the future is dependent on the type of equipment being planned and the lead-time. Basically, the lead-time is the period necessary between the initial plan and the operational availability of the equipment. An illustration of lead-times is given in Fig. 1.

The quantity of equipment planned for the network will depend upon the value of the forecast demand. This is estimated using the best information available at the time. Because the forecast is set some years into the future, it could include considerable errors. In determining required equipment quantities, the network planner must be aware of the quality of the data upon which his plan is based.

Strategic Planning Problems

A major aspect of strategic planning is the consideration of the likely usefulness of new types of equipment. Before money is spent on a development, a long-term economic advantage to the network must be indicated. The scale of such decisions

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[*] In this article, the term *link* is used to indicate the existence of transmission facilities of unspecified number and type between two nodes of the network

varies from the introduction of digital plant, through optical-fibre transmission developments to the choice of coaxial cable sizes.

Often a proposed new system is not a direct replacement for an existing one; its economic use may require a completely different pattern of use in the network. The topology of the network is very sensitive to the cost structure of equipment. For example, in the case of line systems, those having low initial but high incremental costs give rise to a well interconnected network; those with high initial but low incremental costs give rise to a poorly interconnected network.

There may be constraints upon the number of different types of equipment that the network planner has at his disposal. Although a particular type of transmission system might be the optimal choice in a given network situation, its development may not be justified by the total requirement in the network. The manufacture of a new type of equipment will only be started if there is the prospect of adequately maintained ordering levels.

The Network Plan

The most important tool used to aid decision making in planning is *the network plan*. In transmission network planning, the plan is a description of the network from the present time until far into the future. This description is the network intended by the planner on the basis of his present information. When the plan for a particular type of equipment becomes critical, as determined by its lead-time, then it is turned into a decision. In other words, when forced to make a decision, the planner implements the relevant part of his latest plan.

In a large field such as transmission network planning, there is rarely one all-embracing plan. Parts of the planning organization are responsible for different decisions and they may have their own plans appropriate to those decisions. The necessary range and detail of a plan is determined by the nature of the decisions that will be made from it. However, there is an overall plan for the organization, even if it is only implicit. The individual explicit plans must be consistent if the planning is to be done in the most effective manner. It can be seen that one of the major tasks in network planning is the creation of an appropriate network description for the future.

HISTORICAL BACKGROUND

The use of computers, network models and optimization methods in network planning is a relatively recent innovation. The first major use by the BPO of computer aids in main-network transmission planning was in 1964. This has been followed by a succession of computer systems giving increasingly sophisticated help to the planner. These systems are used in the short-term (5-year period) annual planning cycle, which determines necessary augmentation for the network. None of these systems could be used to answer strategic problems; they do not look far enough into the future and they rely on manual, partial optimization of the network, as it is planned each year.

The first important use of a model to study long-term strategies was by the UK Trunk Task Force (UKTTF) in 1970[2]. This model covered the whole network: switching and transmission; main, junction and local networks. Primarily, it was designed to examine the implications of the introduction of digital telecommunications. To achieve such a comprehensive coverage, many simplifications had to be made. These simplifications dictate that a model, such as the UKTTF one, cannot usefully be employed on precise problems of strategy in the main transmission network; something much more detailed, having the capability of automatic optimization, is required.

Until a few years ago, it was considered that the production of a system with both detail and automatic optimization was beyond current capabilities. At that time, the computers then available were neither large nor fast enough, nor were the algorithms good enough to compete with the intuitive optimization of the human planner. However, recently, the situation has changed. Computer power is increasing at unimagined rates and even a relatively old machine (by today's standards), such as the IBM 370/168, provides power and facilities greatly in excess of those available 10 years ago. Within the next 5 years, machines may be available with one hundred times the power of the IBM 370/168. Just as computer power has been increasing, so has computing cost decreased. But, computer power is useless without the algorithms to exploit it. In the area of network-optimization algorithm development, much pioneering work has been done over the past 10 years, in both Bell Laboratories (USA)[3] and CNET (France)[4]. Although most of this work dealt with very simplified problems, the potential was quite apparent.

In the BPO, interest in an optimization system for strategic main network transmission planning began around 1974. It was prompted by the need to investigate the possible requirement for trunk waveguide systems in the main network[5]. The unusual cost structure of the waveguide system (very high initial cost and very low incremental cost) meant that no particularly meaningful results could be obtained from existing methods, such as extrapolating forward the current network topology.

It was clear that in order to assess the potential benefits from using waveguides, a much less interconnected network with larger capacity links would be required in the future. Accordingly, a computer program was developed to examine these possibilites. The main-line planning (MLP) system used a very simple model of the network. It had 65 nodes representing the major transmission stations in the country, with the other stations compressed onto their nearest large neighbour. No account of multiplexing was taken and circuits were routed directly on transmission links. However, the relative cost information about the alternative systems was accurately reflected. With this model, it was possible to compare the long-term cost of the network, with or without waveguides, at different circuit growth rates, with a partially optimized network topology for the systems employed. This program provided useful information about the relative value of different broad strategies. However, the lack of detail in the model prevented it from being used either to study medium-range rather than long-range strategies, or to compare strategies that were too similar. To summarize, many interesting possibilities could not be compared because the difference between results would have been comparable to the errors on assumptions in the model.

Although it was not entirely satisfactory for many strategy problems, the MLP system had demonstrated the possibilities and feasibility of such optimization systems. Accordingly, work began aimed at establishing the design of a new computer system that would satisfy the need for answers to transmission strategy problems. This would have to include both fine detail of the network and a high degree of optimization. This work is being completed with the development of an experimental system known as the *CYBERNET* system, which is described later in this article.

BASIC OPTIMIZATION METHODS

In the past 40 years or so, a new field of applied mathematics has developed. This is the optimization of large-scale systems. The field covers nearly all problems of management and design in real-life situations. In such problems, there is always the concept that a given solution may, in some sense, be improved or 'optimized'.

The first difficulty encountered in the optimization process is that of mathematically modelling the physical system in question. This is often the most difficult part of the overall problem. Any physical system may be represented, or modelled, by a very large number of different mathematical descriptions. These have one feature in common: they are all simplifications of the real thing. This is, of course, equally true of mental models that are solved intuitively. The effective mathematical model is one that most nearly reflects the original problem. It is important to avoid meaningless problems in which the answer would be within the noise level of the given data.

The *objective* function must be established. This is generally given in terms of the maximization or minimization of some quantity. Often there are multiple objectives; for example, it may be necessary to minimize expenditure on the network while maximizing the quality of service. These can be superficially incompatible. The objective can only be a straightforward maximization or minimization by expressing everything in terms of one quantity; in the example above, by putting a monetary value on the quality of service. An alternative approach is to take part of the objective and, instead of attempting to optimize it, to set an acceptable limit; taking the example again, to minimize expenditure on the network, subject to the quality of service being at least as good as some given figure.

The quantities in the model are either *variables*, if their values are to be determined in the solution of the problem, or *parameters*, if their values are given at the outset. The relationships between the variables and the parameters are known as the *constraints* of the problem. The set of constraints defines a region of feasibility to which any valid solution to the problem must belong. Any solution within this region of feasibility is known as a *feasible solution.*

A locally optimal solution, known as *local optimum*, is a solution from which, in the case of a minimization, a small change in any direction (which stays within the feasible region) causes an increase in the objective function. The smallest of these local optima over all possible values of the variables is known as the *global optimum*. Depending upon the nature of the problem, there may be one or many local optima, which may be close or widely spread in value. An illustration of local and global optima is given in Fig. 2.

The most widely used type of optimization problem is the *linear programming* problem, in which the objective function and all the constraints are in linear form. This type of problem has powerful and comprehensive solution methods available. A commonly encountered variant of linear programming is that of the *integer linear programming* problem. This is as before, but with the added restriction that all the variables must have whole number values. It is much more difficult to find the exact solution to a integer linear programming problem than that of a linear programming problem of the same size.

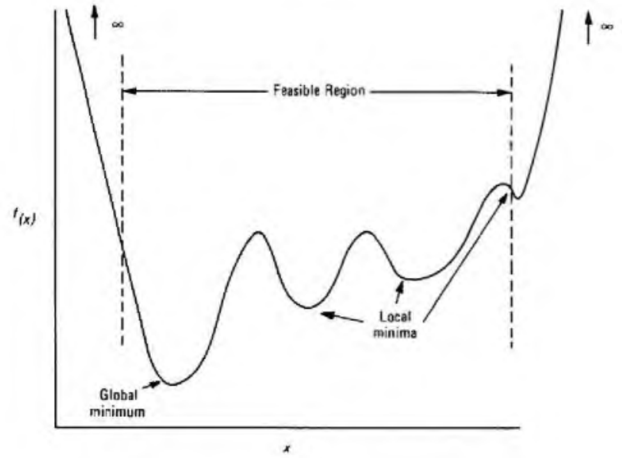

FIG. 2—Minima of a function

THE MODEL OF THE MAIN TRANSMISSION NETWORK

The full model of the network must reflect the detail of information normally used in planning. The fundamental variables in the model are known as *elements* of the network. Each element has a number of attributes:

(*a*) TIME — the year at which the element is planned to exist,
(*b*) LEVEL — the level in the multiplexing hierarchy (extended to include systems, cables, etc.),
(*c*) NODE-PAIR — the two nodes in the network between which the element exists,
(*d*) TYPE — the technical type of the equipment of which the element is comprised,
(*e*) ROUTING — the path, through elements of a higher level, over which the element is routed, and
(*f*) NUMBER — the number of units in the element.

Considering, for example, two 15-supergroup hypergroups, planned to exist in 1983, with terminals situated at Leicester and Cambridge, both routed over 12 MHz line systems between Leicester and Peterborough and then Peterborough and Cambridge, it is easy to see how this description fits into the list of attributes given above. The list of attributes, provided that it is sufficiently precise, contains all the information normally considered necessary to describe the planned or existing network. For costing purposes it may be important to have some subsidiary information, such as the geographical length of the element.

The element attributes which make up the model are now described in more detail.

Time Periods

There is no reason why any particular time intervals should be used. However, it is normal in network planning to use one year as the basic interval. To say that certain equipment is planned at a given year means that the equipment is intended to be in service at the beginning of that year. Enough equipment is planned to meet the requirement until the beginning of the next year. In practice, of course, equipment will be brought into service continuously over the year in question in quantities appropriate to economic procurement.

Hierarchical Levels

It is convenient to treat the various types of equipment which make up the main network structure as constituent items for use at particular hierarchical levels in the network. This is easily appreciated when one thinks of the basic analogue multiplexing hierarchy, as shown in Fig. 3. The concept of the multiplexing hierarchy can be extended to include digital transmission and all types of equipment from circuits to duct sections. An illustration of a more complex hierarchy of levels is shown in Fig. 4. The concept of the level in the network is

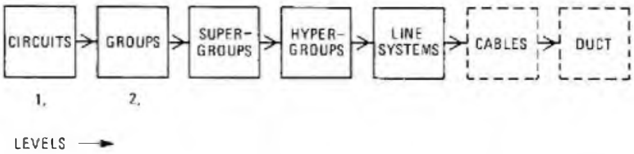

FIG. 3—An example of a simple multiplexing hierarchy

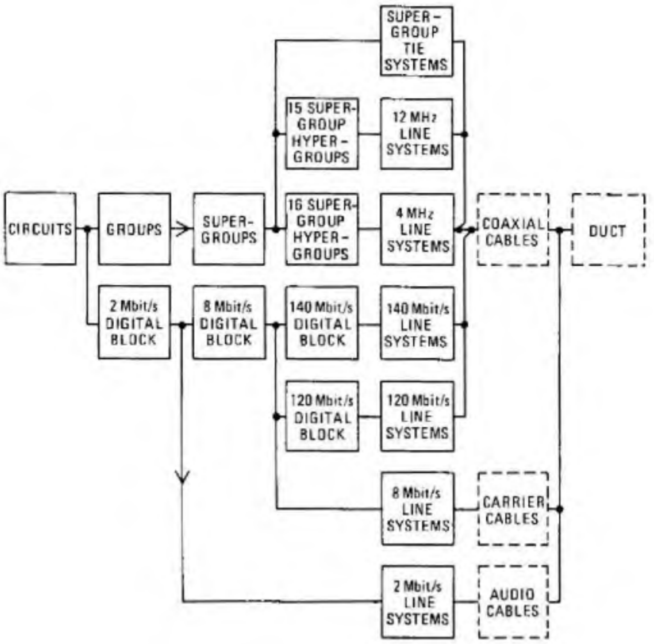

Fig. 4—An example of a complex multiplexing hierarchy

based on the idea that with progression through the hierarchy, a requirement at one level is routed on elements at the next level. The requirement may be an external one (that is, a customer's requirement) or it may be an internal one (that is, initiated by a routing decision at the next level below). For example, an external requirement for circuits may dictate that the circuits be routed on groups. This generates an internal requirement for groups between the terminals of the elements used in the circuit routing. These group requirements must then be found routings on supergroup elements, and so on. Only the final level in the hierarchy does not need a further routing.

Node-Pairs

The terminal nodes of an element represent the points between which the transmission facility exists. Access to the facility from the next level below is available at these nodes, and at nowhere in between. For example, the terminal nodes of a hypergroup are where the supergroup translating equipments are situated. Supergroups can be carried on the hypergroup from these points; no access to the hypergroup from supergroups is available elsewhere. This definition must be carefully interpreted in some cases (such as cable sections) where the availability of access from line systems may not be so obvious as in the case of hypergroups and supergroups.

Equipment or Facility Type

This attribute describes the facility type and the particular equipment used. Versions of essentially the same type are separated only if there is some differing constraint on their use. For example, 15-supergroup hypergroups are considered a different type to 16-supergroup hypergroups because one is routed on 12 MHz line systems while the other is routed on 4 MHz line systems. External requirements or demands are represented as particular facility types even though there may be no internal equivalent.

Routing or Path

The routing is a list of other elements at the next level above. These form an unbroken path between the terminal nodes of the element being described.

Objective Function

The primary costs in the network are due to new installation and re-arrangements. Of these, the new installation cost is the predominant one, but re-arrangement costs are significant. Maintenance costs can be added as a lump-sum to the installation cost. There are particular costs associated with each element which depend on many factors; for example, equipment availability, equipment type, and so on. The total cost of the network, which is the objective function to be minimized, is then the sum of all the element costs.

Constraints

For each link in the network there is a constraint which forces the sum of all the routings (elements) of that link to be at least equal to the total requirement on the link. The total requirement is made up of the internal and external demands on the link.

For each link in the network there is a constraint which states that the total number of units must not be less than that for the same link at the previous year. This is to prevent the apparent recovery of installation costs by removing equipment.

There are constraints for each link which state that no more than a given proportion of the total requirement on that link shall be routed on a single element at a specified higher level, usually circuits on cable sections.

Scale of the Network Modelling Problem

The attributes of the network elements give an indication of the size of the model. Considering, for example, 20 time periods, 10 levels, 2000 node-pairs and 5 types (at each level), there are already 2 million variables without allowing for the different routings. The number of possible paths between 2 nodes in the network is combinatorially large. Even allowing only 10 technically feasible paths between each node-pair there is a problem with 20 million variables. Each of the variables must be integer valued (it is not possible to have a fraction of a hypergroup). Modern mathematical programming systems can deal with very large problems, but this is several orders of magnitude larger. The solution of a problem such as this can only be achieved by specially designed heuristic algorithms which take account of the particular structure of the problem.

Summary of Network-Model Data

The network model described takes account of:

(*a*) many years of network development,
(*b*) all levels in the analogue/digital multiplexing hierarchy,
(*c*) all nodes and links in the real network,
(*d*) all types of equipment, existing and projected,
(*e*) all technically feasible routings of requirements, and
(*f*) the discounted costs of all equipment and re-arrangements.

SOLUTION METHODS

The complete problem of optimizing the plan for a transmission network is much too large to be solved by a direct approach. The technique discussed here is to use the structure of the problem to split it into manageable parts, to use efficient algorithms to solve the components, and then to re-combine them^6. To illustrate the process, a simple problem will now be examined.

A Simple Routing Problem

The routing problem considered here includes most of the difficult aspects of the real problem but is reduced in its complexity; one time-period and a two-level hierarchy only are considered. This problem could be thought of as routing a demand for circuits directly onto a network of transmission system links at one particular year with no consideration for past or future. It is a useful simplification: it allows the fundamentals of the full problem to be identified and, as will be seen later, it can be used as a sub-problem in the decomposition of the full problem. The routing process can be considered as that shown in Fig. 5; with inputs of demand, cost and constraints, and outputs of link capacities. Some basic algorithms to solve this problem are given below.

Minimum-Cost Routing Algorithm

A flow chart of the minimum-cost routing algorithm is shown in Fig. 6. In appropriate simple circumstances (that is, linear and continuous costs, no diverse routing or security constraints), this algorithm gives the global minimum. When applied to a full problem, but with reduced dimensionality, it generally finds a local minimum. There are numerous variants of this basic algorithm.

Greedy Heuristic Algorithm

The success of the greedy heuristic algorithm does not depend upon the continuity/integrality of the link costs. In various forms, this algorithm has been found to give good local optima in relatively small amounts of computing time. A flow chart of the algorithm is given in Fig. 7.

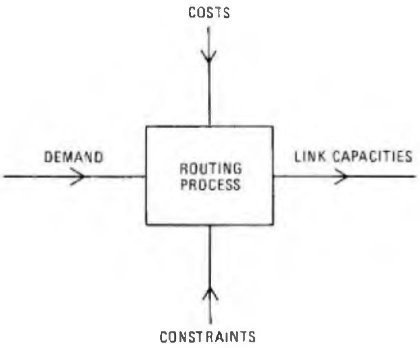

FIG. 5—The basic routing process

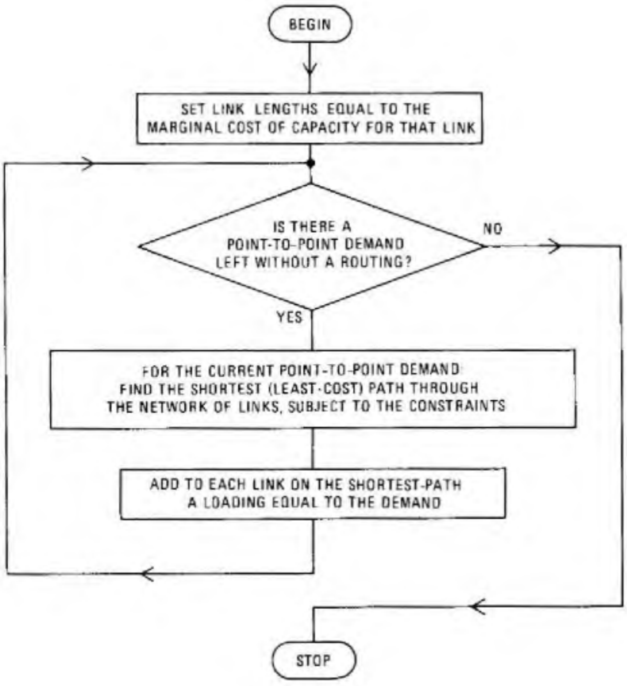

FIG. 6—Minimum-cost routing algorithm

Decomposition of the Problem

There is a very natural decomposition scheme for the main-network transmission planning problem[6]. This involves considering the routing process at each combination of time period and level as a sub-problem. The inter-relationships between two adjacent sub-problems, of different levels but the same time period, are shown in Fig. 8. The information flow between the two routing processes is cyclic. Apart from the constraints, the solution of the first process provides the internal demand

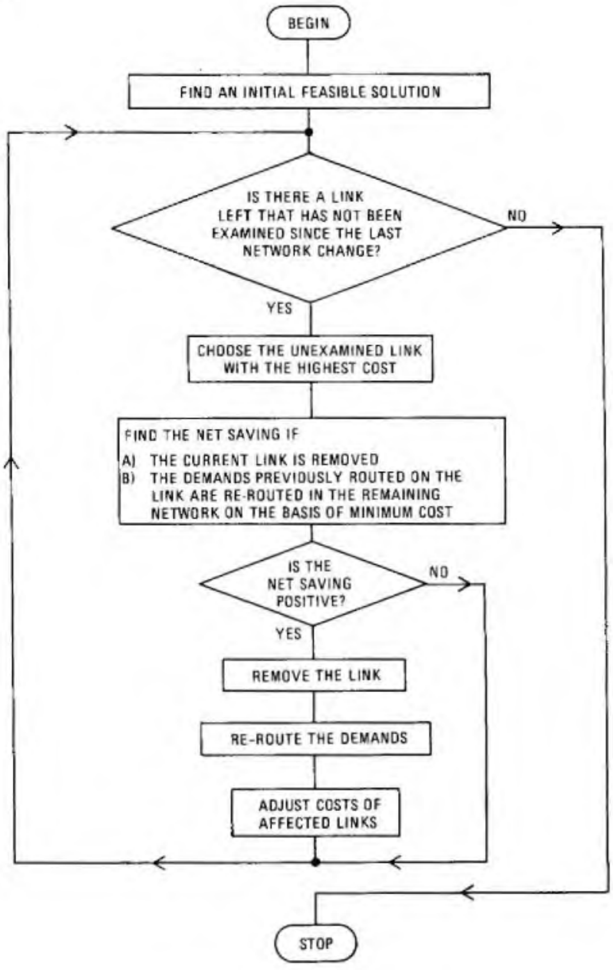

FIG. 7—Greedy heuristic algorithm

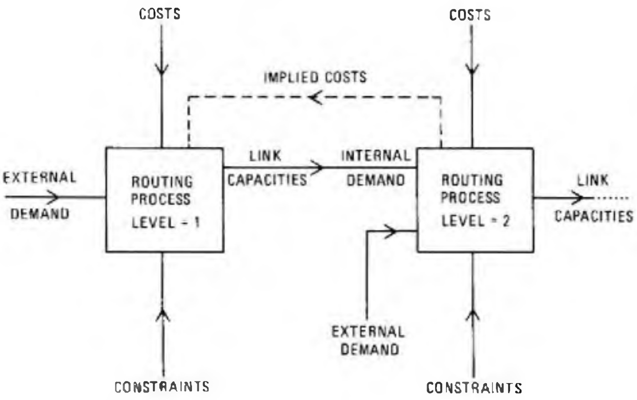

FIG 8.—The interrelationship of 2 routing processes at the same time but at different levels

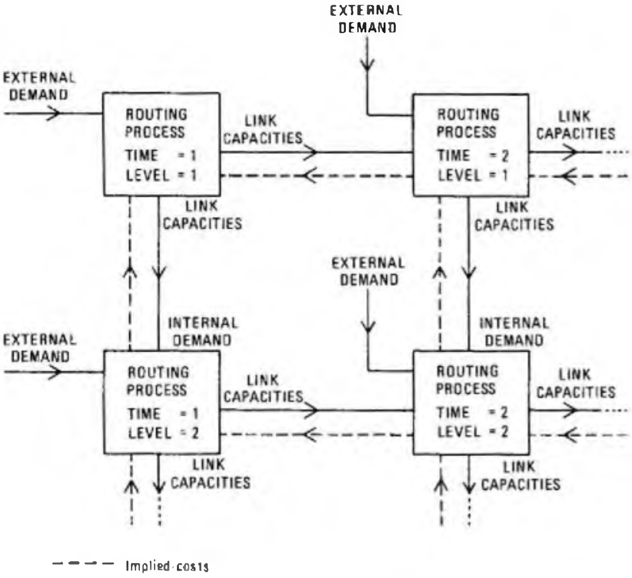

FIG. 9—The interrelationship between routing process at differing times and levels

to the second process which in turn alters the costs as seen by the first process. The implied costs are the partial derivatives of the total network cost with respect to the variables of the sub-problem. The connexions between sub-problems with different time and level are shown in Fig. 9; some constants are omitted to aid clarity.

The cyclic information flow dictates that the solution of the sub-problems cannot start at one point and simply proceed in the direction of the information flow. An initial solution must be found; it is then iteratively improved by solving the sub-problems. The solution of one sub-problem passes variables forward and passes cost information backwards to other sub-problems. An appropriate ordering of sub-problem solution can lead to convergence onto a good solution to the overall problem.

COMPUTERS IN NETWORK PLANNING

Any realistic implementation of the types of planning method discussed in this article will require a powerful digital computer. Apart from the computational power needed, there are a number of aspects that demand attention when a large digital computer is brought into a planning system. These can be divided into two categories: namely, *advantages* and *problems*.

Advantages

The computerization of a system requires that all its processes be precisely defined. This often leads to an examination of the real, rather than supposed, needs of the system.

The scale of a computer enables the handling of much larger systems than would be the case with a manual process. This can ensure consistency in the treatment of the various examples of a system. Any studies, for example to examine different strategies, can be carried out using exactly the same method, yielding directly comparable results. The computational power makes it possible to do many examples of such studies.

The input data requirements of a computer process usually dictate that a large data-base has to be created. This in turn requires that the data collected must be complete and self-consistent, as seen by the computer process. This consistent data-base will enable comprehensive statistical information to be derived from it. The data collection will also highlight areas where existing data is poor.

Problems

Computer processes, while they may save money in the long-run and may permit the achievement of otherwise impossible tasks are, inevitably, expensive to establish. Even when they are complete, poor development and management policy can lead to very high running and maintenance costs. The data collection necessary for a large comprehensive system can be highly time and labour consuming. Often, more data is required by a computerized system than by the manual one that it replaces. This is generally due to greater human ability to interpret incomplete data correctly.

Full benefit from a computer process may depend upon organizational changes. These are usually more difficult to implement than the computer process itself. Another problem encountered is that of credibility. Compared with the slow-speed manual process, where the reasoning at each step is obvious, the computer process can be very opaque to a user confronted by an answer with very little explanation.

THE CYBERNET SYSTEM

To implement the network model and optimization methods described in this article, an experimental computer software system is being developed. The CYBERNET (CYBERnetic NETwork planning) system has the objective of producing medium- and long-range plans for strategy studies. It is designed to cover all aspects of the task from data input, through optimal plan production, to graphic output. The system will use the BPO DPE IBM 3033 machine. The software is being constructed in a modular way so that it is primarily a framework for a computer planning system, rather than the implementation of any particular process. In this way, it is hoped that the CYBERNET system can be modified and extended as the situation demands. The basic flow diagram of the CYBERNET system is shown in Fig. 10.

Input Section

The purpose of the input section of CYBERNET is to provide all the necessary data for the optimization section. This data may need to be collected from various computer accessible files, thus interfacing with other computer systems. Most of the necessary data can be extracted directly from two existing systems operated by the Transmission Department of the BPO Telecommunications Headquarters: these systems are known as the *HFP3* suite and the *RAMIS* main network transmission records data-base. However, some modifications and additions are necessary to achieve the comprehensive cover, from circuits to cables, required by CYBERNET. It is the network description data that makes the largest contribution to the difficulty of the input data preparation; other categories, such as cost data and technical constraints data, are small enough in scale to be manually prepared and maintained. The data prepared by the input section does not have to be re-created for each run of the system; previous versions of the data are stored for future use, and can be partially modified, if necessary. In this way, only the changes in the data from one run to another need cause any manipulation.

Optimization Section

The function of the optimization section is to take all the input data and use it to produce a plan for the network, as near optimal as possible. The optimization is carried out in two phases.

Phase one of the optimization is to produce an initial feasible solution; that is, a plan is produced for the whole network and study period which satisfies all the constraints, but which may not be optimal. The aim is to produce as good a solution as possible without incurring high computation

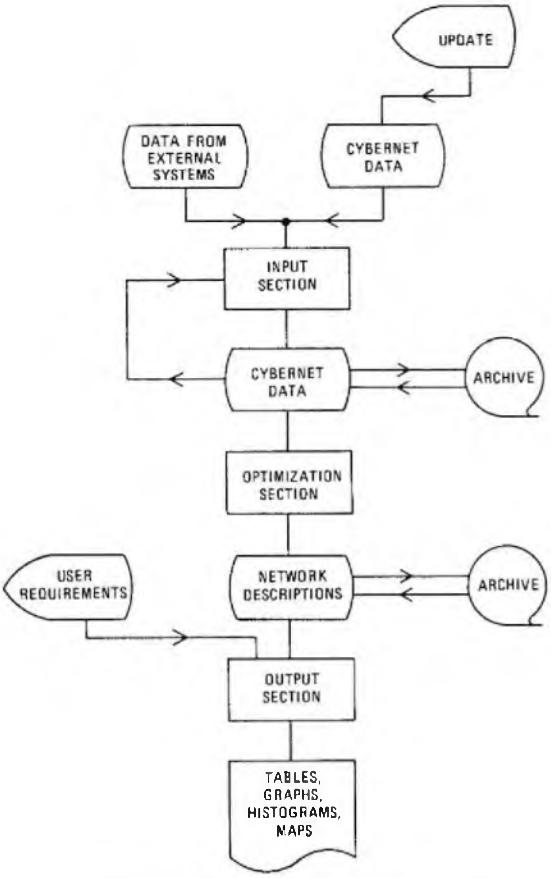

FIG. 10—The basic CYBERNET flow diagram

costs. This is achieved by starting with the existing network and enlarging it, year-by-year, adding capacity and re-routing demand as necessary. This is a non-iterative, single-pass process.

In phase two of the optimization, the initial plan is taken and attempts are made to improve it. Using the decomposition scheme described earlier, the program passes through the plan, examining each element in the network. It calculates the net saving on the cost of the network if that element was reduced in capacity. This is the sum of the savings made by reducing augmentation on the element and the possible extra cost elsewhere in the network, caused by re-routing the displaced demand. When either no more improvements can be made or the rate of improvement has fallen to a satisfactory level, the process ends.

Output Section

The optimization section produces a vast amount of data. This is simply the complete network description for each of 20 years. It would be both wasteful and unmanageable to keep all this data on some manually-accessible medium such as paper or even micro-fiche. Instead, only essential information summaries, such as ordering profiles for equipment types, is produced on paper. The bulk of the data is archived on magnetic tape. The data can be interrogated later using a management information system such as RAMIS, so that the user can extract the particular details required. The output data can be displayed in various forms; tables, graphs, histograms and maps will all be available at the user's discretion. The output section is designed with the requirement that the results of the optimization must be given in a clear, concise and attractive form.

CONCLUSION

This article has outlined the problems facing the transmission network planner and has described the methods used to develop an optimization system. This computer-based system, known as *CYBERNET*, is intended to determine medium-range to long-range strategies for planning the network.

A detailed model allows the planner to study many different facets of the problems; a powerful optimization system allows him to choose between the vast number of options. A single strategic decision may have complex and far-reaching consequences for the network. Without the sort of assistance CYBERNET system is designed to give, it is difficult to assess these consequences or even to recognize their existance.

There is always uncertainty about the future, and it is inevitable that the conditions upon which an optimum plan is based will have changed before the plan can be put into effect. In this context of uncertainty, the optimum plan is one which is most likely to give the optimum network over the period studied. The sensitivity of the plan to changing circumstances can be examined, enabling the planner to see the outcome over a range of possibilities.

It is important to recognize the limitations of these methods. However good a plan is produced, it must be updated regularly to take account of changing forecasts of demand, cost, and technology. The role of automated planning systems should be kept in perspective; the computer is not expected to make the decisions, but only to provide information. There is no suggestion of accepting the conclusions of a computer system without question; no more than would be the case with the conclusions of a single human planner.

The strength of the CYBERNET system is based on a good model of the real network. It reflects all the important features of the network and takes the existing (or firmly planned) network as its starting point.

A modern telecommunications network is a very complex system. Computer optimization systems such as the CYBERNET system promise to be of enormous value in planning the network of the future.

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Use of Vehicles in the Telecommunications Business

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UDC 656. 1 : 654. 01

The transport fleet of the British Post Office (BPO) telecommunications business is the largest in the UK. The vehicles represent a considerable capital investment. The efficient use of vehicles and the purchase of replacement and additional vehicles are important factors in the administration of that investment and to the efficiency of the BPO telecommunications business; this article discusses these factors.

INTRODUCTION

The British Post Office (BPO) telecommunications business owns or leases approximately 46 000 official motor vehicles and 6 000 vehicular mechanical aids; this is the largest fleet of vehicles operated by a single concern in the UK, and probably the largest in Europe*.

The composition of the fleet is matched uniquely to the needs of the telecommunications business, the main transport requirement of which is the large-scale provision of mobile workshop or toolbox facilities in the field. Several of the larger units are mechanized to carry out field operations formerly done manually.

The gross book value of all vehicles in the BPO telecommunications business exceeds £80M, with an annual bill for new vehicles of approximately £21M. This article shows how the efficiency of use of the transport fleet is maximized, thus ensuring that this massive capital investment is soundly based, while giving each vehicle user the service required. Basically, this is done by providing the minimum level of transport which allows user operational performance to continue normally.

The purchase of official motor vehicles for the BPO telecommunications business is reserved to Telecommunications Headquarters (THQ), thus ensuring standardization throughout the UK and maximum purchasing discounts. Fleet serial numbers are issued nationally and recorded on a BPO vehicle-record (POVR) asset register.

The BPO has 22 main vehicle types to serve the needs of 53 defined work occupations, into which the 98 000-strong staff of its engineering technical grades (ETGs) is divided.

THE SIZE OF THE TRANSPORT FLEET

The size and composition of the BPO's telecommunications transport fleet is regulated annually in a review procedure. The review is divided into 2 main parts: namely, *additional* and *replacement* vehicle estimates, which are essentially different in character, although the resultant figures are eventually summated to give total contract requirements.

Estimates for Additional Vehicles

Additional vehicles constitute the smaller part of the contracts let for vehicle purchase since they relate to the marginal variations in ETG staff, whereas the replacement programme relates to all vehicles used by ETGs.

Normally, additional vehicles are needed only where the number of staff is growing, or where there is a policy to introduce smaller working parties. It can be seen from Figs. 1, 2 and 3 how inconsistent is the staff variation between the widely varying disciplines of telecommunications engineering.

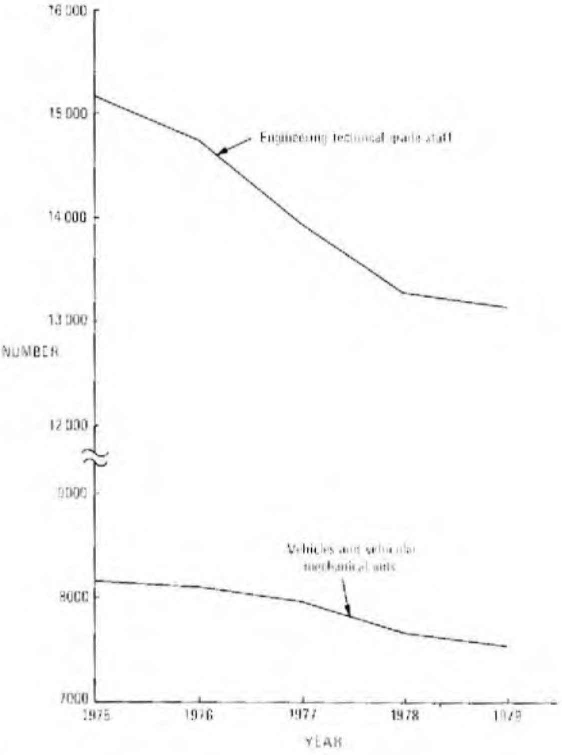

FIG. 1—Number of staff and vehicles employed on EXTERNAL WORKS duties

These graphs indicate that a regular growth in vehicles used for maintenance duties may be expected, while considerable care must be taken to predict the number of vehicles used for installation duties.

Reducing occupations do not normally feature in the additional-vehicle estimates. At the time of the annual review, in the early autumn of each year, Area transport-control officers submit their estimates, based on expected staff variations, to the motor transport (MT) efficiency specialists in the Regional office. Most Regional MT efficiency duties prepare their own independent forecasts, based on the accumulated manpower forecasts for the Region as a whole. The Area forecasts provide a useful comparison, and give a positive indication as to the distribution of the eventual additional vehicle allotment. Following discussion on provisional estimates submitted about 2 months earlier, the Regional office puts its bid for additional vehicles to THQ at the end of September of each year. At each higher checking stage, the estimates are scrutinized in the light of manpower requirements submitted at the same time from Regional level to the Business Planning Department of THQ.

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† Formerly of Operational Programming Department, Telecommunications Headquarters

* The size of the transport fleet and financial details are approximations based on the BPO Report and Accounts 1979

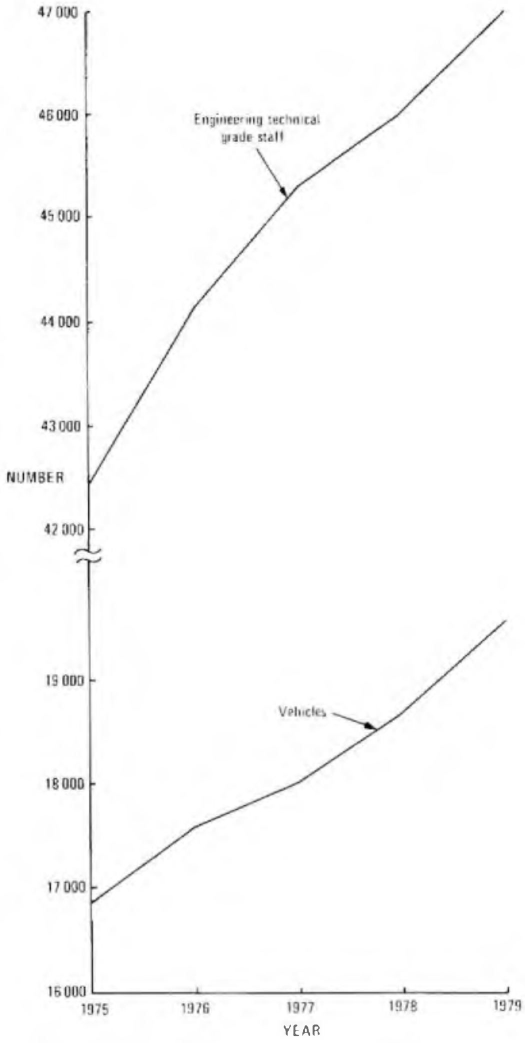


FIG. 2—Number of staff and vehicles employed on MAINTENANCE duties

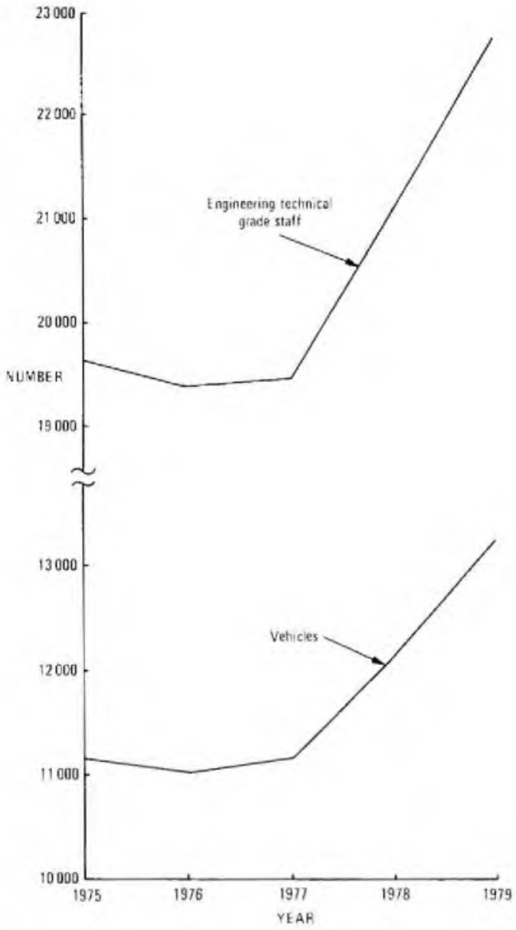


FIG. 3—Number of staff and vehicles employed on INSTALLATION duties

Estimates for Replacement Vehicles

For budget purposes, each type of telecommunications vehicle has a theoretical life expectancy. However, the precise moment when the staff of the Regional MT officer declare that a vehicle is nearing the end of its useful life depends entirely upon its condition. Once this decision has been made, the vehicles concerned are listed, and the Area transport-control officers throughout the Region are consulted as to whether each vehicle needs replacement, or whether a different type of vehicle is required in replacement. Thus, the replacement programme is the most significant single means of regulating the fleet. The replacement estimates are submitted to THQ on the same timetable as the additional-vehicle estimates, and are subject to the same preliminary discussion on the basis of provisional estimates.

THE VEHICLE-PURCHASE CONTRACT CYCLE

The BPO is heavily conditioned to its financial year commencing 1 April of each year. Vehicle provision must therefore commence each year on or about that date, to coincide with the staff recruitment deriving from the new financial year's money allotment. The vehicle-purchasing contract cycle thus precedes the new financial year. For 7 cwt and 15 cwt vans, it is necessary to sign contracts in mid to late autumn to fulfil this tight delivery schedule, and the arrival in THQ of the vehicle estimates at the end of September makes the ordering cycle just possible. The tightness of this schedule makes it impossible for discussion to occur on the estimates, except at the earlier provisional stage.

The contract lead-time for larger vehicles is longer than for the small vans, especially where separate contracts are necessary for the chassis, the body, and any specialized superstructure. The small-van contracts incorporate a contingency allowance, to cater for variations in the requirement caused by manpower forecast changes which may occur as the year proceeds.

THE TRANSPORT NEEDS OF DIFFERING OCCUPATIONS

Very broadly, the size and nature of the vehicle fleets of large operators are governed by the rate and nature of the demand for service. In this respect, the telecommunications business of the BPO is no different in the general sense, but the application of the principle is more complex than is the case in, say, haulage contracting, or in the BPO's postal business. In both these cases, bulk conveyance of goods is the prime object, whereas, in telecommunications, a vehicle is one of a number of tools in a complex field operation. Indeed, the field operation itself exists in several distinct forms, so necessitating sectionalization of the vehicle fleet.

This situation presents a considerable challenge in fleet and vehicle design, since there is a great financial advantage in minimizing the number of vehicle types ex works. In particular, this applies to vehicles of 7 cwt and 15 cwt carrying capacities, which, together, comprise about two-thirds of the transport fleet. The more field operations that can be satisfied by a single basic vehicle, the greater the financial advantage to the business. This concept also allows for flexibility in fleet deployment, since a basic vehicle can be taken from one occupational specialist and given to another.

Fleet control is complicated by the changing pattern of the field operations. As telephone penetration into homes and businesses in the UK approaches its theoretical saturation point, so the emphasis will swing away from the provision of cable in the local telephone network, while the provision rate of the trunk and junction network is governed by the even more fickle characteristic of calling rate.

External Works

The world recession of the mid-1970s made the estimating process more complex in regard to the ultimate size of the cable network, since it was not clear how much of the run-down in cabling work was due to the suppressed demand rate caused by the recession, and how much to the approach of saturation point. While it is obviously desirable to reduce the holdings of large vehicles for cabling work, whatever the cause of the decline in demand, it is not until the recession is completely over that the full picture will emerge. It must also be borne in mind that the lead time on large vehicles for telecommunications external work operations is of the order of 2 years, as they are all purpose-built for this specialist work. Thus, disposal without replacement should not be undertaken lightly. However, the financial penalty per unit for not disposing of genuinely surplus vehicles of these types is considerable.

Note: This unit is operated by 2 men. It has a power auger for hole boring, and a crane for lowering in the poles

FIG. 4—Pole-erection unit

Note: This unit is operated by 2 men, and incorporates a rod-pushing machine and a cabling winch

FIG. 5—Rodding and light-cabling vehicle

The rate of decline in the numbers of external works staff and vehicles since 1975 is shown in Fig. 1. The reduction in vehicles is less marked than the reduction in staff because working-party sizes are also reducing due to a greater degree of mechanization of works practices. Two of the latest external works vehicular mechanical aids are shown in Figs. 4 and 5.

Internal Construction

The vehicle needs of exchange construction and allied staffs present less of a problem, since large numbers of those concerned in this category of work need no official transport at all, so minimizing the problems of vehicle estimating. An example of the type of transport needed for internal construction duties is shown in Fig. 6, which shows a 30 cwt closed stores-carrying vehicle being loaded with an exchange equipment rack. The vehicle, which is still regarded as experimental, has been designed to match the load to be carried; it meets with the vehicle weight-limit regulations of the European Economic Community so that a driver does not need to hold a heavy goods vehicle licence, and it costs considerably less than previous designs.

Maintenance

By comparison with the occupations already mentioned, the section of the fleet concerned with the maintenance of the BPO telecommunications network is subject to less complex and more regular variation. With the network growing at a measurable rate per annum, the number of maintenance staff is increasing at a lesser but related rate, while their vehicle fleet increases at an even smaller, but still related, rate (see Fig. 2).

A productivity element accounts for the difference between the network and staff growth-rates; the lower rate of vehicle growth is due to the fact that not all maintenance staff need transport (for example, those employed at large telephone exchanges). Again, there is a swing towards a greater pro-

FIG. 6—A 30 cwt closed stores-carrying vehicle

portion of small vehicles, since cable network growth is less pronounced than the growth of the number of telephone stations.

Installation

The number of vehicles required for installation work is the most difficult section of the fleet to regulate, since it exists to satisfy the month-by-month demand pattern for telephone service. The fleet size is therefore subject to the vagaries of economic booms and recessions, and the effects of changes of political climates, both at home and abroad. To complicate matters, a telephone system growth rate of about 4% per annum can be met by existing installation staff, but a growth rate above this figure necessitates more staff, with a low staff-to-vehicle ratio. Worse still, the elusive forecast must be divided into the business and residential sectors of telephone service, so that an assessment of the need for 7 cwt vans (for installation fitters) and 15 cwt vans (for installers) can be arrived at by the time of finalizing the annual contracts. Installation staff and vehicle complements are shown in Fig. 3. The normal vehicles for fitters and installers are those shown in Figs. 7 and 8 respectively; either of these vehicle types may also be used on maintenance work.

Other Occupations

Occupations such as storekeeping, etc., require comparatively little transport. Approximately 900 vehicles are also operated under the direct control of the THQ formations, for long-distance stores delivery, research, development, and radio station operation.

Reserve Vehicles

A fleet of shared reserve vehicles is held to cover the non-availability of the service fleet units in the event of out-of-service time for maintenance or breakdowns. The 7 cwt and 15 cwt vehicles have reserve cover at a rate of one reserve to every 20 service vehicles; the coverage for larger utility units is at a rate of one reserve to every 15 in service, provided that the service fleet is large enough at any one centre to allow this to to be achieved. Where this principle cannot be applied (for example, in rural areas), one reserve vehicle covers more than one service type. For example, a 30 cwt vehicle is often used to give temporary cover for 1 ton, 30 cwt, and 4 ton utility vehicles.

Annual capital allotments always contain a contingency fund for the early replacement of vehicles written off due to fire or accident.

For 1 ton vehicles, experiments are planned to examine the use of demountable vehicle-bodies as an aid to speeding the changeover of tools and stores to and from reserve vehicles.

USE OF REMOVABLE BINS IN SMALL VANS

As already mentioned, it is desirable to employ a basic interior design for each vehicle type which satisfies as many work occupations as possible, so maximizing vehicle contract discounts. Having achieved this, it is also desirable to recommend standard bin complements for each defined occupation, thus simplifying the ordering procedure for the bins and standardizing on the smallest acceptable vehicle size for each type of work. Where a particular occupation requires a fixture for a special function (for example, a hinged post for stowing reflecting road cones, for customer apparatus and line maintenance work), this can be incorporated into the bin kit for that occupation.

In the 1978/9 financial year, this principle was put into effect in an evaluation trial of plastic bins suspended on louvred panels in 7 cwt vans. Opportunity was taken to base the trial on revisions of the standard tool and stores complements of each of the main occupations concerned. The interior of an installation fitting vehicle participating in the trial is shown in Fig. 9. The trial was an unqualified success, leading to the general introduction of the new standard in all 4000 (approximately) new BPO telecommunications 7 cwt vans purchased in 1979/80.

Note: This type of vehicle is used for 20 different occupations in the BPO telecommunications business, but the great majority are used by customer-apparatus and line-maintenance staff and by installation fitters. On the current field trial, the ladder rack has been raised to allow long items to be carried on the roof in PVC duct

FIG. 7—The latest design of 7 cwt van

Note: This vehicle is used for 5 different occupations, but it is used primarily on installer and faultsman-jointer duties

FIG. 8—A 15 cwt utility vehicle

Note: The vehicle shown has been kitted out with the new standard louvred panels, together with the standard kit of plastic bins (BPO Kit No. 344A), tools and stores for this occupation

FIG. 9—A 7 cwt vehicle used for installation fitting

The louvred panels are incorporated in all new 7 cwt vehicles ex works, and the bins, or kits of bins, are ordered in advance by the Area transport-control officer of each of the 61 Telephone Areas of the UK on behalf of each specialist van user. The new racking has necessitated redesign of the welded-mesh bulkhead screen, the new version of which has withstood a 35 *g* retardation test on a fully-laden vehicle shell without any items entering the driving cab. Approximately £60 net per vehicle is being saved per annum by these racking and binning changes, bringing a net annual benefit to the business of approximately £0·25M and, at the same time, improving user flexibility and enhancing the principle of vehicle sharing through standardization of tool and stores lists for each occupation.

The success of the trial with 7 cwt vans has led to a similar exercise on the 15 cwt utility vehicle in 1979/80. The trial pattern of racking is shown in Fig. 10; and Figs. 11 and 12 show the installer and faultsman-jointer layouts respectively.

OTHER SPECIALIST CONSIDERATIONS

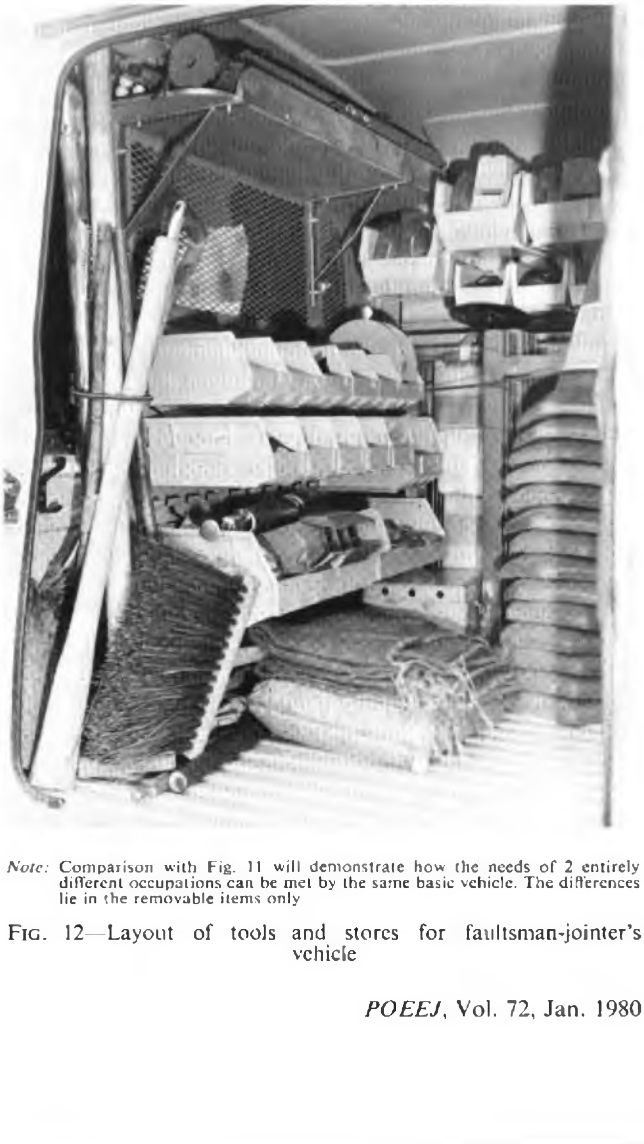
The new, flexible approach to the interior design of vehicles also allows for the removal of the bins, leaving only the louvred panelling, so maximizing the floor loading space, especially the width. An example of this design can be seen in Fig. 13, which shows a (still experimental) false floor unit used for the conveyance of teleprinters and other bulky items in 7 cwt vans; necessary tools and small job stores are carried in drawers beneath the main load. The items in the drawers can be contained in the smaller standard plastic bins. (This idea is based upon a suggestion from the field, under the BPO awards scheme.)

Fig. 10—A 15 cwt utility vehicle fitted with louvred panelling

The provision of louvred panelling in the 15 cwt utility vehicle also gives a new interior width which is greater than that of the rear door opening. This fact, together with the non-provision of a ladder rack, allows for the new-style utility vehicle to double as a stores carrier when the plastic bins are not carried, so eradicating the need for a separate 15 cwt stores-carrying vehicle contract and increasing the utility-vehicle contract size, thus increasing the discount on the contract price. Greater user flexibility is also achieved. Experiments are in progress to introduce louvred panelling into a section of the interior of the 30 cwt utility vehicle.

Now that the purchasing philosophy for official vehicles is more user-oriented, the question arises as to how universal is the need for roof-mounted ladder racks on 7 cwt and 15 cwt vans. It was mentioned above that the non-provision of a ladder rack gives greater economy, and it is also questionable as to whether disposal of the used ladder rack as part of a life-expired vehicle is cost effective. From 1980 the BPO will re-use ladder racks from vehicles of these sizes, so justifying the omission of the racks from all new replacement small vans. As it is difficult to cater for variants on a standard production line, new additional vehicles will not be fitted with ladder racks, but will be supplied from stock as required. In this case, any separate ladder-rack contract which may be necessary

Fig. 11—Layout of tools and stores for installer's vehicle



Note: Comparison with Fig. 11 will demonstrate how the needs of 2 entirely different occupations can be met by the same basic vehicle. The differences lie in the removable items only

Fig. 12—Layout of tools and stores for faultsman-jointer's vehicle

FIG. 13—A 7 cwt van fitted with a false floor unit

would be on a much smaller scale than previously when all vans were produced incorporating the racks.

Since a local fitting operation is made necessary by these changes, the opportunity has been taken in the field trial to design kits of brackets to adapt the new or re-used ladder racks more closely to the needs of the relevant users.

A 7 cwt van, fitted with a standard ladder rack raised to accommodate three 3 m lengths of standard BPO PVC duct of 102 mm diameter (normally used for underground cabling), to give stowage for two 900 mm roadworks-guarding flexible signs and a set of pruning rods, is shown in Fig. 7. The duct is available locally, and the comparatively few brackets required are available as a variant in the kit of plastic bins for the customer-apparatus and line-maintenance occupation. The stowage of long items under the ladder also derives from the BPO awards scheme.

In the case of the 15 cwt van, not all users need the double ladder rack previously provided. Therefore, the new standard of provision will be the nearside ladder rack only. However, the offside ladder rack will be available as a bolt-on extra if the need is justified.

A special side-and-rear loading ladder-rack for the 7 cwt van is also on trial for use where congested on-street parking presents a ladder-loading problem, and possibly elsewhere.

EFFICIENCY OF VEHICLE USE

Measurement of Vehicle Use

There are 2 statistical methods by which the use of the BPO telecommunications transport fleet is measured. The first is by observation of the use of each vehicle from examination of the vehicle log-sheet, from which serviceable-not-required (SNR) days are recorded. High SNR indicates that the vehicle spends much of its time immobile in the depot; this clearly shows under-use. Low SNR indicates that the vehicle spends much of its time out of the depot, but tells nothing about its use other than that. A more positive measurement is the relationship between ETG staff numbers and the fleet size, as staff-to-vehicle ratio is not affected by the location of the vehicle.

A committee, drawn from Regional and THQ staffs, has agreed on recommended staff-to-vehicle ratios and vehicle types for each defined occupational group. Thus, a comprehensive performance measurement is now in use throughout the business; this is known as the *MT capital indicator*, and compares outturn vehicle deployment with the recommended transport fleet, based on staff by occupation. The capital indicator is calculated as

$$\frac{\text{equated fleet, in \textit{standard vehicles}}}{\text{recommended fleet, in \textit{standard vehicles}}},$$

where a *standard vehicle* is the cost equivalent of a 7 cwt van, compared on the basis of annual charges. The equated fleet is a measure of vehicles in service converted to standard vehicles, plus 8000 mile units of ETG private car mileage on official business at the standard repayment rate, and the recommended fleet is computed from a summation of the standard vehicles recommended for the ETG level for each occupation, plus an allowance for reserve vehicles.

The lower the capital indicator, the sounder is the capital investment in vehicles, the limit being where operational field performance starts to be adversely affected by lack of vehicles.

Cost Control Methods and Statistics

A comprehensive computer scheme to deal with all the main costing and control features of the BPO telecommunications transport fleet is due to be introduced by the BPO during 1981. Statistics of SNR and related mileage analyses of all vehicles, compiled at first-line supervisor level, will be incorporated, including a management-by-exception assessment, which compares local outturns with average figures.

A field trial of another computer system, known as the *staff and transport analysis return* (STAR) has been in progress for 4 years, and national implementation is currently planned. The STAR program relates the size and character of the fleet to the occupational groups, both in respect of deployment and MT capital indicator. To enable distributed ETG manpower figures to be used as a base, the computerization of the engineering staff tree (THQ Form 976) forms a major part of the scheme. Historical quarterly outturns are kept on file, so that performance trends may be observed and used as the base for staff and vehicle forecast projections, and to assist in estimating. Management by exception is also a feature of the

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
REGION        ENGINEERING STAFF TREE   AS AT (DATE)            PAGE 1
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


       WORKS EXTERNAL
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
OG    COL  NO   GRADE            ETG     DISCRIPTION
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                 CABLING IN DUCTS
 1          1   (T1)              17     FOREMEN
 1          2   (T2A)             35     HANDS
 1          2   (OTHER)            2     HANDS
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                 RODDING AND CABLING 3MAN PARTIES
 2          3   (T1)               2     FOREMEN
 2          4   (T2A)              4     HANDS
 2          4   (OTHER)            0     HANDS
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                 GENERAL PURPOSES PARTIES
 3          5   (T1)              58     FOREMEN
 3          6   (T2A)            103     HANDS
 3          6   (OTHER)            6     HANDS
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
TOTAL STAFF COL 1 6              238
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                 SPECIALIST PARTIES
 4          7   (T1)              31     RODDING AND CABLING 2MAN
 4          7   (OTHER)           28     RODDING AND CABLING 2MAN
 5          8   (T1)               8     TEL STA AND PLEM ELV 2MAN/
                                         OVERHEAD
 5          8   (OTHER)            7     TEL STA AND PLEM ELV 2MAN
                                         OVERHEAD
 6          9   (T1)              18     POLE ERECTION UNIT
 6          9   (OTHER)           16     POLE ERECTION UNIT
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
TOTAL STAFF COL 1 9              346
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

FIG. 14—Example of an engineering staff tree print-out (part) of the STAR computer system

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..........................................................................................................................
        REGION                        AREA    PRINT OF FORM A2595    COLS 6  28 ONLY                ON (DATE)
..........................................................................................................................
ASSESSED GROUPS
EXTERNAL WORKS GROUP

OG   OCCUPATIONAL                 TYPE CODE      CURRENT STANDARD VEHICLE
CODE GROUP NAME                   302  313  615  627  647  617  659  651  655  651  601  602  652  606  115  120  704  718  703  735  669  757  OTHER
..........................................................................................................................
  1  CABLING IN DUCT               ••   ••   ••   ••   ••    1   ••   15    2   ••   ••   ••   10   ••   ••   ••   ••   ••    1   ••   ••   ••    ••
  2  RODDING AND CABLING           ••   ••   ••   ••   ••   ••   ••    2   ••   ••   ••   ••    2   ••   ••   ••   ••   ••   ••   ••   ••   ••    ••
  3  GENERAL PURPOSE PARTIES        1   ••   ••   ••    3   34   ••   36    2   ••   ••   ••    5   ••   ••   ••   ••    1   ••   ••   ••   ••    ••
  4  RODDING AND CABLING           ••   ••   ••   ••   ••    1   ••        ••   ••   ••   ••        ••   ••   ••   ••   ••   29   ••   ••   ••    ••
  5  OVERHEAD PARTY 2MAN            1   ••   ••   ••    1    3   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••    8   ••   ••   ••   ••    ••
  6  POLING PARTIES                ••    2   ••   ••    3    1   ••    1   ••   ••   ••   ••    1   ••   ••   ••   ••        ••   15   ••   ••    ••
  7  JOINTERS (T1+T2)
  7  JOINTERS (ST)                 34  202   ••   ••  120   18   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••    ••
  8  CABLE BALANCING               ••   ••   ••   ••   ••   ••   ••   ••   ••   ••    1   ••   ••    1   ••   ••   ••   ••   ••   ••   ••   ••    ••
  9  WORKS SUPERVISOR              68    3   ••   ••   ••   ••   ••   ••   ••   ••   21   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••    ••
 10  ESTIMATING LIAISON OFFICER     2   28   13   ••   ••   ••   ••   ••   ••   ••    3   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••    ••
 12  BOX BUILDING PARTIES          ••   ••   ••   ••   ••    3   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••   22   ••   ••   ••   ••   ••    ••
 13  PLANNING AND ESTIMATING
     STAFF                         13    8    2    1   ••   ••   ••   ••   ••   ••    1    3   ••   ••   ••   ••   ••   ••   ••   ••   ••   ••    ••
```

Note: The vehicle-type codes refer to the dominant vehicle-type grouping currently in use in the field

FIG. 15—STAR computer system print-out of fleet deployment by occupational group

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..........................................................................................................................
        ........REGION        ........AREA       PRINT OF FORM A2595       COLS 1–5 + COLS 29–35 ONLY       ON (DATE)
..........................................................................................................................
ASSESSED GROUPS
EXTERNAL WORKS GROUP
                                                                                                        RECOM-
                                               RECOMMENDED   STAFF/STANDARD          STANDARD  PRIVATE  EQUATED  MENDED  CAPITAL  INDICATOR
OCCUPATIONAL GROUPS                    STAFF   VEHICLE       VEHICLE MULTIPLIER      VEHICLES  CARS     FLEET    FLEET   AREA     REGION

  1   CABLING IN DUCT                    55    651              0.694                  81.0              81.0     38.2   2.120
  2   RODDING AND CABLING 3               6    651              0.926                   9.0               9.0      5.6   1.612
  3   GENERAL PURPOSE PARTIES           177    617              0.708                 208.3             208.3    125.3   1.662
  4   RODDING AND CABLING 2              59    703              1.896                 112.1             112.1    111.9   1.002
  5   OVERHEAD PARTY 2 MAN               15    718+302          2.198                  36.8              36.8     33.0   1.116
  6   POLING PARTIES                     34    735              4.773                 159.1             159.1    162.3    .980
  7   JOINTERS (T1 + T2 + OTHERS)       409    647+314          1.030                                             421.3
  7   JOINTERS (ST)                      34    302              1.000                 592.9      .2     593.2     34.0   1.303
  8   CABLE BALANCING                     5    606              2.404                  11.3              11.3     12.0    .940
  9   WORKS SUPERVISOR                   98    302              1.000                 107.0     1.2     108.2     98.0   1.104
 10   ESTIMATING LIAISON
      OFFICER                            46    615              1.183                  56.8      .1      56.8     54.4   1.044
 12   BOX BUILDING PARTIES               56    704              1.305                  63.8              63.8     73.1    .873
 19   PLANNING AND ESTIMATING
      STAFF                             193    615              0.148                  36.5     12.4     48.8     28.6   1.709
..........................................................................................................................
EXTERNAL WORKS OVERALL                 1187                                          1474.4     13.9    1488.3   1197.5   1.243
..........................................................................................................................
```

Note: The Regional capital indicator column is blank in this example because the print-out is a Regional summation

FIG. 16—Capital indicator print-out of the STAR computer system

STAR computer system. Occupational performance graphs, with average curves superimposed, are available under the scheme.

A typical engineering staff tree print-out section is given in Fig. 14; a fleet deployment print-out is given in Fig. 15, from which unsuitable vehicles per occupation can be seen with ease; Fig. 16 shows the capital-indicator print-out per occupation; Fig. 17 shows the summary page, giving the overall capital indicator for the Region concerned. Typical occupational staff-to-vehicle ratio graphs are shown in Fig. 18. Graphical presentation of data will be based on the MT capital indicator when full implementation is achieved.

Provided that the tighter control given by the computer analyses is acted upon at local level and the vehicle-replacement programme is pruned to eradicate unwanted vehicles (especially high-cost external-works units—see Fig. 1), the computer schemes will pay for themselves in the first year of operation. A saving of only 5% on the vehicle capital outlay is worth £1M per annum, and it is likely that this level of saving will be considerably exceeded.

FUEL SUPPLY CRISES

The efficient operation of a transport fleet as large as that of the BPO telecommunications business depends upon a ready supply of fuel. The fleet's dominant need is for commercial-grade petrol, although the larger units use diesel, and some of the vehicular mechanical aids are powered by liquid petroleum gas (LPG). The use of LPG in small vehicles, as an alternative to petrol, is also in course of evaluation.

Optimum mileage per gallon is achieved by restricting fuel flow in carburettors but, at times of shortage in fuel supply,

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**************************************************************************************************
          REGION     AREA     PRINT OF FORM A2595     COLS 1-5 + COLS 29-35 ONLY  ON  (DATE)
**************************************************************************************************

******** SUMMARY ********                                                RECOM-
                                          STANDARD  PRIVATE  EQUATED  MENDED  CAPITAL INDICATOR
OCCUPATIONAL GROUPS               STAFF   VEHICLES  CARS     FLEET    FLEET   AREA      REGION

  1    SECTION 1 PAGE 1 TOTALS    2642    2810.5    23.4     2834.0   2455.7
  2    SECTION 1 PAGE 2 TOTALS    4221    2560.7    53.7     2614.4   2206.0
  3    SECTION 1 TOTALS           6863    5371.2    77.1     5448.3   4661.7  1.169
  4    RESERVE VEHICLES                    289.8                       279.7
  5    TOTAL ASSESSED STAFF
       AND VEHICLES               6863    5661.0    62.7     5723.7   4941.4  1.158
  6    TOTAL NON-ASSESSED
       STAFF AND VEHICLES          806              11.0
  7    RESERVE VEHICLE RATIO               18,5
  8    GRAND TOTAL AND
       VEHICLES                   7669

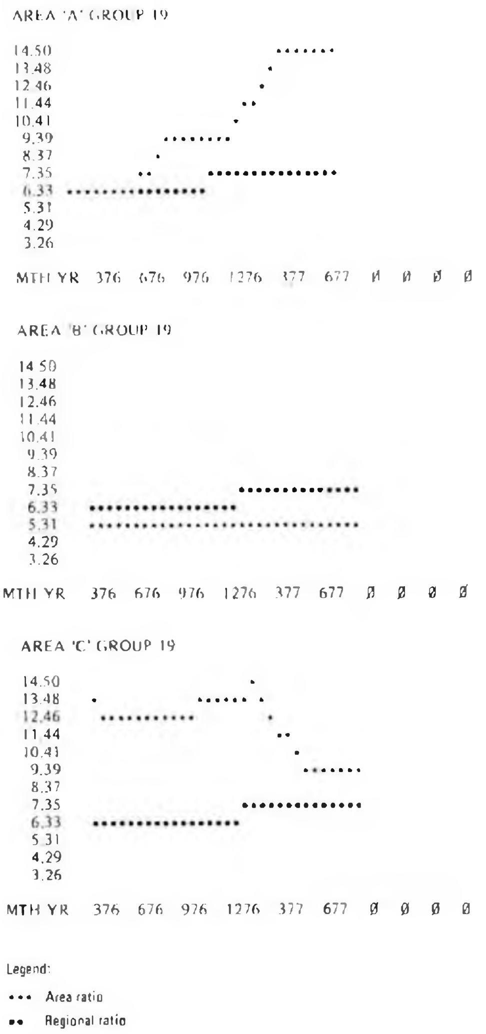

LONG TERM SICK AND SPECIAL LEAVE            0
TOTAL ADULTS IN POST AT 31st MARCH       7669
TOTAL VEHICLES COLS 6 TO 28 LINE 8       4366
                                                  *********
OVERALL CAPITAL INDICATOR FOR REGION IS           * 1.158 *
                                                  *********
```

FIG. 17—Capital indicator summary page of the STAR computer system

there is a clear case not to increase the fuel consumption of the fleet, even though additional vehicles are brought on to strength. To achieve this, it becomes even more important to regulate the overall fleet size by means of tight control on the vehicle-replacement programme, especially as regards minimizing the size of the replacement types, and not replacing unwanted units. As shown in Fig. 1, it is fortunate that the most likely vehicles not to require replacement are some of the larger units, which consume most fuel. This particular source of saving relates more to diesel than to petrol, but the principle of good housekeeping outlined in this article also leads to minimizing petrol consumption by limiting the size of the transport fleet.

The BPO is co-operating with the Greater London Council in the experimental use of 15 cwt electric-powered vehicles, both from the point of view of conserving fossil fuels, and minimizing environmental pollution.

The prime operating problem for electric vehicles is the strict range limit while operating permanently laden. However, there is a practical and economic problem in that none of the 300 (approximately) BPO telephone engineering centres have a power supply sufficient to charge more than about 5 or 6 vehicles overnight, whereas about 200 vehicles are based at each depot. A large capital outlay to supplement the electricity supply is foreseen if a wholesale transition to electric vehicles occurs in the future. However, this may be a necessary price to pay in the 21st century to give flexibility in the production and use of energy.



Note: A high-value staff-to-vehicle ratio is generally considered to be good from the viewpoint of vehicle use

FIG. 18—Staff-to-vehicle ratio graphs of a given occupational group with Regional-average graph superimposed

CONCLUSION

Careful staff computation is the basis for assessing both the size and character of the BPO telecommunications transport fleet. Modern computerized methods are being introduced to help control this computation tightly, and to rationalize the fleet at Area, Regional, and national levels. Coincident with this strategic control, more work than ever before is being done to adapt a minimal number of standard vehicle types to meet the needs of all specific occupations, while also standardizing the recommended tool and stores lists for each occupational group.

ACKNOWLEDGEMENTS

Thanks are due to the Area staff and Regional MT officers who assisted in the development of the prototype of the revised 7 cwt van ladder rack, the revised van layouts for faultsman-jointer and installer vehicles, and the false floor unit.

The MOST Director

Part 1—System Outline, Technology and Call Routing

K. H. GRUNWELL and D. WALTON†

UDC 621.395.341.7: 621.382.3

Large-scale integrated-circuit technology has been used in the replacement of remaining common electromechanical equipment in Strowger director exchanges, with the result that further reductions in maintenance costs and savings in space have been realized.

INTRODUCTION

The local-exchange metal-oxide-semiconductor-transistor (MOST) register-translator (Type-13 register-translator), referred to as the *MOST director*, provides facilities similar to those of the stored-program-control (SPC) register-translator described in a previous article,[1] but with an increased saving in space and a further reduction in maintenance costs. The A-digit selectors, directors, director routiners and local registers in the 243 director exchanges not equipped with SPC register-translators, will gradually be replaced by MOST directors. Unlike the SPC register-translator, the MOST director is not a processor-controlled system, but is similar in principle to the electromechanical register-translators used for controlling STD calls in non-director areas. It has registers in which the incoming dialled digits are stored, and a common translation store to which each register has access; the translation store is the only common part in the system. The reduction in size of the system has been achieved by extensive use of custom-built integrated circuits (ICs) using MOST 4-phase dynamic logic. There are 24 custom-designed ICs in the system which, along with the system itself, were developed jointly by Pye TMC Ltd. and the British Post Office's Telecommunications Development Department.

The physical design uses a modified form of Type-62 equipment practice (designated T8316), which mounts on a standard 1·37 m (4′ 6″) Strowger rack, allowing the MOST director to be fitted into any spare rack space in an existing exchange. A fully-equipped MOST director rack accommodates 180 registers and all the associated common equipment, which means that most exchanges require only one rack. A general view of the equipment is shown in Fig. 1.

The common equipment is accommodated in the three centre shelves, and includes:

(*a*) triplicated translation stores,
(*b*) translator control equipment,
(*c*) system monitor and routiner equipment, and
(*d*) a visual display unit.

A teleprinter is also provided, external to the rack, to record fault and routine information. Fig. 2 shows the control-and-monitor part of the rack.

A typical trunking arrangement at a director-area local exchange using the MOST director is shown in Fig. 3. The equipment interfaces with the existing exchange at the A-digit hunter grading, each register replacing an A-digit selector. A fully-equipped rack with 180 registers replaces up to 14 racks of electromechanical equipment which, assuming an average calling rate, means it can provide director facilities for up to three 10 000-line exchange units.

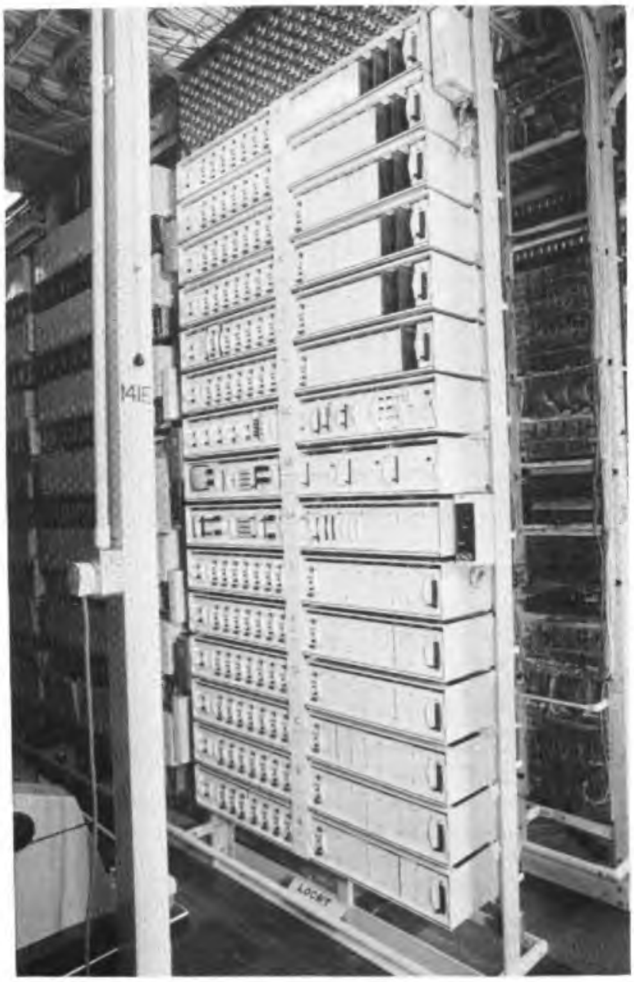


FIG. 1—MOST director rack

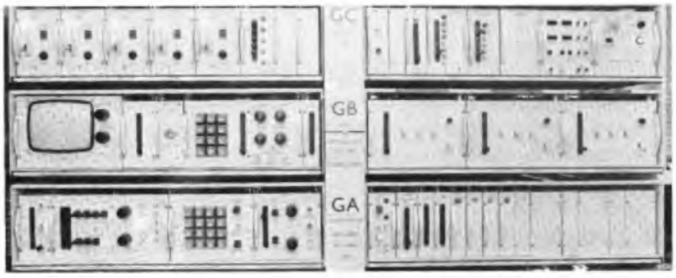


FIG. 2—Control-and-monitor part of rack

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† Telecommunications Development Department, Telecommunications Headquarters

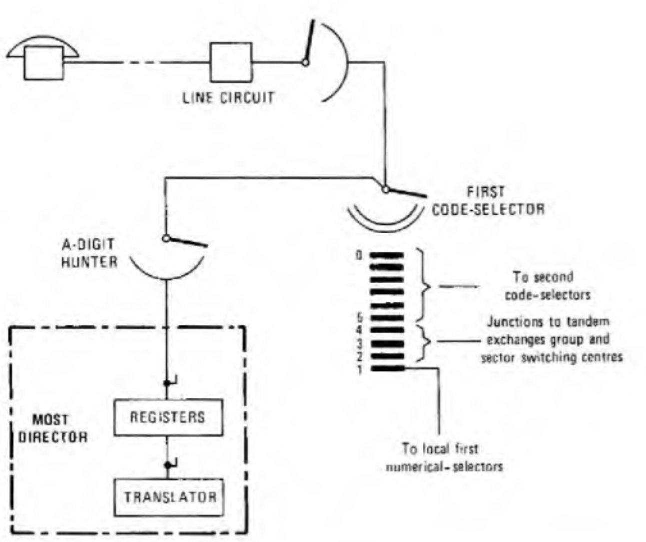


FIG. 3—Trunking diagram for a director-area local exchange with MOST director

SETTING-UP A CALL

An originating call seizes a first code-selector, which causes a free register in the MOST director to be seized via the A-digit hunter. Dial tone is returned to the caller from the register. The incoming pulse trains from the caller are detected and stored in the register. As each complete digit is received, it is compared with a stream of translation addresses being constantly received by the register from the translator's cyclic store. When sufficient digits have been received for a complete address comparison to be made (for example, the three code digits of a local director call), the register stores translation information which immediately follows the compared address in the translation stream. This information contains the sending program and the necessary routing digits. The sending program is in three parts:

(*a*) the number-length information, which indicates the total number of digits to be received (for example, seven for a local director call),

(*b*) the omitted-digits information, which indicates the number of received digits not to be retransmitted (as a general example, the three code digits of a local director call are not retransmitted), and

(*c*) the outgoing inter-digital pause (IDP) information (for example, on local director calls, all transmitted digits are separated by an 800 ms IDP, except for the last routing digit which is followed by 950 ms IDP).

Following storage of this information, the register pulses-out the routing digits, followed by the digits from the caller indicated for retransmission in accordance with the sending program. Completion of sending results in release of the register from the first code-selector; the register, after clearing its internal digit stores, returns to the free state in readiness to route subsequent calls.

MOST TECHNOLOGY

The basic principles of the MOST device, and an indication of its uses, have been covered by a previous article[2].

The MOST director uses 4-phase dynamic logic to achieve the lowest possible power dissipation and the largest number of transistors on each IC.

Fig. 4(*a*) shows a 4-phase inverter gate, known as a *type-1* gate. When ϕ_1 is at state 1,† the node capacitance, shown dashed as C1, is charged via transistor TR1. This process is known as the *precharge* and repeats for every ϕ_1 clock pulse. Transistor TR2 is turned on at the same time by ϕ_2 but has no significant effect at this point. When ϕ_2 returns to state 0, transistor TR1 turns off, but transistor TR2 remains on as ϕ_1 is still at state 1.

With the input at state 1, transistor TR3 is on and, consequently, the node capacitance discharges via transistors TR2 and TR3 in series. When ϕ_2 returns to state 0, C1 has discharged and state 0 exists at the output; that is, the inverse of the input condition.

With the input at state 0, transistor TR3 is off and no path exists to discharge capacitor C1. When ϕ_2 returns to state 0, the output is at state 1 as C1 has not discharged.

Fig. 4(*b*) shows a *type-3* gate, which is identical in layout and operation to a type-1 gate but is driven by ϕ_3 and ϕ_4 clock pulses instead of ϕ_1 and ϕ_2.

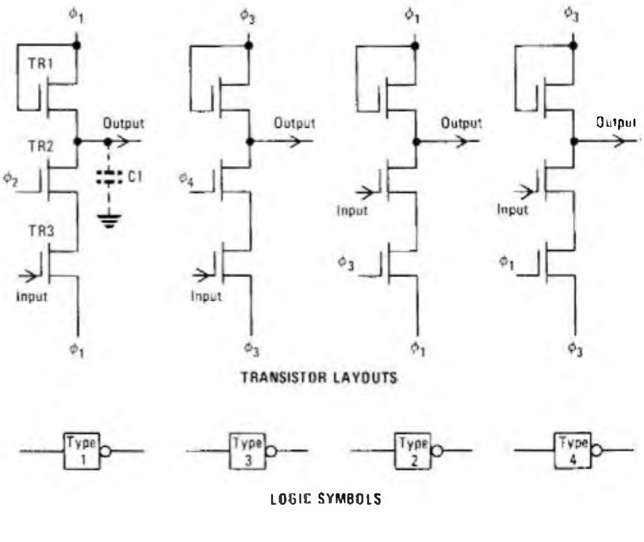
If a type-1 gate and a type-3 gate are connected together, they form a one-bit shift-register stage, in which the condition presented to the input is shifted to the output during one complete clock cycle. The operation of this circuit has been fully described in a previous article[3].

The store IC (D4004) used in the MOST director is made up of such shift-register stages. A D4004 is a dual 800 bit shift-register; that is, it has 1600 shift stages. As each shift stage uses 6 transistors, there are 9600 transistors on a silicon chip approximately 5 mm square.

The other two types of gate used in the MOST 4-phase technology are real-time inverters known as *types 2* and *4*, and are shown in Figs. 4(*c*) and 4(*d*). These gates give an inversion in the logic level within a clock cycle: they do not introduce any delay. A type-2 gate is used to give an inversion between a type-1 gate and a type-3 gate, and a type-4 gate is used between a type-3 gate and a type-1 gate. These gates operate in a manner identical to that described above with reference to the connected clock supplies.

Fig. 5 illustrates the realization in 4-phase dynamic logic of an $(A + B)C$ function combined with a 1 bit shift and having two outputs, one of which is inverted.

It also shows a variation of the basic gate known as a *twin-tee* output (formed by transistors TR1, TR2, TR6 and TR7), applied to a type-1 gate. This type of output can also be



(*a*) Type-1 (*b*) Type-3 (*c*) Type-2 (*d*) Type-4

ϕ_n: Clock-pulse train

FIG. 4—Basic 4-phase gates

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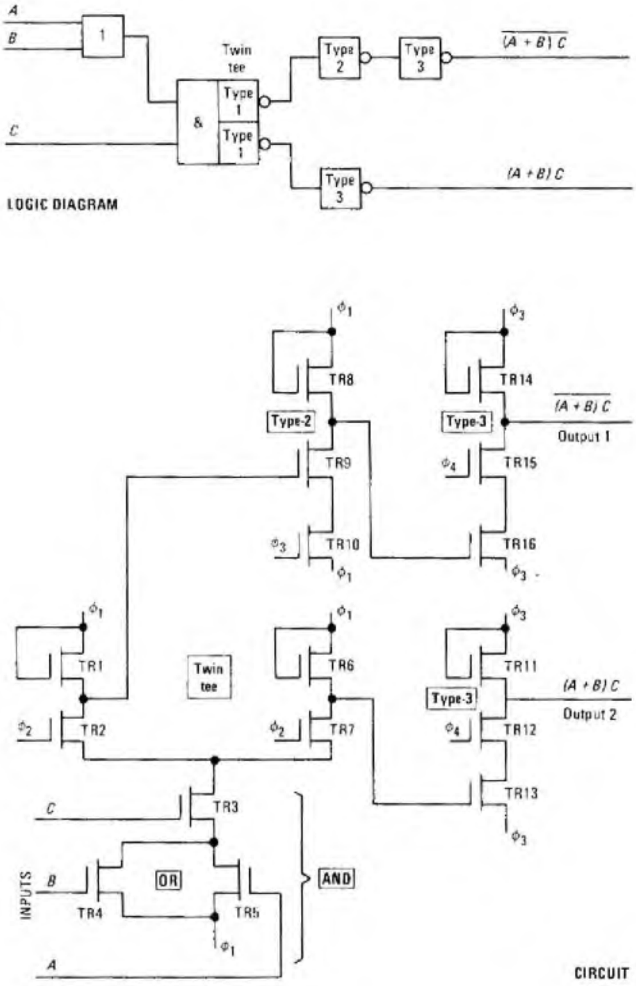
† Negative-logic notation is used in this article, with logic 0 equal to 0 V and logic 1 equal to −26·5 V (nominal)



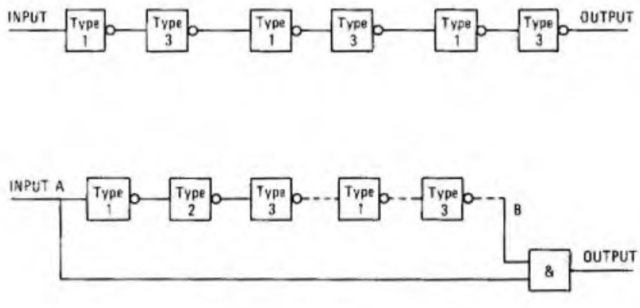
I: OR function } Conventional symbols as
&: AND function } defined in BS 3939

FIG. 5—Typical 4-phase logic element

used with a type-3 gate, and is provided when two different types of gate are to be fed from the same output: in this case, a type-2 and type-3 gate.

Fig. 6 shows two typical gate combinations using the MOST 4-phase dynamic logic. Fig. 6(*a*) is the basic shift register used extensively in the MOST director for storing information.

The circuit shown in Fig. 6(*b*) is built around the shift-register circuit and is known as a *one-shot* circuit. It gives a fixed-length output pulse provided that the input signal is longer than the required output. The number of shift-register stages in arm AB of the circuit determines the number of clock cycles for which the output is maintained. Assuming that the input goes from state 0 to state 1, the output will go from state 0 to state 1, as point B is initially at state 1 due to the action of the type-2 gate. After one clock cycle, the output goes to state 0 when point B goes to state 0 (assuming there is only one shift stage in arm AB). This condition continues until the input signal is removed, whereupon point B returns to state 1 after one clock cycle, and the circuit is ready then to receive another input.



(*a*) Basic shift register
(*b*) One-shot circuit

FIG. 6—Common 4-phase logic circuits

In the MOST director, the circuits described are combined in various ICs to perform the necessary digit-storage and logic functions required by the system.

TRANSLATOR

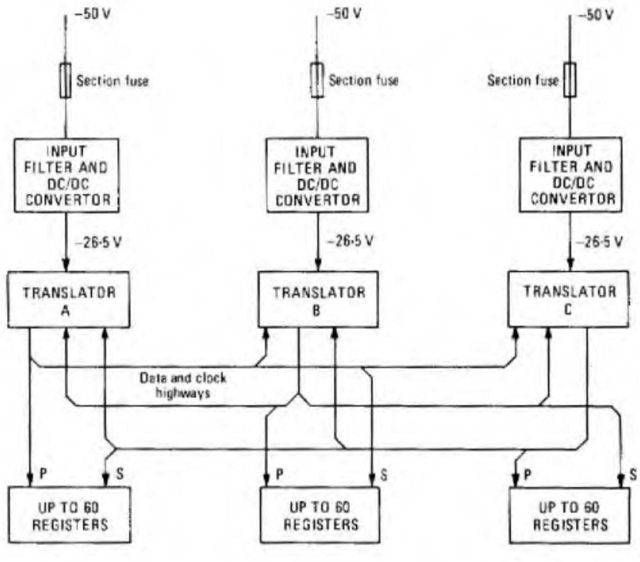
The translator is an electrically-alterable dynamic shift-register store containing program codes to control the routing of calls. The control information is continuously cycled and applied to data highways which feed the registers. As this information is vested with central control of the system (and thus of the outgoing section of an exchange), the following special precautions have been taken to ensure maximum reliability of the equipment.

(*a*) The entire unit is triplicated. The three translators are identical and, apart from test patterns, contain the same information. Each translator provides clock pulses and data on a primary highway for a maximum of 60 registers, and provides a secondary source of information for a second group of up to 60 registers. Each translator can therefore supply two-thirds of all the registers. If two translators fail, only one-third of the registers will be out of service (See Fig. 7).

(*b*) Each translator takes its power from a separate −50 V section fuse, and has its own −26·5 V MOST supply unit.

(*c*) To prevent corruption or loss of stored data in the event of an exchange power-supply failure, or when removing the unit from the rack, a battery is included in each translator unit to power the MOST clock circuits immediately the power-supply voltage falls below −23·5 V. The battery is a stack of rechargeable nickel-cadmium cells, which are trickle charged from clock phase ϕ_1, and which are capable when fully charged of supplying the clock circuits for a minimum of 6 h.

(*d*) Each translator repeatedly checks the information stored within it, and compares its own data with the data



P: Primary highway
S: Secondary highway

FIG. 7—Security of data

stored in each of the other two units. Any corruption of the data can thus be detected by all three units. Under certain conditions, an error in a translation word can be automatically corrected. To check the stored data, 8 bit sum-check codes are incorporated as part of the data format. A translator word is used only if the sum-check is found to be correct. The data is compared bit-by-bit with the data from the other two translators. If a disparity is detected, a two-out-of-three majority decision is used to select the correct data bit before it is applied to the data highway.

Fig. 8 is a general view of a translator, and Fig. 9 shows the function of a translator unit in block-diagram form.

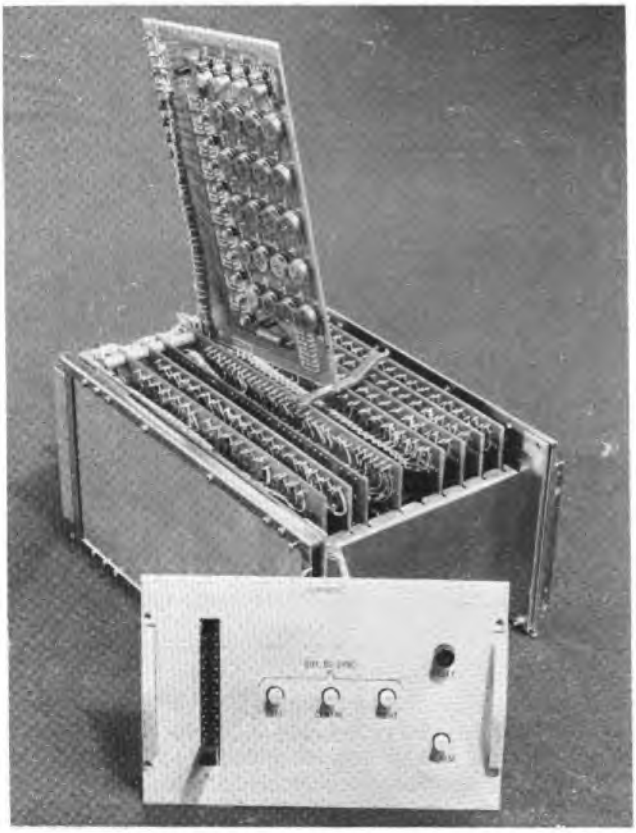


FIG. 8—Translator unit, showing a store card removed for maintenance

Clock-pulse Generation and Synchronization

The MOST ICs in the system require four clock signals. These are produced by IC D4006 and have a nominal frequency of 345·6 kHz. A similar set of waveforms is generated in each translator.

The waveforms are generated from a 2·7648 MHz crystal oscillator which feeds IC D4006. Each clock cycle consists of 16 periods, each of which is one half-cycle of the basic oscillator signal. The waveforms produced are shown in Fig. 10. The four phases from IC D4006 are taken to discrete-component drivers to provide the clock signals for the rest of the translator unit.

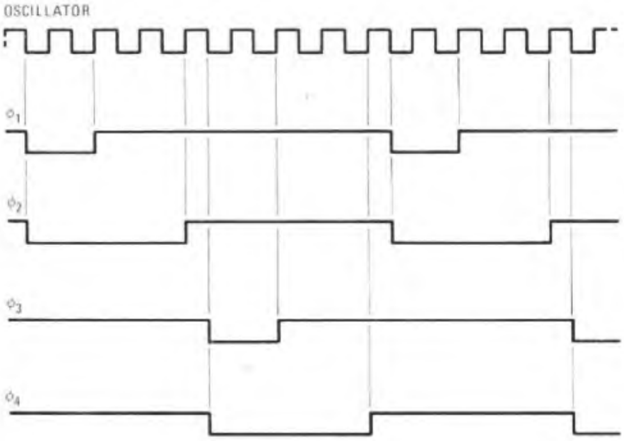


FIG. 10—IC D4006 output waveforms

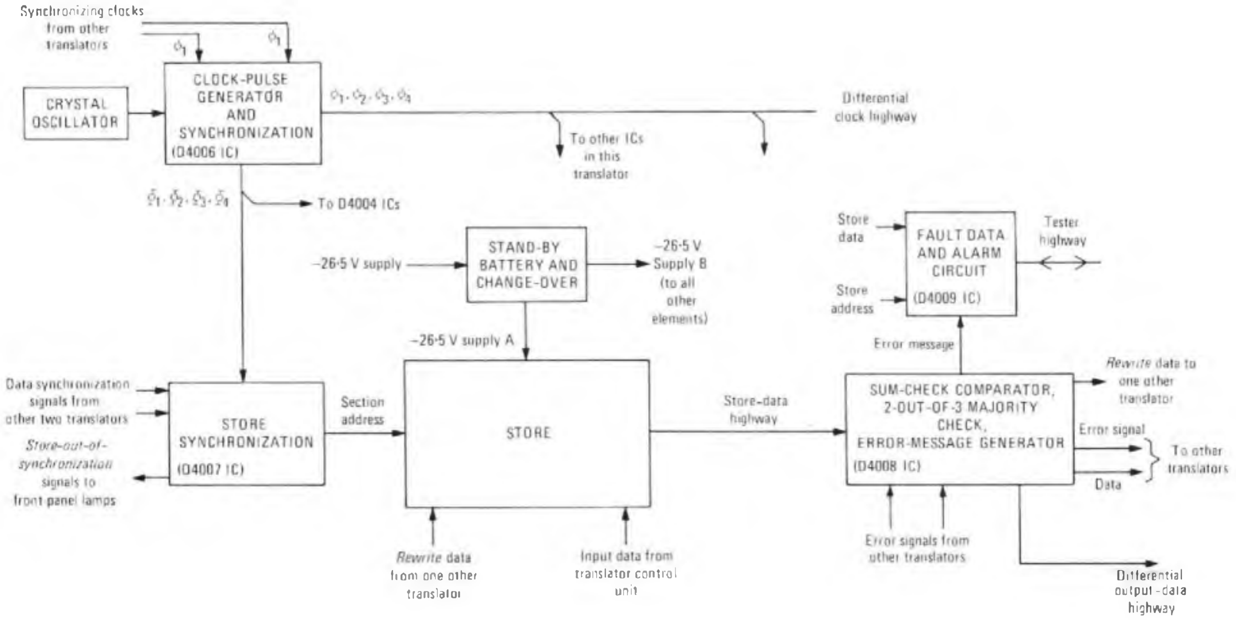


FIG. 9—Block diagram of translator

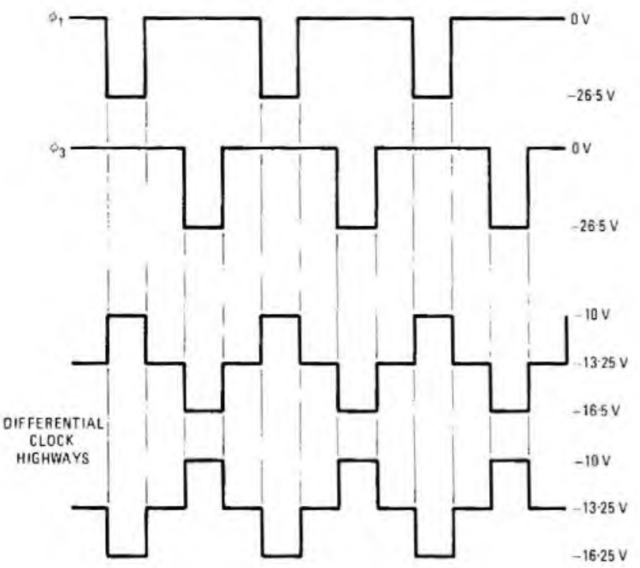


FIG. 11—Clock-highway waveforms

A second set of clock waveforms, used by the storage ICs, is produced by dividing the fast clocks by 10, giving a frequency of 34·56 kHz. These are identified as Φ_1, Φ_2, Φ_3 and Φ_4.

Clock pulses ϕ_1–ϕ_4, as well as driving the logic in their home translator, are fed to one-third of the system's registers as a primary supply, and to another one-third as a stand-by supply; they also feed other control units. To give better noise immunity and to reduce the amount of rack cabling, only ϕ_1 and ϕ_3 are transmitted over a balanced clock-highway. Each unit thus receives ϕ_1 and ϕ_3 and derives from them its own ϕ_2 and ϕ_4. The clock-highway output is provided in a coded form as a differential (current) switched output. Fig. 11 shows the basic output waveform and its relationship with the ϕ_1 and ϕ_3 clocks.

Since the three translator units must be kept independent of each other, the three sets of clocks will be unrelated and, due to component tolerances, will be running at slightly different speeds. However, since the three units have to pass data between each other, it is essential that their clock systems run at the same speed and are in phase with each other. This synchronization is achieved by feeding the ϕ_1 clock to the other translators.

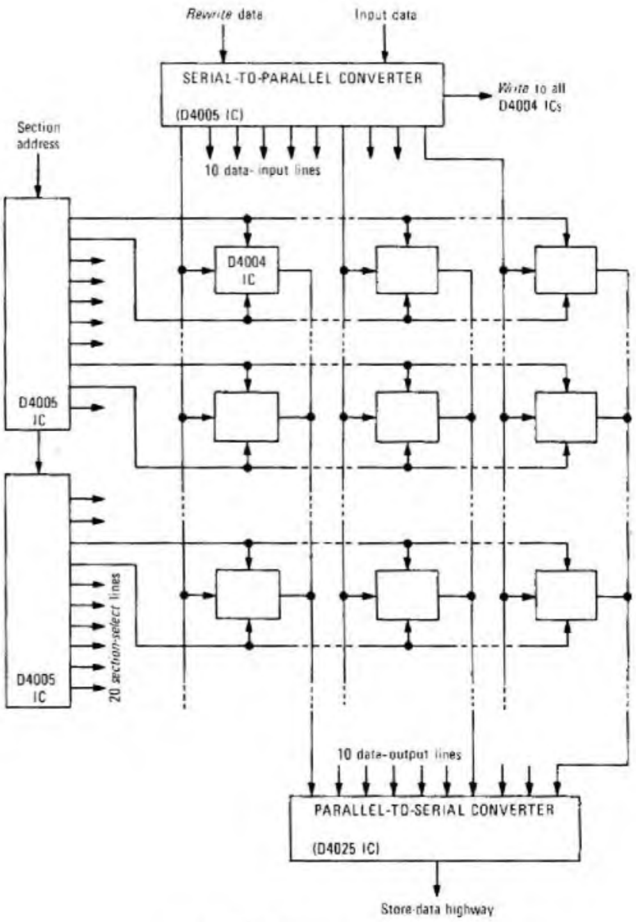


FIG. 12—Store structure

Store Structure

The store structure is illustrated in Fig. 12. The store consists of a matrix of two-hundred 800 bit MOST shift-registers, effectively forming one large shift-register with a single recirculating loop. The maximum length of the store is 2000 words (160 000 bit). Two of these shift-registers are contained in each D4004 IC.

TABLE 1
Double-Marker Word Format

10 bit prefix marker			Second marker						Note 1	Note 2			Note 3									
11	1111	1111	0111	1111	1110	0000	0000	0000	Time-out value	COS 1	COS 2	COS 3	5 or *W* or 3	1 or - or 2	0000	0000	0000	0	--	---	-	0
			W	*X*	7	–	–	–					Test pattern		–	–	–		Sum-check			
1	3	7	11						35	39	43	47	51	55				71				80

← 80 bit →

W: Binary 14
X: Binary 15
COS: Class of service

Note 1 Time-out can take any value between 2 and 15 (in binary form), each value representing a step of 1·42 s

Note 2 COS 1–3 can take any value between 1 and 10 (in binary form)
COS 1: Ordinary line
COS 2: Public coin-collecting box
COS 3: Renter's coin-collecting box

Note 3 See Table 3

TABLE 2

Normal Data-Word Format

11	1111	1111	*A*	*B*	*C*	*D*	*E*	*F*	NL	ODP	IDP	T_1	T_2	T_3	T_4	T_5	T_6	0	--	---	-	0
Marker			Address code						Sending Program			Translation code							Sum-check			
1	3	7	11						35			47						71		75	79	80

← 80 bit →

NL: Number length
ODP: Omit-digits program
T: Translation digit
A–*F*: Address digits

TABLE 3

Highway Test Patterns

Highway/Translator	Bit								Hexadecimal Equivalent
	51	52	53	54	55	56	57	58	
1	1	0	1	0	1	0	0	0	51
2	0	1	1	1	0	0	0	0	W-
3	1	1	0	0	0	1	0	0	32

The store is divided into 20 sections of 100 words each. Each section is selected in turn and its contents read out onto a common highway before the next section is selected. Each section is made up of 10 recirculating shift-registers of 800 bit each. These operate in parallel using the 34·56 kHz store clocks Φ_1–Φ_4. The parallel mode is used because MOST ICs dissipate power only at each transition of the clock waveforms; therefore, the power consumption is proportional to the clock frequency. This method allows up to 100 store ICs to operate at one-tenth of the power they would consume if operated in the serial mode. At each store cycle, one bit is extracted from each of the 10 shift-registers. These bits are read into a parallel-to-serial converter (IC D4025), which converts them into a 10 bit serial word at the speed of the fast clocks. When data is to be written into the store, it is sent serially at fast clock rate to a D4005 IC which converts each group of 10 bit into parallel form so that one bit can be loaded into each of the 10 parallel shift-registers (D4004 ICs).

The data held in the store is grouped into words each of 80 bit. The formats of the data words are shown in Tables 1 and 2. The *double-marker* format is used for the first word in the store only, and the *normal* format is used for all other words. Information contained in these words is discussed more fully later. The highway test pattern must be different for each translator, as shown in Table 3.

Store Synchronization

Each translator continuously compares its own data with the data stored in the other two. To do this, the three stores must all be synchronized so that corresponding store locations are available at the same time. Since the three translators are independent, they will not naturally be in synchronism but must be pulled together. This is performed by the D4007 IC, which can cause the store-clock cycle to be increased to 11 bit. This has the effect of slowing down the store by 1 bit/store-clock-cycle without disturbing the data in the store.

All three translators have lamps to indicate when they are out of synchronism.

Data Checking

The data extracted from the store is taken to the D4008 IC, which checks the data, compares it with the data from the other stores, and generates error messages. A signal is also produced if the *check* digits of the word are found to be incorrect.

Each word in all three streams of data is compared. Normally, all three words will be identical and no errors will have been found. In this case, D4008 IC accepts the data derived from its own store. If any errors are indicated, or if the three words are not identical, then IC D4008 chooses whichever one appears most likely to be correct, and transmits an error message to the D4009 IC, which reports the event to a system monitor. In this way, any corruption of the data in one store can be detected, and is prevented from interfering with the rest of the system.

Under certain circumstances, it is possible for incorrect data in the store to be corrected automatically.

REGISTER

In the idle state, the register is receiving the data and clock highways from two translators. The primary highways are examined and, if no error is detected, these are used to *enable* the register. If an error is detected on either the primary clock or data highway, then a change-over signal is generated and the secondary highways are used. During initial powering-up, highway change-over or manual reset, a monostable circuit busies the register to prevent seizure.

Clock pulses ϕ_1 and ϕ_3 are reproduced directly from the clock highway. Waveform ϕ_2 is generated by switching the ϕ_2 signal to state 1 (−18 V) with ϕ_1, and switching it to state 0 (0 V) with ϕ_3. Waveform ϕ_4 is similarly produced: ON with ϕ_3 and OFF with ϕ_1.

Data being received on the data highway is similarly converted to logic levels, and consists of a serial stream of up to two-thousand 80 bit words. One of these, the double marker, has two 10 bit prefixes all at state 1. These are used to synchronize the receiving logic.

The double-marker word contains a time-out value, class-of-service information and a highway test pattern, as shown in Table 1. The time-out value can be set from 2·84 s to 21·3 s in steps of 1·42 s. If the delay between incoming digits exceeds this programmed value, a forced-release is initiated. The value stored in each class-of-service location is used only if the register receives that particular class of service on its class-of-service input leads. It then inserts this programmed value at the end of a marked translation to indicate the class of service to an operator. The highway test pattern indicates to the register the translator from which the data was derived.

On detection of the double marker, and on condition that the error-detecting code *sum-check* (the last 8 bit of the word) agrees with the internally-generated code, the time-out and class-of-service information are stored.

The remainder of the data words have the format shown in Table 2; this consists of an address code, digits to indicate the number length, the number of digits to be omitted and the sending program to be selected, a translation code and an 8 bit sum-check code. In the idle state, a separate sum-check is generated for each data word received for comparison with the sum-check received from the translator. If two consecutive data words have incorrect sum-checks, a highway change-over signal is generated to select the secondary highway.

Seizure

Opto-electronic couplers are used to isolate -50 V line signals from the MOST logic levels. An anti-bounce circuit monitors the seizure conditions, and successful detection of these results in the connexion of dial tone.

Pulsing-In

Pulses are received in the form of breaks in an earth condition on an input lead. Each BREAK period is converted into the state 0 condition. A break has to be present continuously for 5 ms to be recognized. The detection of the first BREAK pulse causes dial tone to be disconnected.

Subsequent BREAK pulses are detected and counted until a MAKE period of longer than 150 ms is received; this is recognized as an IDP. The count of pulses is then stored as a complete digit. Subsequent digits are stored in a similar manner.

If the IDP exceeds the time-out value stored from the double-marker word, a forced-release condition is applied to the first code-selector.

Comparison

The address code contained in each of the 1999 words (all words except the double marker) on the data highway is compared with the incoming code digits as they are transferred into the store. Stored (data-highway) address codes are terminated in digit X (binary 15) unless they consist of the maximum 6 digits.

Comparison between the stored incoming digits and the translation address-codes is commenced from the first double marker following the receipt of the first stored digit. Comparison ceases on any store cycle when either a partial or complete comparison is achieved.

A partial comparison occurs when the stored digit(s) agrees with the comparable digits in the translation address-code but the subsequent digit in the translation address-code is not X. This is applicable only to the first 5 digits, as a full comparison must exist after the receipt of 6 digits.

A complete comparison occurs when the stored digit(s) agree with the comparable digits in the translation address-code, and the subsequent digit in the translation address-code is X.

TABLE 4
Code Expansion

Store Location	Address Code
(*i*)	23XX
(*ii*)	2344X
(*iii*)	2345X
(*iv*)	234X
(*v*)	2X
Digit(s) Received	Result of Comparison
2	Partial at (*i*)
23	Partial at (*i*)
234	Partial at (*ii*)
2345	Complete at (*iii*)
or 2346	Complete at (*iv*)
or 24	Complete at (*v*)

This method of comparison allows code expansion to be achieved with the use of one extra store location for each expansion. For example, to expand the code 234 to route codes 2344 and 2345, the address codes would be written in the store as shown in Table 4.

The 2X location would normally have a blank translation, which is recognized by the register as a spare code. This facility is used to obviate writing-in all the unused codes. (If the register recognizes two double markers without having a comparison of either type, a forced release is initiated).

Following complete comparison, the number length, omit-digits program, sending program and translation digits associated with compared address are stored. The register starts to pulse-out as soon as the translation has been stored in accordance with these instructions.

CONCLUSION

This article has described the design principles and main traffic-handling aspects of the system; Part 2 will describe the built-in fault-reporting, maintenance and call-accounting facilities, the traffic-metering and state-of-call information systems, and the methods of loading translation information.

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[1] HOOKER, D. S., and DUNN, R. T. A New Register-Translator using Stored-Program Control for Director-Area Local Exchanges. *POEEJ*, Vol. 67, p. 181, Oct. 1974.

[2] REYNOLDS, F. M., and MORTON, W. D. Metal-Oxide Semconductor (MOS) Integrated Circuits. *POEEJ*, Vol. 62, p. 168, Oct. 1969 and Vol. 63, p. 105, July 1970.

[3] LOCK, P. J., and SCOTT, W. L. The Regenerator 5A—A Microelectronic Project for Strowger Exchanges. *POEEJ*, Vol. 71, p. 110, July 1978.

Institution of Post Office Electrical Engineers

General Secretary: Mr R. E. Farr, THQ/NP9.5.4, Room S 04, River Plate House, Finsbury Circus, London EC2M 7LY; Tel. 01-432 1954
(Membership and other local enquiries should be directed to the appropriate Local-Centre Secretary as listed in the Oct. 1979 issue)

THE FEDERATION OF TELECOMMUNICATIONS ENGINEERS OF THE EUROPEAN COMMUNITY (FITCE)

The modified proposals for the terms of IPOEE association with FITCE, referred to in the October 1979 issue of the *Journal*, were endorsed by a special meeting of Council in August 1979 and subsequently presented to the FITCE Executive Committee at a meeting in Dublin.

In essence these proposals are that:

(*a*) IPOEE Members of EE level (and those listed as equivalent in Rule 5.1a) and above shall be eligible to join FITCE without the need for a personal qualification during a period of six months following the agreement of the terms of IPOEE entry by the FITCE General Assembly. After the expiry of this period, any such member wishing to join FITCE would need an appropriate university or equivalent qualification.

(*b*) IPOEE Members of AEE level (and those listed as equivalent in Rule 5.1b) and Affiliated Members would only be eligible to join FITCE if they have an appropriate qualification.

(*c*) IPOEE will define the qualifications to be considered as equivalent to a university degree for FITCE purposes; for example, membership of an appropriate professional institution.

As expected, representatives of some other national associations voiced their concern at the prospect of IPOEE members being allowed to join FITCE without the prescribed university or equivalent qualification, but the Executive Committee nevertheless agreed that each member national association should consider the proposals and report acceptance or otherwise at the next meeting.

The IPOEE must now await a response from the FITCE Executive Committee.

R. E. Farr
Secretary

Notes and Comments

CORRESPONDENCE

Northern Ireland Postal and
Telecommunications Board

Dear Sir,

I have read with interest the Presidential Message on page 73 of the July issue of the *Journal* on the future of engineering in the British Post Office, but was disappointed not to see reference to external professional qualifications as awarded by the Council of Engineering Institutions and its constituent bodies. Perhaps the President could expand on this point.

Younger graduate engineers view with some concern the increasing standards and changing requirements of the Institution of Electrical Engineers, particularly the apparent emphasis on "innovation" as a prerequisite for membership.

The role of the Technician Engineers Institutions is another area for discussion, particularly as this style of qualification is relatively new.

The application to join the Federation of Telecommunications Engineers of the European Community (FITCE), reported in the same issue of the *Journal* by the Secretary of this Institution, is also affected by the external view of engineering professionalism within the BPO. A senior FITCE member explained to me some years ago that the lack of general academic qualification standards for ranks within the BPO could preclude a blanket offer of membership, irrespective of the proven ability of individual BPO employees.

The extent to which an engineering post includes the opportunity to carry responsibility and gain experience qualifying for corporate membership of a chartered institution or FITCE is perhaps the least of BPO worries as restructuring is considered, but members of this Institution should be interested in this topic and this *Journal* could provide a discussion forum away from the hurly-burly of the industrial-relations market place.

Yours faithfully,
A. D. Gowdy

The President replies: I have read Mr. Gowdy's letter with interest and he raises some important issues. In my message, I referred to the continuing need for a sound professional approach to our engineering work and, in principle, I strongly support the establishment and maintenance of professional standards and ethics through membership of the appropriate institutions. In my view it is one of the responsibilities of middle and senior professional engineers to provide the supervision and guidance necessary for their younger colleagues to achieve corporate membership of their institution.

Mr. Gowdy expresses concern at the rising standards required of younger graduates. We need to be cautious about suggestions that might reverse this trend. We live in a world of rapidly growing complexity and Britain is trying to secure an increased share of trade in an highly competitive world market, much of which depends on high technology. For our efforts to be successful depends on many factors, but not least is the skill and professionalism of our engineers. The standards we have set in the UK in the past have tended to lag behind those set in some other countries in Europe, so I do not feel we can be complacent.

As members of this Institution will know, there is at present an enquiry into the engineering profession under way, and its Chairman, Sir Monty Finneston, is due to publish his report very soon. With this report imminent I think it would be inappropriate for me to comment in detail, but I shall be very surprised if the report suggests any diminution of standards of professional education and qualification. "Success through excellence" would be an appropriate motto for the engineering profession, the British Post Office and, indeed, the country.

Yours faithfully,
J. S. Whyte

Publication of Correspondence

The Board of Editors would like to publish correspondence on engineering, technical or other aspects of articles published in the *Journal*, or on related topics. Letters of sufficient interest will be published under Notes and Comments.

Letters intended for publication should be sent to the Managing Editor, The Post Office Electrical Engineers' Journal, NE/P12, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

POST OFFICE TELECOMMUNICATIONS MUSEUM

As reported in the last issue of the *Journal*, the new Post Office Telecommunications Museum is to include an archives section. To this end, the curator is seeking copies of IPOEE printed papers ("Red Papers"). The particular papers missing from his collection are numbers 22–24, 26–28, 30–33, 35–47, 50–56, 58–59, 62, 64, 66–68, 71, 75–76, 81, 84, 86–89, 91–95, 99, 104, 106, 126, 149–151, 164 and 209. Anyone having copies of these papers which they would be willing to donate to the museum should contact the curator on 01-622 2378 before sending them.

CONTRIBUTIONS TO THE JOURNAL

Contributions to the *POEEJ* are always welcome. In particular, the Board of Editors would like to reaffirm its desire to continue to receive contributions from Regions and Areas, and from those Headquarters departments that are traditionally modest about their work.

Anyone who feels that he or she could contribute an article (short or long) of technical, managerial or general interest to engineers in the Post Office is invited to contact the Managing Editor at the address given below. The editors will always be pleased to give advice and try to arrange for help with the preparation of an article, if needed.

Guidance for Authors

Some guiding notes are available to authors to help them prepare manuscripts of *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal*'s editors, printer and illustrators, and help ensure that authors' wishes are easily interpreted. Any author preparing an article is invited to write to the Managing Editor, at the address given below, to obtain a copy.

All contributions to the *Journal*, including those for Associate Section Notes, must be typed, *with double spacing between lines*, on one side only of each sheet of paper.

As a guide, there are about 750 words to a page, allowing for illustrations, and the average length of an article is about 6 pages, although shorter articles are welcome. Contributions should preferably be illustrated by photographs, diagrams or sketches. Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that is required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour prints and slides can be accepted for black-and-white reproduction. Negatives are not required.

It is important that approval for publication is given at organizational level 5 (that is, at General Manager/Regional Controller/THQ Head of Division level) and authors should seek approval, through supervising officers if appropriate, before submitting manuscripts.

Contributions should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NE/P12, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

APOLOGY

On behalf of the printers, the Board of Editors wishes to apologize for the quality of reproduction of the October 1979 issue, which fell below the standard which it is aimed to achieve.

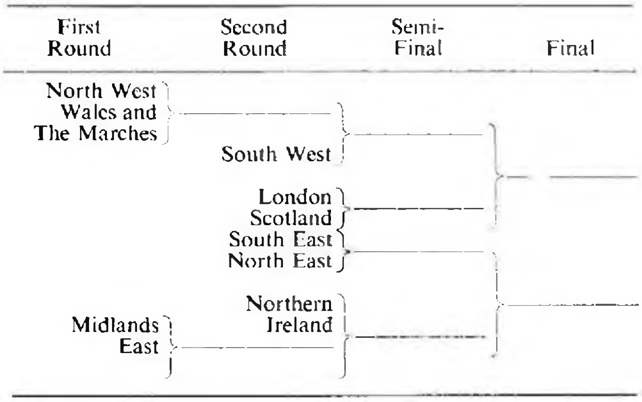
The Associate Section National Committee Report

MEETINGS

Since the annual conference, two meetings of the National Executive Committee have been held. In addition, the Chairman, Treasurer and Secretary met the Secretary of the Institution, Mr. R. Farr. This was a very useful meeting and the topics discussed included the financial state of the National Committee, the lack of support for the papers' awards, the certificate of registration, insurance, revision of Telecommunications Instruction M2 F0010, non-affiliated centres and the Technician Education Council.

NATIONAL TECHNICAL QUIZ

The draw for the 1979–80 technical quiz is as follows:



The final will take place at the Institution of Electrical Engineers, Savoy Place, London on 25 April 1980 when the Bray, E. W. Fudge and Cotswold trophies will be presented. The guest of honour will be Mr. R. E. G. Back, Senior Director of the Network Executive.

TECHNICAL VISITS ABROAD

It has become apparent that some centres, and certainly individuals, make visits abroad during which they visit establishments of technical interest. It was suggested at the recent Regional Liaison Officers' conference that the National Committee Visits Secretary should compile a directory of contacts so that information would be available for those wishing to make such visits in the future. Therefore, if you have had an interesting visit of a technical nature, please contact Joe Anning, EIM1, Telephone Exchange, Westhill Road, Torquay, Devon TQ1 4NT, or telephone 0803 35113, and give him any information available.

ITEMS FOR SALE

I have been asked to announce once again those items that are available for purchase. The items normally available are key fobs, lapel badges, car stickers, ties, diaries and honorary membership scrolls.

It has been suggested that the design of the tie should be updated, and this will be discussed at the annual conference.

M. E. Dibden
Secretary

Associate Section Note

EDINBURGH CENTRE

The programme for the 1978–79 session has now been completed and the talks and visits which were arranged by the Centre were well attended.

The session opened with our annual golf outing to West Linton. This event is very successful each year, and members enjoy themselves while competing for our two trophies. A visit to the Global Seismology Department of the Institute of Geological Studies in Edinburgh included a talk on the department's work and equipment. As all the data was recorded on a computer, we were able to see print-outs showing details of recent earthquakes around the world.

On a visit to the Mine Rescue Station at Coatbridge, all aspects of mine safety and rescue equipment were explained to the members present. Members combined with the Aberdeen and Dundee centres for a talk on System X, given at Perth by a member of staff from Telecommunications Headquarters.

Another visit was to Surgeons' Hall in Edinburgh, where specimens, beautifully preserved and displayed, of many types of ailments were seen.

This year, the quiz team was unfortunately beaten by Inverness in a close contest in the first round. In future, quiz teams in the Region will be competing for a Regional Trophy.

A. Johnstone

Forthcoming Conferences

Further details can be obtained from the conference department of the organizing body.

Institution of Electrical Engineers, Savoy Place, London WC2R 0BL. Telephone: 01-240 1871

Submarine Telecommunications Systems
26–29 February 1980
The Institution of Electrical Engineers, London

Communications 80: Communications Equipment and Systems
15–18 April 1980
National Exhibition Centre, Birmingham

Secretariat 1980 International Zurich Seminar, Miss D. Hugg, Dept. ENF, BBC Brown, Boveri and Co. Ltd., CH-5401 Baden, Switzerland. Telephone: +41-56-299038.

International Zurich Seminar on Digital Communications (Digital Transmission in Wireless Systems)
4–6 March 1980
Swiss Federal Institute of Technology

The Post Office Electrical Engineers' Journal

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The Board of Editors is not responsible for the statements made nor the opinions expressed in any of the articles or correspondence in this *Journal*, unless any such statement is made specifically by the Board.

Subscriptions and Back Numbers

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The price to British Post Office staff is 48p per copy.

Back numbers will be supplied if available, price 70p (£1.05 including postage and packaging). At present, copies are available of all issues from April 1974 to date with the exception of the April and October 1975 issues; copies of the July 1970 and April and October 1973 issues are also still available.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.

Employees of the British Post Office can obtain the *Journal* through local agents.

Binding

Readers can have their copies bound at a cost of £5·25, including return postage, by sending the complete set of parts, with a remittance, to Press Binders Ltd., 4 Iliffe Yard, London SE17 3QA.

Remittances

Remittances for all items (except binding) should be made payable to "*The POEE Journal*" and should be crossed "& Co."

Advertisements

All enquiries relating to advertisement space reservations should be addressed to The Advertising Manager, *Post Office Electrical Engineers' Journal*, Kemps Publications Ltd., Federation House, 2309 Coventry Road, Sheldon, Birmingham, B26 3PG, (Telephone: 021-742 4471).

Advertisement copy should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NE/P12, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Distribution and Sales

Correspondence relating to the distribution and sale of the *Journal* should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG.

Communications

With the exceptions indicated above, all communications should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NE/P12, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY (telephone 01-432 4840).

Model-Answer Books

Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Copies of the syllabi and question papers are not sold by *The Post Office Electrical Engineers' Journal*, but may be purchased from the Department of Technology, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

INDEX TO ADVERTISERS

Advertisements

Communications, advertisement copy, etc., should be addressed as shown on p. 275 of the *Journal.*

No responsibility is accepted by the Journal for any of the private or trade advertisements included in this publication.

GEC Telecommunications Ltd.	*7*
Herman Smith Ltd.	*6*
Mullard Ltd.	*4*
Thorn Ericsson	*1*
Viking Alloys Ltd.	*3*
Walton Electronics Ltd.	*2*
Whipp & Bourne Ltd.	*2*

IPOEE CENTRAL LIBRARY

Any member who does not have a copy of the catalogue can obtain one on loan from the Librarian, IPOEE, 2–12 Gresham Street, London EC2V 7AG. Library requisition forms are also available from the Librarian, from honorary local-centre secretaries, and from Associate Section centre secretaries and representatives.

Alternatively, the panel below, or a photocopy, can be used (only by members) to borrow any book listed in the catalogue or in the updating lists published in recent issues of the *POEEJ*. The form should be sent to the Librarian at the address above; a self-addressed label must be enclosed.

IPOEE Central Library

LIBRARY REQUISITION FORM

For use only by members of the Institution of Post Office Electrical Engineers

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....

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Official Address ....

MODEL ANSWERS

CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS FOR THE TELECOMMUNICATIONS TECHNICIANS' COURSE

Back numbers of the *POEEJ* are available, complete with model-answer Supplements containing model answers to past examinations of the City and Guilds of London Institute Telecommunication Technicians' Course. A list of those available, showing the examinations covered in the respective model-answer Supplements, can be obtained by writing to *The Post Office Electrical Engineers' Journal*, Room S 09, River Plate House, Finsbury Circus, London EC2M 7LY.

MODEL ANSWER BOOKS

A series of 6 model-answer books is also available, in which selected answers from past examinations have been collected together to cover the following subjects.

	Price (post paid)
Elementary Telecommunication Practice	60p
Telecommunication Principles A	£1.00
Line Plant Practice A	60p
Radio and Line Transmission A	85p
Telephony and Telegraphy A	85p
Telecommunication Principles B	£1.00

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG. Cheques and postal orders, payable to "*The POEE Journal*", should be crossed "& Co." and enclosed with the order. Cash should not be sent through the post.

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