# The Post Office Electrical Engineers' Journal

VOL 69 PART 4 JANUARY 1977

# THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

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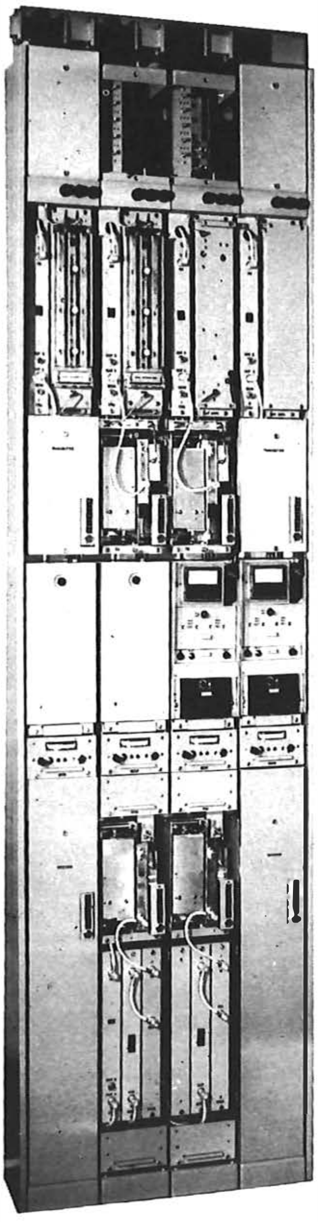

Four 6.8 GHz equipment racks.
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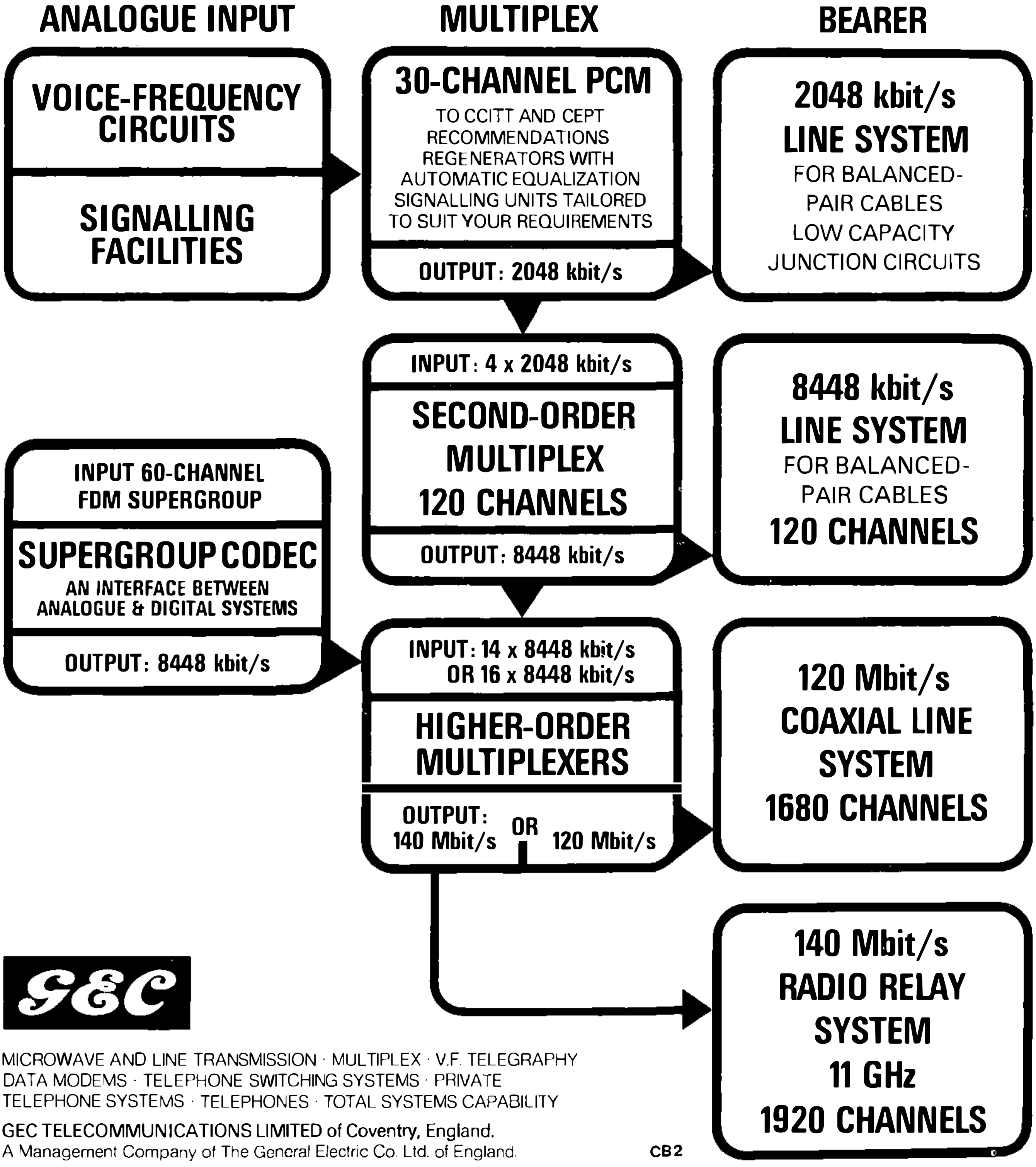

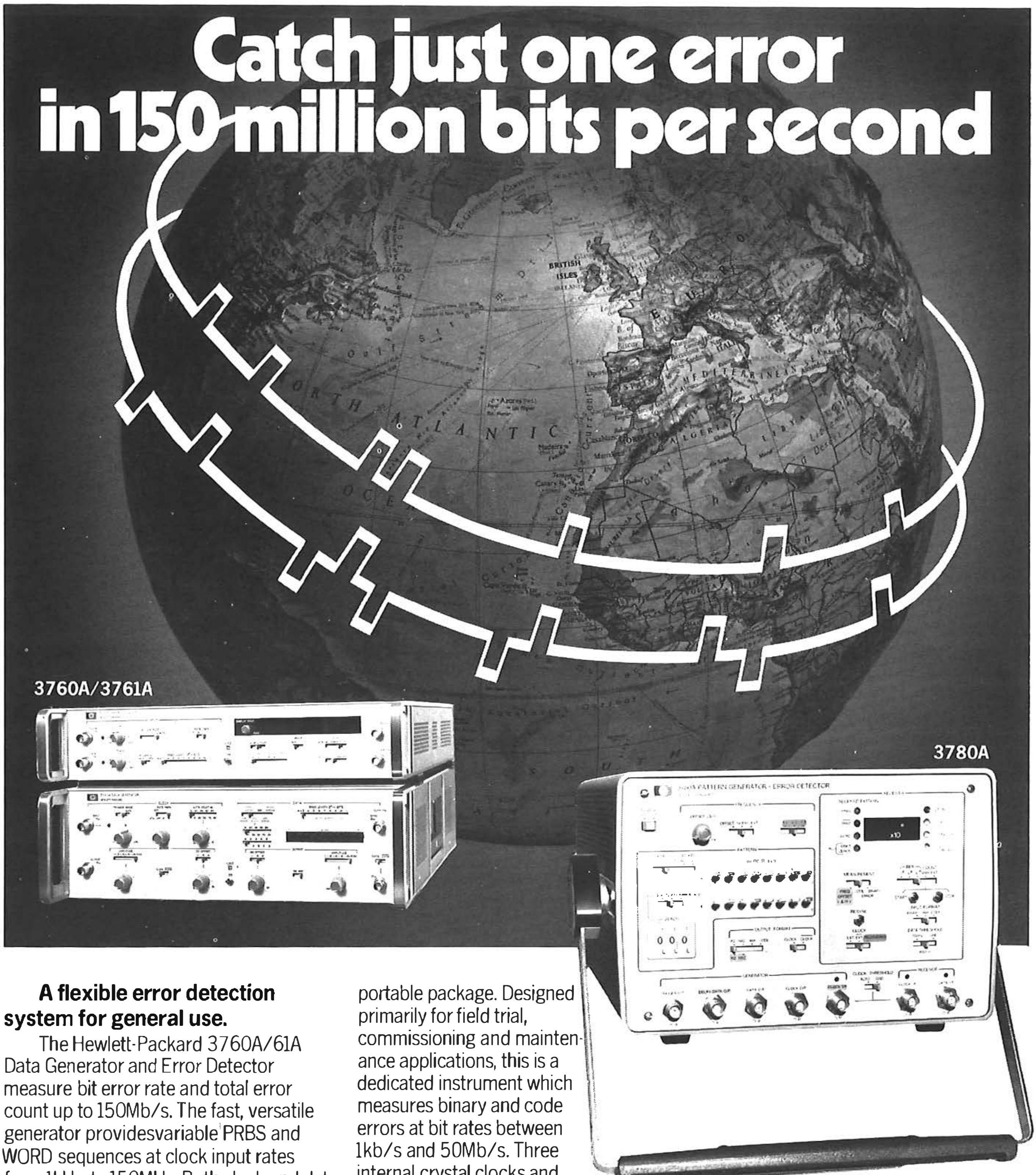
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# The Post Office Electrical Engineers' Journal

## EDITORIAL

An international conference on Millimetric Waveguide Systems, arranged by the Institution of Electrical Engineers, was held in London on 9–12 November 1976. Delegates attending this conference from all over the world were invited to a demonstration of the British Post Office (BPO) waveguide system presented at the Martlesham Research Centre. This 14 km long waveguide system between Martlesham and Wickham Market has been on field trial for the past year, during which time its performance and reliability as a high-capacity low-cost transmission system has been established. The success of the field trial has led the BPO to evaluate plans for installing a 123 km 6-repeater waveguide system between Bristol and Reading. The waveguide system was produced jointly by the BPO and British industry, and plans are being made to offer the waveguide for export, industry producing the waveguide and terminal equipment and the BPO acting as consultants.

Previous articles in the April 1976 and July 1976 issues of the *Journal* have outlined the current situation with regard to waveguide systems, and described in detail the design and the methods of production and installation of the waveguide itself. In this issue of the *Journal*, a detailed description of the terminal and repeater equipment is included.

It is now over 10 years since the first production electronic exchange was opened by the BPO. Since this first TXE2 exchange came into service at Ambergate, Derbyshire, in 1966, more than 800 TXE2 exchanges have been installed, and there has been a progressive development of the original TXE2 concept to cater for the changing needs of the expanding BPO network. The evolution from the original (Mark 1) TXE2 exchange to the current (Mark 3) system is also described in this issue.

# TXE2 Electronic Exchange System: The Evolution from Mark 1 to Mark 3

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UDC 621.395.722

*This article describes the progressive development of the TXE2 reed-electronic exchange system which, together with the TXE4 exchange, is playing a major role in the modernization of the national telephone network. The evolution from the Mark 1 to the Mark 3 exchange is described, together with the reasons that necessitated further development of the original system.*

## INTRODUCTION

The reed-electronic local-exchange system, designated *TXE2*, was introduced into the British Post Office (BPO) telephone network in 1966 and, to date, more than 800 exchanges of the same generic type have been installed. Continued expansion of the national telephone network has necessitated the progressive development of the original TXE2 concept. Today, Mark 3 TXE2 exchanges offer greater telephone traffic capacity, an increased number of subscriber connexions and enhanced system security, when compared with the Mark 1 exchanges. This article outlines the operational requirements that led to the progression from the original (Mark 1) TXE2 to the current (Mark 3) exchange, and examines the differences between them. Earlier articles[1,2] have described the design philosophy and physical realization of the Mark 1 and 2 exchanges, but, to facilitate an appreciation of the Mark 3 exchange, a brief recapitulation of the early TXE2 development phases is given.

## MARK 1 TXE2 EXCHANGES

Mark 1 exchanges, the first of which was installed at Ambergate, Derbyshire, were the result of a successful collaborative development involving the BPO and the principal exchange equipment suppliers.* The manufacture and supply of TXE2 exchanges to the BPO is currently undertaken by the General Electric Company Limited (GEC), Plessey Telecommunications Limited (PTL) and Standard Telephones and Cables Limited (STC). Mark 1 TXE2 exchanges provide for up to 2400 subscriber connexions and were designed to replace small local non-director exchanges functioning within self-contained numbering schemes.‡ Early in the TXE2 installation programme, modification of the exchange system became necessary to allow wider use as a satellite exchange in linked numbering schemes.** Modifications to the common-control equipment and register were necessary to allow TXE2 exchanges to function in linked as well as self-contained numbering schemes. The modified exchange, providing for up to 4200 subscriber connexions, was designated the *Mark 2 TXE2*.

## MARK 2 TXE2 EXCHANGES

Mark 2 TXE2 exchanges were designed to serve small local communities that would ultimately need no more than 4200 subscriber connexions, with not more than 40% shared service, and having a low calling-rate; typically, a bothway traffic of 0·06 erlang. Expansion of some of these communities was much greater than expected and these high rates of growth meant that the ultimate capacity of the exchange was exceeded prematurely. In most cases, the limiting factor was subscriber connexions, but, in some cases, the traffic handling capacity proved inadequate. Where there was a demand for additional subscriber connexions, increased traffic capacity, or both, a second TXE2 unit was installed in parallel with the existing one. There are 2 ways in which a second TXE2 unit can be connected to an existing unit, as shown in Figs. 1 and 2.

Cost studies have shown that D-linked working, shown in Fig. 1, is the more expensive of the 2 methods. The increased cost for a D-linked system is due to the additional equipment required to permit interworking between the 2 units. For a non D-linked configuration, shown in Fig. 2, each TXE2 unit is provided with exclusive incoming and outgoing junction routes and an individual numbering scheme identified by a different dialling code. Both configurations permit a doubling in subscriber connexions and offered traffic; a major disadvantage of the second method is the need for additional levels at the group switching centre.

To overcome the economic penalties associated with the double-unit working, the Mark 2 exchange was developed further. The development sought to remove the 2 principal deficiencies by meeting the requirement for additional subscriber connexions and increased traffic capacity, and resulted in the development of the Mark 3 TXE2 exchange. This enhanced TXE2 system provides for up to 7000 connexions (8400 subscribers at 20% shared-service provision). Additionally, switched traffic capacity has been increased to 450 erlangs for a single-unit exchange. (The Mark 3 exchange offered traffic capacity is 360 erlangs which generates 450 erlangs of traffic in the switching network.) The realization of the Mark 3 TXE2 exchange is described in detail in the next section.

One standard facility of the Mark 3 exchange can be provided retrospectively on the Mark 2 version. This is the provision of 3500 connexions per calling-number-generator (CNG) rack; the standard Mark 2 rack provided 3000

---

† Telecommunications Development Department, Telecommunications Headquarters

* Electronic exchange development took place under the auspices of the Joint Electronic Research Committee (JERC)

‡ In a self-contained numbering scheme, the dialling code for a particular exchange may vary from exchange to exchange within the local-call area

** In a linked numbering scheme, the same number is dialled to call a particular subscriber, irrespective of which exchange within the linked numbering scheme originates the call

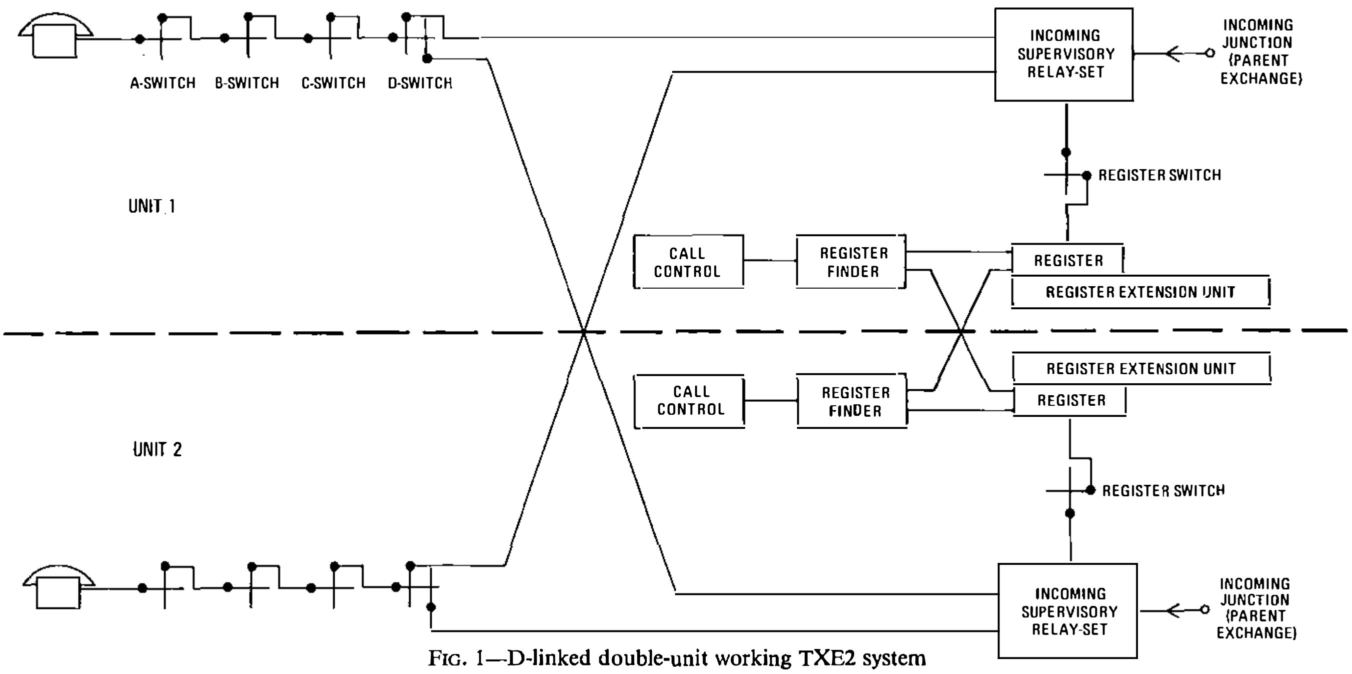


Fig. 1—D-linked double-unit working TXE2 system

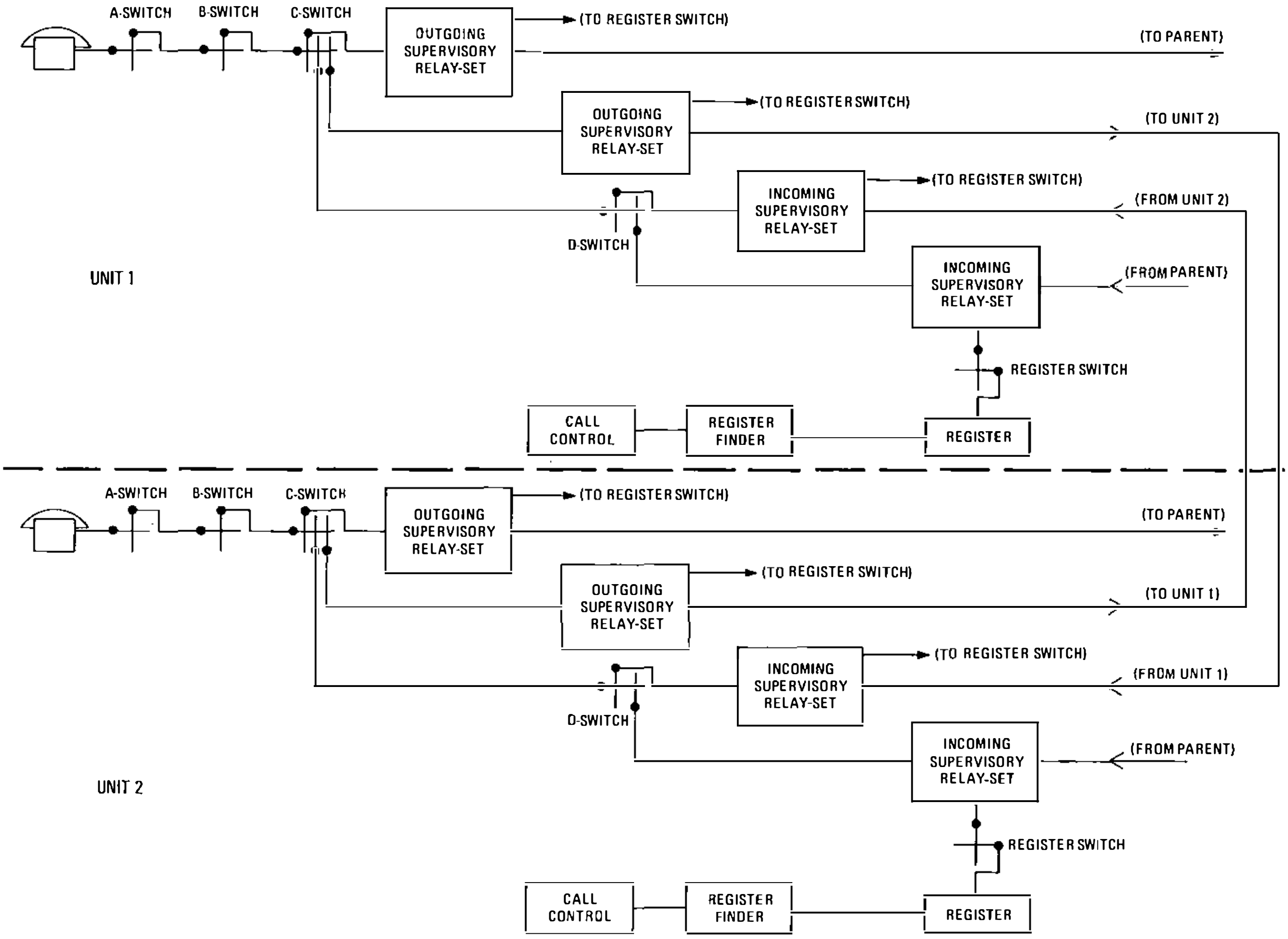


Fig. 2—Non D-linked double-unit working TXE2 system

connexions. Experience indicated that, in many cases, the fitting of one additional subscriber's-line-unit (SLU) rack, would provide a Mark 2 TXE2 with sufficient capacity for the design life; each SLU rack provides 500 connexions. If the seventh SLU rack could not be fitted, double-unit working became mandatory. Therefore, the TXE2 manufacturers were requested to amend rack-wiring information to allow the fitting of 7 SLU racks on Mark 2 exchanges, and this feature has been incorporated as a standard facility on Mark 3 exchanges.

## THE MARK 3 TXE2 SYSTEM

The Mark 3 TXE2 system has been designed to carry approximately 360 erlangs of offered traffic; equivalent to 450 erlangs of A–B link traffic with an average call-holding time of 2 min.

### Calling-Number Generation and Register Selection

With one CNG rack and one class-of-service rack, the exchange has a capacity for 3500 subscriber's line circuits, 220 incoming junctions and 5000 directory/engineering numbers. The addition of second CNG and class-of-service racks enables the above capacities to be doubled. To achieve these capacities, GEC and STC have jointly used different methods from PTL; however, in both cases, the basic TXE2 system philosophy has not changed. Where Mark 3 designs differ between manufacturers, the basic principles of both are described.

Traffic simulation studies of the earlier TXE2 systems showed that approximately 75% of lost incoming-junction calls were lost because the first call store in the CNG was engaged when the call occurred. The other lost incoming-junction calls were lost because the register connexion time exceeded 200 ms; that is, the remaining time in the inter-digital pause.

To overcome these traffic limitations, an additional call queueing store has been added, requiring the redesign of the CNG control. Figs. 3(*a*) and (*b*) illustrate the principle of the 2 methods used.

In Fig. 3(*a*), an additional first call store is provided, so that this new system has 2 parallel first call stores (call stores 1A and 1B), which accept alternate calls offered to the exchange. Having accepted a call into a first call store, the CNG control detects whether the second call store (call store 2) is free or busy. When the second call store is free, the CNG control transfers the call to it and resets the first call store. The register selector is instructed by the CNG control to choose a free register, and the chosen register is connected to call store 2 for the call to be transferred to the register's store. On completion of the transfer, the register is disconnected from call store 2, which is then reset by the CNG control.

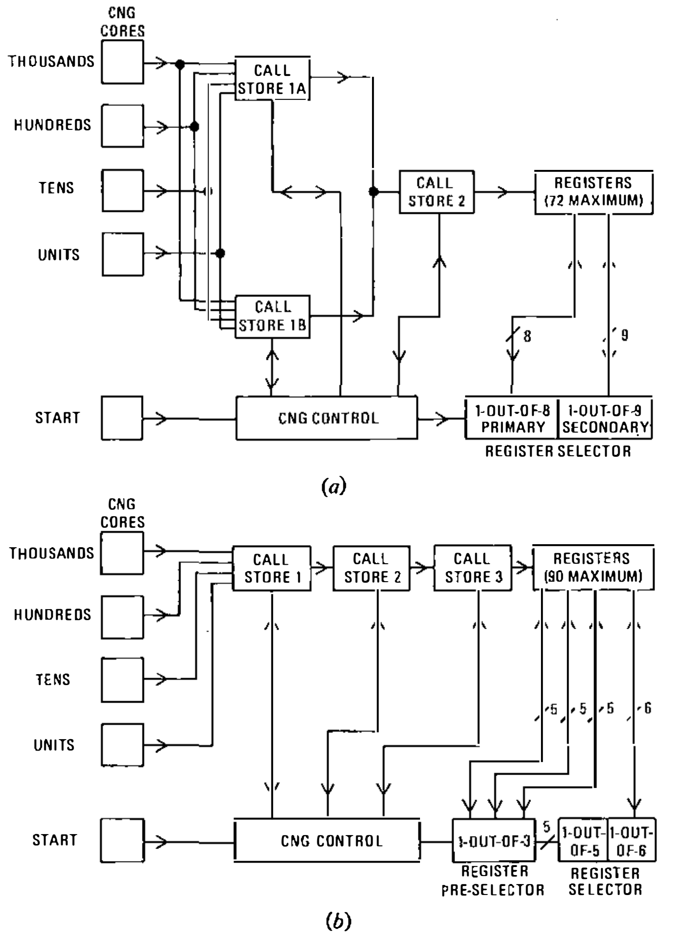
In Fig. 3(*b*), call store 3 is additional, so that this new system has 3 serial call-queueing stores. The CNG control is informed when call store 1 has received a call, and sends instructions to the stores to transfer the call to call store 2 and reset call store 1. If call store 3 is free, the call is transferred to it and the second store is reset. The CNG control instructs the register selector to choose a free register, which is connected to call store 3 for transfer of the call to the register store. On completion of this transfer, call store 3 is reset and the register disconnected from it.

These CNGs enable more calls to pass into the system; that is, an approximate maximum of 12 400 call-demands/h, compared with 6400 call-demands/h for the earlier versions of the system.

The increased traffic capacity of the CNG equipment permits a larger number of call demands on the system main control. The critical occupancy for a TXE2 main control depends upon the traffic mix, but is typically 0·4 erlang. The occupancy of the main control in a full-size Mark 2 TXE2 exchange is 0·2 erlang and, for a Mark 3 TXE2 exchange 0·3 erlang, so there is sufficient spare capacity to deal with the increased demands without change.

Increased call demands revealed that the previous maximum of 30 registers must be increased. This is achieved by modifying the register selector and finder equipments. The earlier register selectors and finders consisted of a 2-stage selector, comprising a 1-out-of-5 primary stage and a 1-out-of-6 secondary stage.

One method used to increase the maximum register provision is to replace the existing register selectors and finders with larger stages; that is, a 1-out-of-8 primary stage and a 1-out-of-9 secondary stage. This method enables a Mark 3 TXE2 exchange to be equipped with a maximum of 72 registers, and is shown in Fig. 3(*a*).



CNG—Calling-number generator

FIG. 3—Calling-number generation and register selection

The second method used to increase the register provision is to add a third stage (known as *pre-selector* and *pre-finder*) of 1-out-of-3 to the existing 1-out-of-5 primary and 1-out-of-6 secondary register selectors and finders. This method enables a Mark 3 TXE2 exchange to be equipped with a maximum of 90 registers. Fig. 3(*b*) illustrates this method of register selection.

To generate the higher traffic, it must be possible to connect more subscribers to the exchange. This required redesign of the CNG rack to increase the subscriber's line circuit capacity from 3000 to 3500 and enable a second CNG rack to be added. A Mark 3 TXE2 exchange can accommodate a maximum of 7000 subscriber's line circuits and 440 incoming-supervisory relay-sets. The additional subscribers and incoming junctions require the exchange to have a larger number capacity. The number capacity of the class-of-service rack has been increased from 4000 to 5000 by redesigning the rack layout to accommodate 10 additional final decoder units; one unit decodes 100 numbers. A Mark 3 exchange, with 2 class-of-service racks, can provide a maximum of 10 000 directory/engineering numbers.

### Sectioning of the Switching Network

To carry 450 erlangs of A–B link traffic, the size of the switching network has been increased from 10 majors† for a

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† A major consists of all the A-switches in 3 A-switch groups, plus the 5 associated B-switches (as shown in Fig. 7) and 5 inlets of each of the 10 C-switches

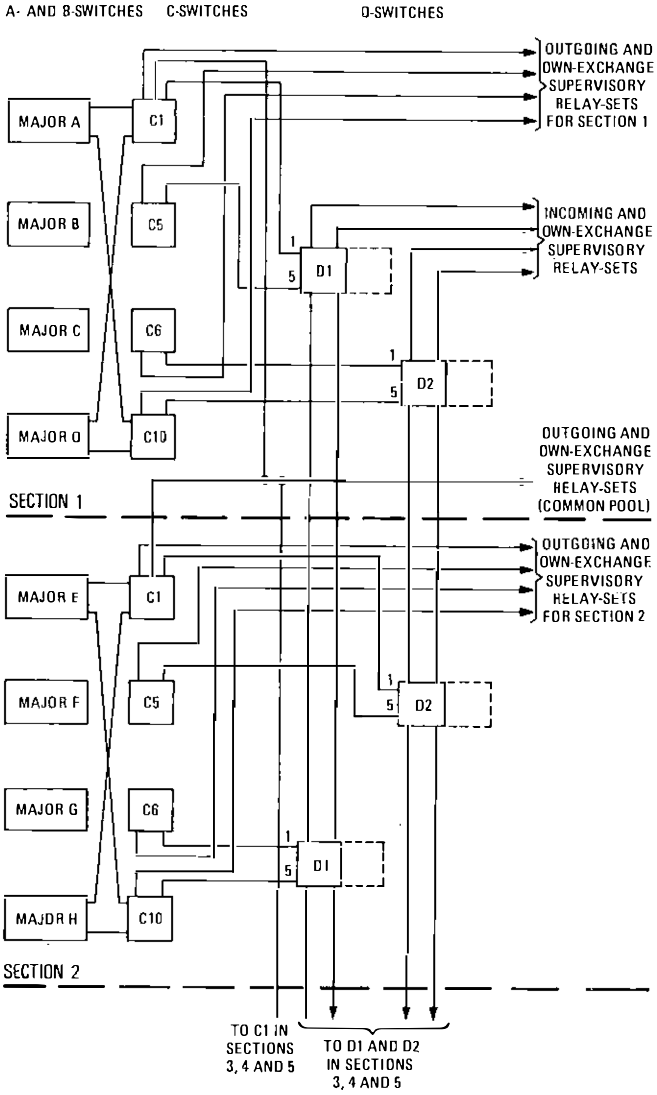


Fig. 4—Sectioned switching network

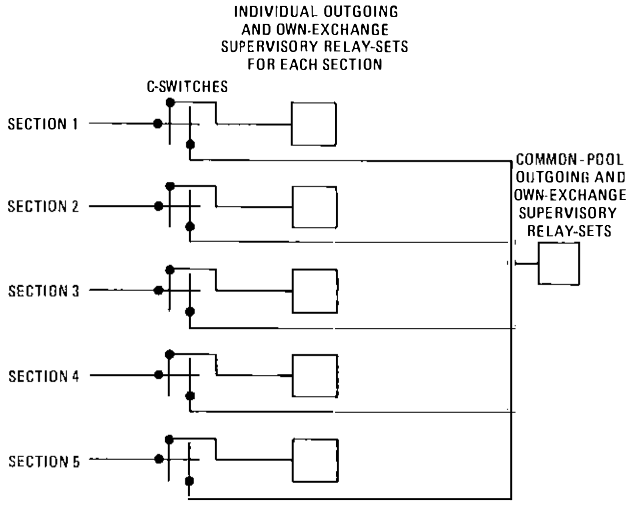


Fig. 5—Individual and common-pool supervisory relay-sets

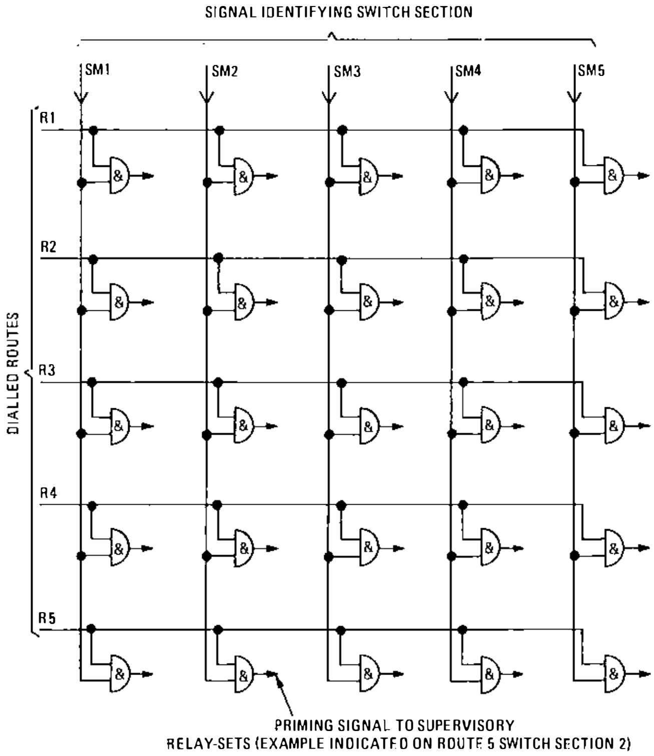


Fig. 6—Part of new route-selection equipment

Mark 2 TXE2 exchange to 20 majors for a Mark 3. All previous TXE2 systems were equipped with 10 C-switches. Because the C-switches grow in 2 dimensions (inlets and outlets) as the exchange traffic increases, the 10 C-switches of a 20-major exchange would be very large. Large matrix switches are both costly and inefficient; therefore, to reduce the cost and increase the efficiency of the C-switches, the switching networks of Mark 3 TXE2 exchanges are sectioned. Fig. 4 shows 2 sections of a Mark 3 switching network. Each section has its own associated 10 C-switches, which are limited in size because a section is restricted to a maximum of 4 majors. A full-size Mark 3 TXE2 exchange is equipped with 20 majors, divided into 5 sections, and has a total of 50 C-switches.

Sectioning the switching network produces very large savings in C-switch reed relays; a 20-major exchange not sectioned would require approximately 70 000 reed relays for the 10 C-switches, whereas an equivalent 5-section exchange requires approximately 15 000 reed relays for the 50 C-switches. However, sectioning introduces the following disadvantages.

(*a*) Larger, and therefore more costly, D-switches are required to enable every incoming and own-exchange supervisory relay-set to obtain connexion to every subscriber. D-switches must have outlets to C-switches in all switch sections. The size of the D-switches, therefore, increases as the exchange grows and the number of switch sections increases; this is illustrated in Fig. 4. In a single-section exchange, each D-switch requires 5 outlets to C-switches, whereas each D-switch in a 5-section exchange requires 25 outlets.

(*b*) A larger total number of outgoing and own-exchange supervisory relay-sets is required for a sectioned exchange than for an equivalent non-sectioned exchange This is because a separate group of supervisory relay-sets is required for each switch section. The increase in the number of supervisory relay-sets is minimized in Mark 3 TXE2 exchanges by providing a second choice or overflow group known as a *common pool*. As shown in Fig. 5, the common-pool supervisory relay-sets are available to subscribers in all switch sections, but are used only when all the supervisory relay-sets of the required type available to the section are busy.

The additional cost of larger D-switches, plus the cost of additional supervisory relay-sets, is small compared with the cost savings obtained by reducing the size of C-switches. However, it is expensive to section the supervisory relay-sets on junction routes carrying less than 40 erlangs. For such

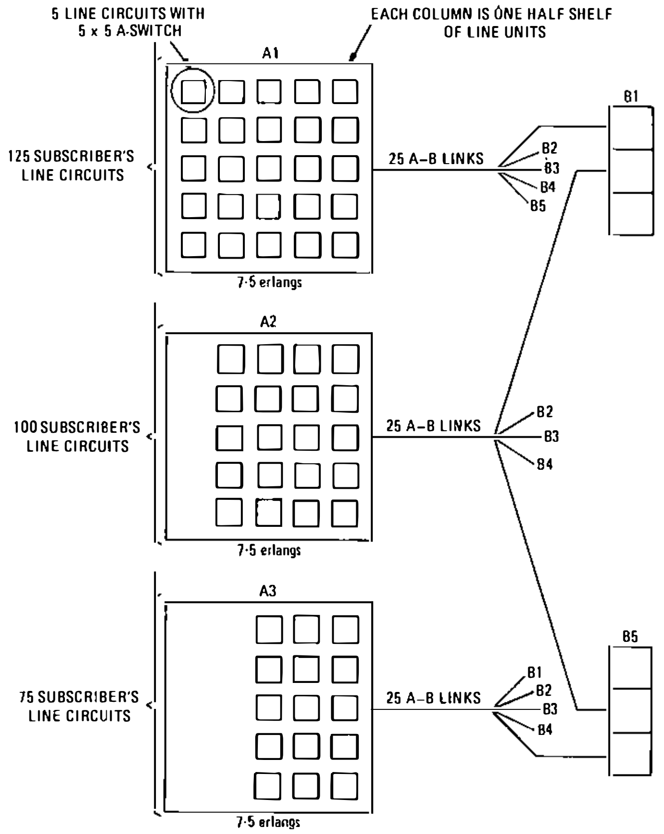


Fig. 7—Three sizes of A-switch group available on Mark 1 and 2 TXE2 exchanges

routes, the C-switch outlets from each switch section are commoned together and connected to a common pool of supervisory relay-sets.

Junction routes carrying more than 40 erlangs have sectioned and common-pool supervisory relay-sets, which required the redesign of the route-selection equipment. The new route-selection equipment is required to prime supervisory relay-sets, not only on the required route, but also on the required switch section. Fig. 6 shows that the required supervisory relay-sets are primed by applying the route and section information to a matrix. If all the supervisory relay-sets on the required route and section are busy, the route-selection equipment then primes the common-pool supervisory relay-sets on the required route.

The 25 A–B links from each A-switch group can carry 7·5 erlangs of bothway traffic; so each A-switch group should be equipped with sufficient subscribers to produce this quantity of A–B link traffic. Prior to development of the Mark 3 TXE2 exchange, only 3 sizes of A-switch groups were available on the SLU racks. These provided for A-switch groups of 75, 100 and 125 subscriber's line circuits, as illustrated in Fig. 7. This limited flexibility in the number of subscriber's line circuits that could be connected to an A-switch group often resulted in under-loading of the A–B links and, consequently, inefficient use of equipment.

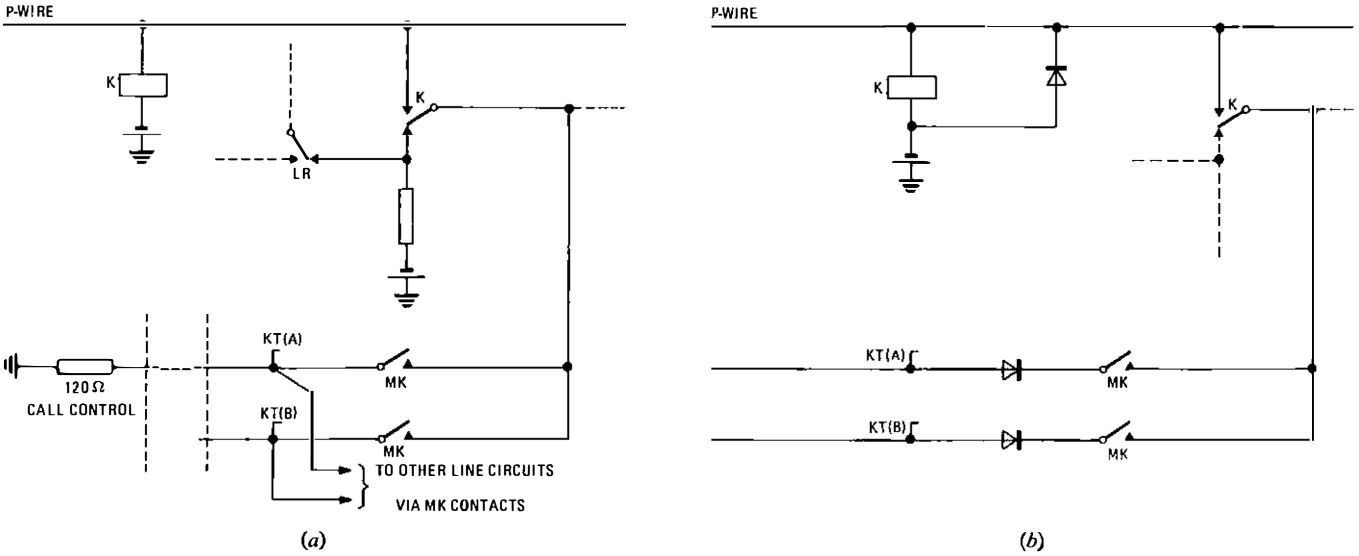
This limited flexibility has been overcome by the introduction of the variable SLU rack, on which A-switch groups can be equipped with a range of subscriber's line circuits from 25–500 in increments of 25. The variable SLU rack not only enables a large number of different A-switch group sizes to be obtained when the exchange is installed, but also permits the group sizes to be varied during the life of an exchange to cater for changes in the traffic pattern. The design of the variable SLU rack enables A-switch groups to be formed from half shelves (consisting of 25 subscriber's line circuits) and multiples of half shelves of subscriber's line circuits located on different racks.

## TXE2 SYSTEM SERVICE SECURITY

Security is the ability to maintain continuous service in the presence of equipment malfunction. The TXE2 system contains various features designed specifically to ensure continuity of service in the presence of equipment faults. The features are applicable to all marks of TXE2 and include

(*a*) duplication of the control equipment,
(*b*) multiple paths through the switching network,
(*c*) path continuity checks,
(*d*) second-attempt call set-up,
(*e*) non-homing switch selections, and
(*f*) count of call set-up failures.

Compared with step-by-step control systems, common-control systems have an inherent weakness in that a fault in the control equipment can affect the whole system. In the TXE2 system, security is achieved by duplication of the control equipment, designated *security side A* and *security side B*. Reliability is further improved by dividing each

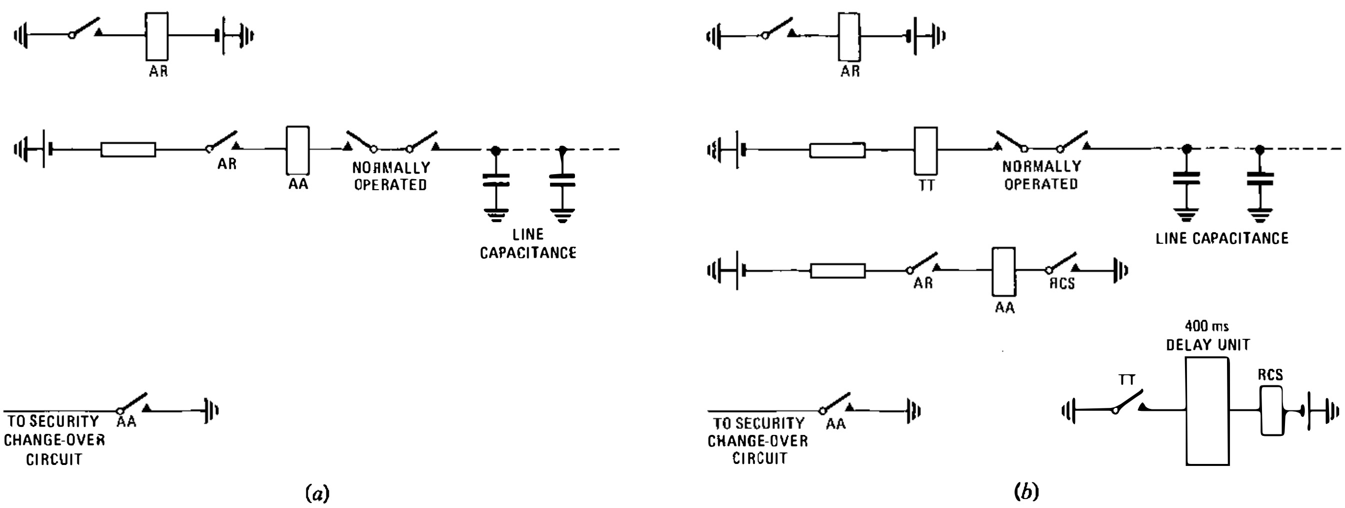


(*a*)

(*b*)

(*a*) Circuit of Mark 1 and 2 exchanges
(*b*) Revised circuit of Mark 3 exchanges

Fig. 8—Part of circuit for interrogating line circuit state



(*a*) Circuit of Mark 1 and 2 exchanges
(*b*) Revised circuit of Mark 3 exchanges

FIG. 9—Part of security change-over circuit

security side into 3 sections. Each security side is brought into service alternately, every 8 min, to prevent the possibility of unknown faults developing in idle equipment. If a fault occurs on one section of a security side, that section is locked out of service until the fault is cleared.

If more than 8 faults are recorded in the control equipment within one change-over period, automatic change-over results, with appropriate alarm conditions displayed on an indicating panel. Automatic repeat attempts are made via different switch paths after unsuccessful call set-ups.

After switching of the path crosspoints connecting the register to the subscriber's line circuit, a path-continuity check is performed by the register, to determine whether a continuous speech-pair connexion exists. This check is performed on every first-attempt originating call.

## TXE2 SYSTEM SERVICE SECURITY IMPROVEMENTS

Prior to development that enhanced the TXE2 system's capabilities, some 10 years of operational, planning and maintenance experience of the system had been gained. Improved knowledge and understanding of reed-relay contact performance under varying circuit conditions enabled a searching reappraisal of the system design to be considered. Assimilation of system fault reports and detailed investigation of circuit performance showed that the TXE2 system security could be improved by

(*a*) reducing the effect of single component failures by circuit rearrangement to alleviate component stress and prevent unwanted feedback paths,

(*b*) additional monitoring of pulse and control highways, and

(*c*) more precise automatic fault detection and indication, to prevent good equipment appearing faulty due to reflected faults.

### Examples of Security Improvements

Some detailed examples of the security improvements are given below.

(*a*) During call set-up to or from a subscriber's line circuit, the call control interrogates the line circuit to determine its state: free, busy or parked. This is achieved by a detector, which recognizes a voltage representing the appropriate line circuit state. Part of the circuitry is shown in Fig. 8(*a*); the KT(A) and KT(B) leads are connected to the call control, KT(A) to security side A and KT(B) to security side B. A condition can occur whereby a welded (short circuited) MK reed contact severely restricts outgoing and own-exchange traffic.

The problem has been minimized firstly by reducing the likelihood of the MK contact becoming short circuited and, secondly, by preventing any effect on the exchange if it becomes short circuited. Switching excessive currents (typically 1 A) causes arcing between the reed contact blades, which tends to weld them. MK contacts can be welded by large back-e.m.f.s produced when relay K releases. Quenching relay K with a diode reduces the back-e.m.f.s to less than 100 V, and thus reduces the risk of welding of the MK contacts. If an MK contact still welds, its effect on the exchange is minimized by providing blocking diodes on leads KT(A) and KT(B) to the call control. This prevents unwanted feedback to other subscribers' line circuits. The revised circuit is shown in Fig. 8(*b*).

(*b*) Three methods of changing over the security sides in a TXE2 exchange are possible: automatically by normal exchange operation every 8 min, manually by a local engineer, or remotely from a test desk. Fig. 9(*a*) shows part of the circuitry. To prevent inadvertent change-over from a remote test desk (due to the effect of junction capacitance, typically greater than 2 $\mu$F), a 400 ms delay had to be inserted in the test access supervisory relay-set. This eliminates transient operation of relay AA, a contact of which provides the security change-over signal. The modified circuitry is shown in Fig. 9(*b*).

(*c*) A redesign of the register fault logic has eliminated a possible source of exchange service restriction. Under certain conditions, some or all exchange registers could lock out simultaneously. The busy limit circuit, which restricts the number of register lock-outs, is effective only when sequential fault signals occur. To cater for the simultaneous lock-out situation, a change in the register signalling sequence to the busy-limit circuit was necessary. The redesign allows a register to notify the limit circuit of its pending busy state before expiry of the pulse time delay; previously, the register had to wait until after locking out to notify the busy-limit circuit. The net effect is that the busy limit operates if a number or all registers are waiting to time out to the same pulse (that is, a simultaneous lock-out situation) and, on the arrival of the timed delay pulse, not more than the limited number of registers lock out.

(*d*) The TXE2 exchange uses S and Z time pulses in the detection of faults, the release of equipment held by a fault, and the removal from service of faulty equipment. To improve their security, the Mark 3 TXE2 exchange has been equipped

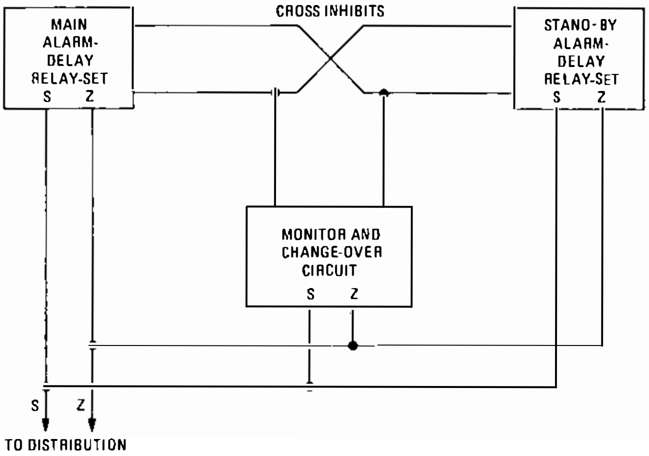


FIG. 10—S and Z pulse monitoring and distribution

with 2 pulse generators, known as *alarm-delay relay-sets*, one the main and the other the stand-by; the earlier TXE2 exchange design was equipped with only one generator. A monitor and change-over unit has been designed to detect failure of S or Z pulses and to change over from the main to the stand-by alarm-delay relay-set (see Fig. 10).

S and Z pulses are checked and the checking circuit is reset periodically by S and Z pulses of a lower frequency. The presence of 2·5 s and 20 s pulses is checked every 30 s by the 30 s Z pulses, and the checking circuit is reset by the 30 s S pulses (see Fig. 11). Similarly, 30 s S and Z pulses and the 3 min S and Z pulses are checked and the checking circuit is reset every 8 min by pulses from the exchange change-over clock.

In addition to checking for complete pulse failures, the monitor also detects the following types of pulse faults:

(*i*) S and Z pulses of the same frequency overlapping by more than 400 $\mu$s,

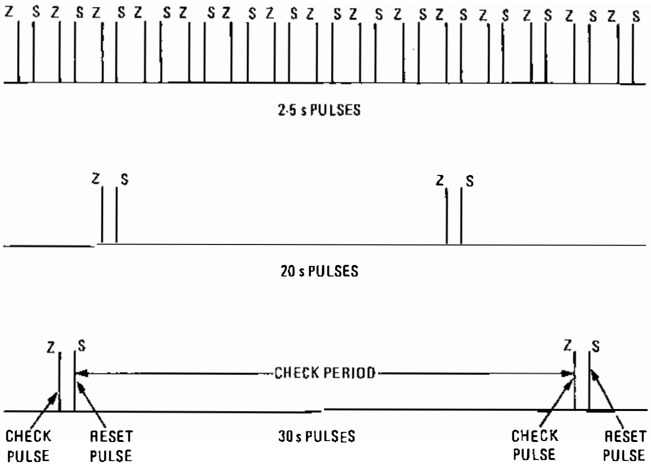


FIG. 11—Checking of 2·5 s and 20 s pulses by 30 s pulse

(*ii*) continuous S or Z pulses, and

(*iii*) short S or Z pulses; pulses must persist for longer than 10 ms.

The security modifications, some of which have been mentioned above, have greatly improved the reliability of the TXE2 system and reduced the possibility of exchange service restrictions. It is not practicable to apply fully all of the modifications retrospectively to all marks of TXE2 exchanges; however, all of the improvements will be applied to Mark 3 exchanges. Development will be continued to improve further the TXE2 system.

## References

[1] LONG, R. C., and GORRINGE, G. E. Electronic Telephone Exchanges: TXE2—A Small Electronic Exchange System. *POEEJ*, Vol. 62, p. 12, Apr. 1969.

[2] STACEY, R. R. Teletraffic Studies of the TXE2 Electronic Exchange. *POEEJ*, Vol. 67, p. 73, July 1974.

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# Book Review

*Introduction to Digital Filtering*. Editors: R. E. Bogner and A. G. Constantinides. John Wiley & Sons Ltd. xii + 198 pp. 125 ills. £7·50.

Books having several authors often suffer from a lack of coherence; this is no exception. It is based on courses on digital-signal processing given at the Imperial College, London, and, in places, the text has the terse construction of lecture notes. An annoying and unnecessary fault is the lack of standardization of symbols, which may confuse the beginner, for whom the book is intended.

Chapter 1 provides a brief introduction intended to set the scene; in places, it covers material dealt with in later chapters. It ends with an inconclusive paragraph introducing Walsh functions, which are not strictly relevant to the subject of the book.

Chapter 2 deals with the mathematical background of sampling and the *z*-transform. Chapter 3 covers some general characteristics of digital filters.

Chapters 4 and 5 deal with the design of infinite-impulse-response digital filters; the former by transformation of continuous filters and the latter by direct synthesis. These chapters are generally good, though slightly biased towards the author's research contributions. For example, the direct-synthesis method is confined to filters derived from a squared-amplitude response, which is a function of $\tan^2 \omega T/2$ (where $\omega$ is the angular frequency and $T$ is the sampling interval), whereas filters based on a function of $\sin^2 \omega T/2$ can lead to equally useful all-pole filters; these are not mentioned even by reference.

Finite-impulse-response filters are introduced in chapter 6, which is somewhat short in view of the importance of the topic. The design methods could have been amplified with advantage. By comparison, chapter 7 deals adequately with the discrete Fourier transform and the fast Fourier transform. Chapters 8 and 9 cover frequency-sampling filters.

A reasonable introduction to the important topic of quantization effects in digital filters is provided in Chapter 10. However, in parts it is misleading. For example, in the paragraph on overflow oscillations, it appears to suggest that setting to zero the outputs of all nodes where overflow has occurred will eliminate overflow oscillations. This contradicts a statement in a reference given, a paper by P. M. Ebert *et al.*

The book concludes with a chapter introducing the topic of optimization techniques.

Digital filters are likely to remain the province of the expert, and this book will appeal more to the intending specialist than to the general reader. Despite some avoidable faults, it should provide a useful introduction for the beginner.

P. F. A.

# Development of a 120 Mbit/s Digital Line System

## Part 2—Equipment Description

M. J. SCHICKNER, C.ENG., M.I.E.E., and L. C. ZICK, B.SC.†

UDC 621.394.4

*The first part of this article described the system principles, the equipment engineering and the maintenance facilities of the 120 Mbit/s digital line system. This concluding part describes the operation of the equipment.*

### INTRODUCTION

Part 1 of this article[4] discussed the principles involved in the design of the 120 Mbit/s digital line system. It also described the engineering practices adopted in producing the equipment and outlined the maintenance facilities provided. This concluding part gives a description of the operation of the digital line system.

### TRANSMIT APPARATUS

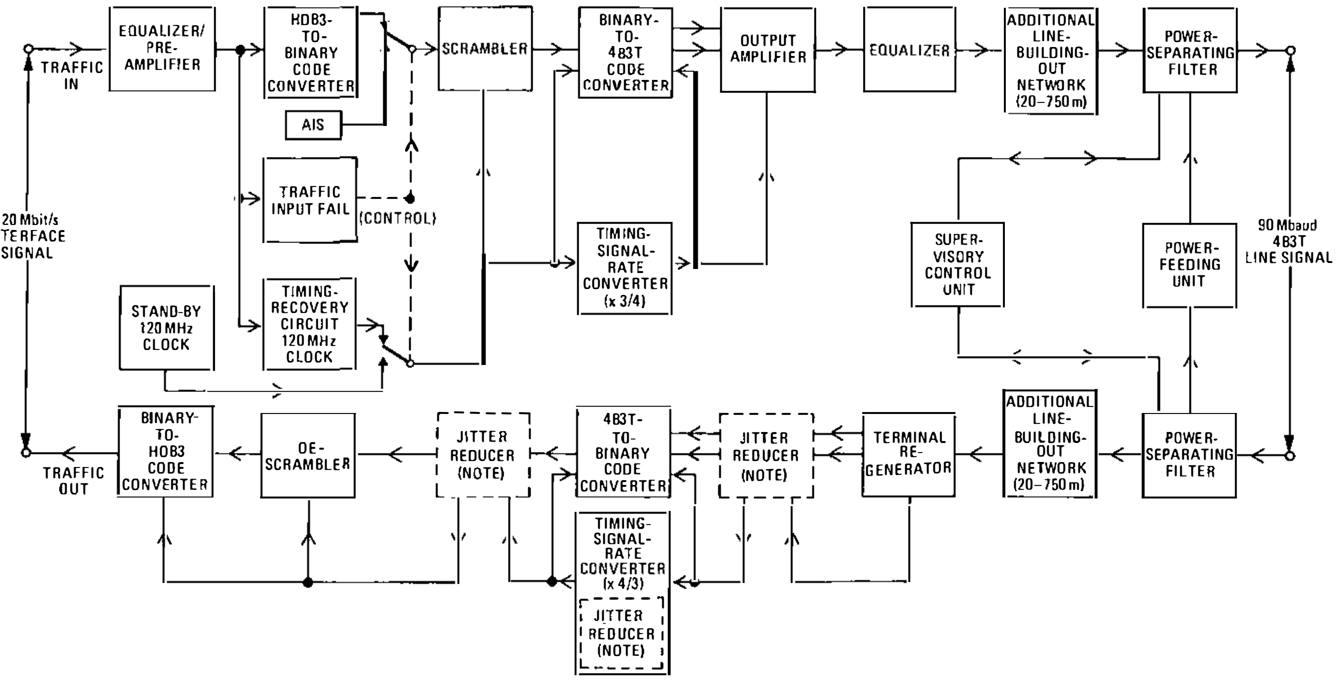
The function of the transmit apparatus of the line terminal equipment is basically code conversion between the HDB3 interface signal and the line code. Interfacing with the line is achieved by using the output amplifier and equalizer circuit of a dependent regenerator.

### HDB3 Decoder

A block diagram of the line terminal equipment is shown in Fig. 10. The traffic-in interface signal is amplified and equalized in a simple automatic equalizer/pre-amplifier to allow for a maximum of 120 m of coaxial cable having a loss of about 11 dB at 60 MHz. Precise equalization is not required at this point because an adequate margin against noise exists. From the equalized waveform, pulses of defined amplitude are generated to drive the HDB3 decoder and timing-recovery circuit, which produces a timing signal at the symbol rate of the input signal, nominally 120 MHz. This timing signal controls all the terminal logic functions, either directly or by using phase-locked sub-multiples of it. A stand-by clock is provided so that a signal is still sent to line if the input signal is removed. The stand-by clock is switched in automatically in the event of such a failure and an alarm-indication signal generated and transmitted.

### Scrambler

Although the properties of the line code are supposedly chosen to allow the transmission of an unrestricted binary sequence, this imposes severe constraints on certain aspects of the system design. This situation is eased if the binary



AIS—Alarm-indication signal
*Note:* Alternative positions for jitter reducer

FIG. 10—Block diagram of line terminal equipment

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† Telecommunications Development Department, Telecommunications Headquarters

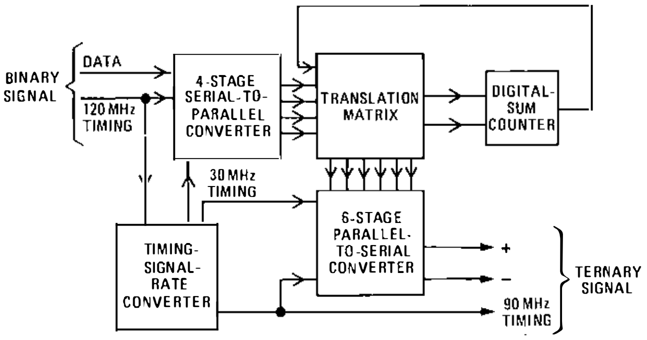
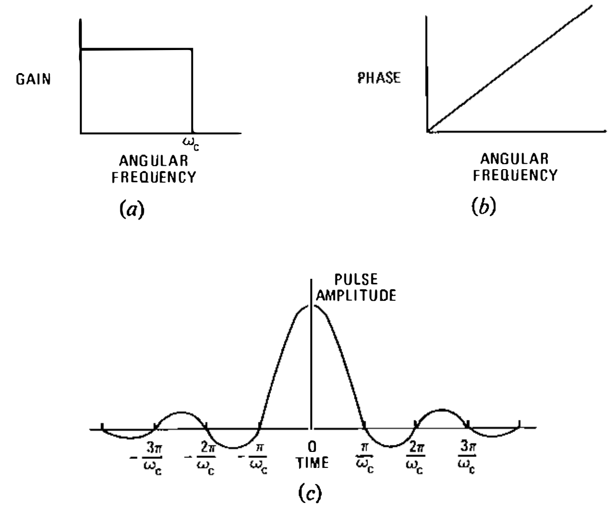


FIG. 11—Block diagram of encoder



(a) Gain/frequency response
(b) Phase/frequency response
(c) Impulse response

FIG. 12—Response of ideal low-pass function

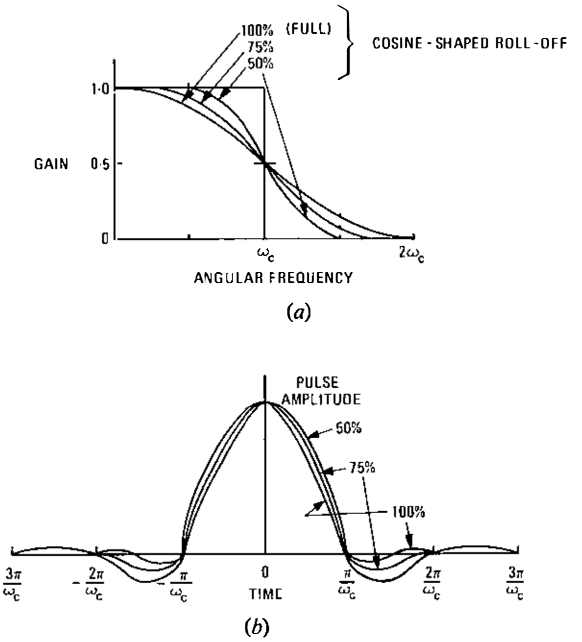
signal can be guaranteed to have a fairly random nature and, for this reason, it is desirable that the binary signal is scrambled before being encoded into the line signal. A type of scrambler is used for this purpose that adds (modulo 2*) the binary signal to a pseudo-random sequence, typically of $2^9 - 1$ bit, and is realized by a 9-stage shift register with selective feedback.

### Line Encoder and Output Stages

After scrambling, the binary sequence is encoded into a 4B3T type line code, as shown in the block diagram of the encoder given in Fig. 11. The output of the encoder is then fed to the output amplifier in the form of a binary-coded ternary signal at a 90 Mbit/s digit rate; that is, the positive and negative ternary signals are individually represented by a binary signal, and are accompanied by a separate timing signal that is derived from the 120 Mbit/s timing signal and has a fixed phase relationship to it. The output amplifier is generally composed of 2 switching amplifiers, one for each pulse polarity, with their outputs combined to produce the 90 Mbaud ternary line signal.

To equalize the attenuation of a section of coaxial cable, appreciable low-frequency attenuation must be added, and part of this attenuation is located at the output of the amplifier before transmission, rather than having it all at the regenerator input. Provision is made for fitting a line-building-out network in the terminal station where a very short line section is adjacent to the station.

Finally, a power-separating filter is provided so that the power-feeding current and the supervisory telemetry signal can be added to the main signal path without mutual interference.



(a) Transmittance functions
(b) Impulse responses

FIG. 13—Impulse responses of transmittance functions

## REGENERATOR UNIT

The basic function of the ideal regenerator is to produce at its output a replica of the original signal, free from distortion. The essence of this function is threshold detection, to decide which type of pulse is present. However, because economic utilization of cables requires that high attenuation of the upper part of the signal spectrum must be tolerated, considerable attention must be paid to equalization and amplification before detection can be reliably carried out.

In addition, a fault-location system is provided to enable faults to be located to the nearest regenerator section from the line terminal equipment using the supervisory telemetry system. This facility is discussed later.

### Bandwidth Requirements and Shaping

Given that certain requirements are met, only random noise from the cable and the input amplifier causes errors in threshold detection. To reduce the noise power, the equivalent noise bandwidth must be reduced, but not to the extent that the signal becomes distorted in a manner that precludes reliable regeneration. Transmission of a pulse through a low-pass network results in an oscillatory tail that can interfere with adjacent pulses, giving rise to inter-symbol interference. This can be avoided by making use of Nyquist's first criterion. Consideration of the impulse response of an ideal low-pass network (Fig. 12) shows that axis crossings occur at $\omega_c t = \pm n\pi$, where $\omega_c$ is the angular cut-off frequency of the filter and $t$ is time. Now, if pulses are repeated at an angular frequency $2\omega_c$, the centre of every pulse is coincident with axis crossings from the tail of all others. Thus, provided the signal is sampled at exactly this instant, there is no inter-symbol interference, and any sequence of symbols can be transmitted at this, the *Nyquist rate* ($2\omega_c$). This is also true for transmittance functions formed by adding skew-symmetrical functions to the ideal low-pass function, and of particular interest are those formed with a cosine-shaped roll-off; these are shown in Fig. 13 with their associated impulse responses.

In practice, instantaneous sampling at exactly the desired instant is not a realistic proposition, and some inter-symbol interference must be tolerated. This situation can be alleviated by choosing a response that satisfies Nyquist's second criterion which, in effect, removes inter-symbol interference half way between pulses by introducing an additional axis

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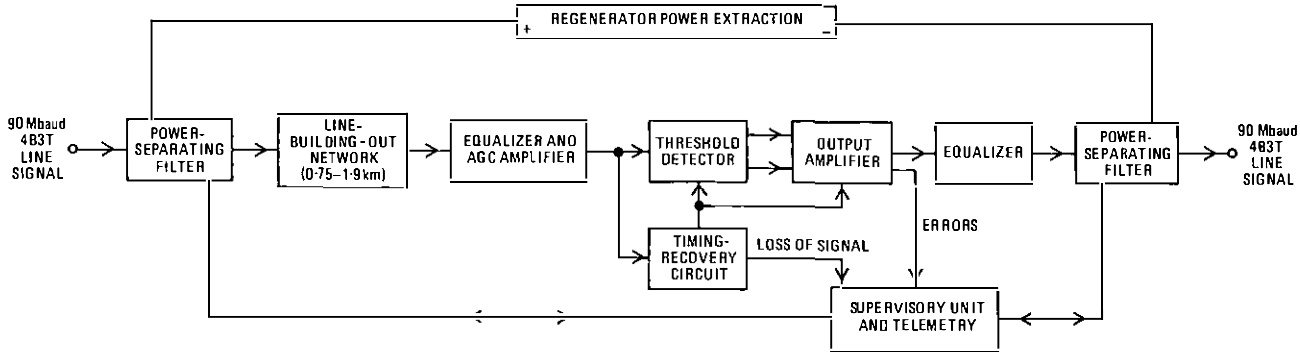
* Equivalent to an EXCLUSIVE OR function



AGC—Automatic gain control

FIG. 14—Block diagram of regenerator unit (one half)

crossing. The classic example of this is the full cosine roll-off, as shown in Fig. 13.

Many other theoretical transmittance functions have been studied, but of most interest are functions that are realizable with a small number of filter sections, derived by simulation, and representing a compromise between inter-symbol interference, equivalent noise bandwidth and circuit complexity.

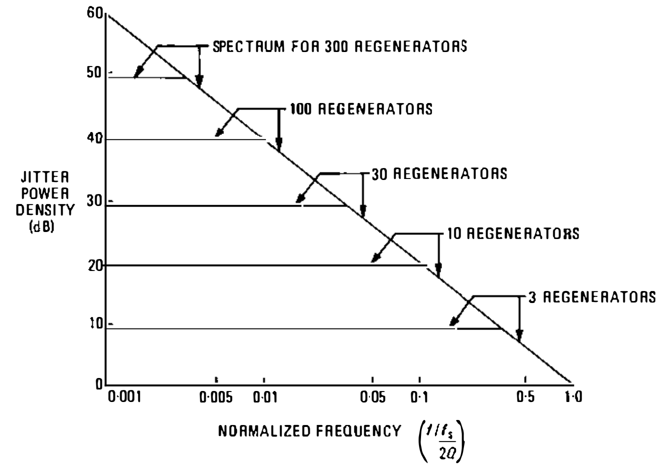
### Power Requirements

The basic elements of a regenerator unit are shown in the block diagram in Fig. 14. Power is derived from the constant-current supply fed along the inner conductor of the coaxial pair and separated from the signal path by a power-separating filter. These filters must be capable of giving good rejection to isolate the output of the regenerator from the input to prevent signal feedback. Surge protection against abnormal voltages due to induction and lightning is also provided to the same standard as for present analogue line systems. To provide for the different current and voltage requirements of each circuit, a number of voltage rails are stacked above one another to facilitate efficient use of the power available from the constant-current supply.

### Range of Automatic Gain Control

Stages of amplification and equalization provide the transmittance function required to give the desired channel response from the output of the previous regenerator to the threshold detector. Because the cable is subject to temperature variations, giving rise to variations in insertion loss, some form of automatic gain control (AGC) is required. To simplify installation procedure, the AGC range is also used to take account of a nominal cable section length range of 1·9–2·1 km. Section lengths that are shorter than the AGC circuit can accommodate are dealt with by fitting line-building-out networks; these can be regarded as simulating a length of cable, though they need not necessarily follow the cable frequency-response law. A range of networks is provided to build out section lengths of 0·75–1·9 km and bring them into the range of the AGC circuit.

As pilots are not provided, the AGC circuit must be controlled by the signal itself, and the equalized pulse amplitude is generally used for this purpose. Unfortunately, with many equalization plans, the peak of the equalized waveform is very dependent on the character of the sequence being transmitted. Thus, when a particular pattern persists for a long period compared with the AGC time constant, the AGC circuit may assume an incorrect value, resulting in increased inter-symbol interference due to incorrect equalization. Once again, the properties of the line code are nominally chosen to circumvent this problem, but, in practice, the provision of scramblers to ensure a random signal is found to be advantageous.



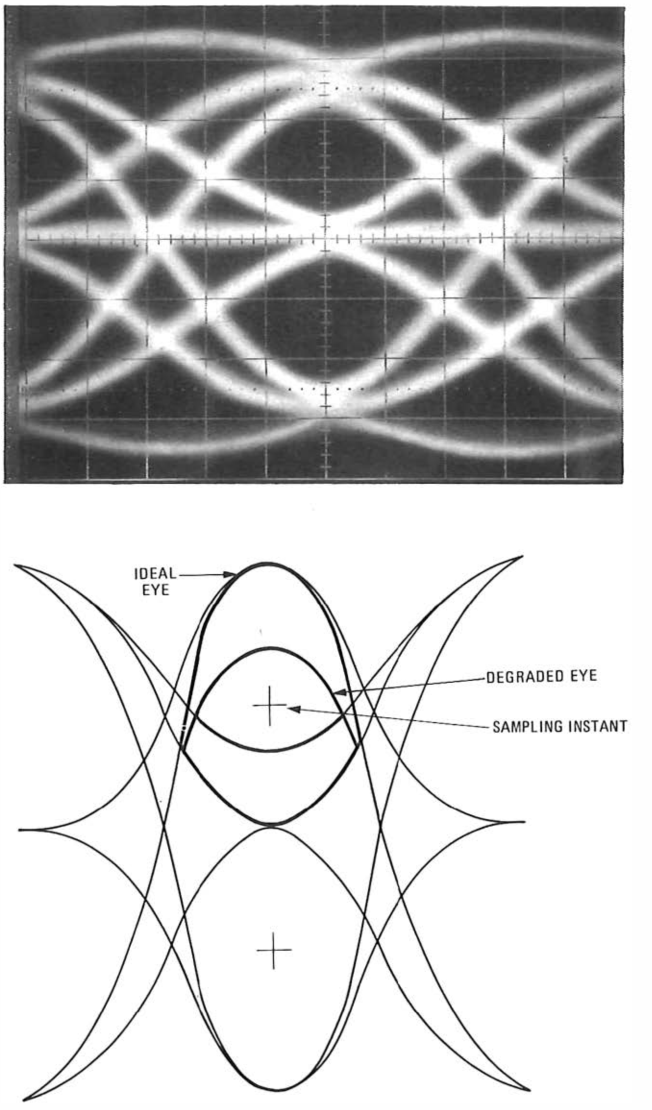
$Q$ is the $Q$-factor of timing-recovery circuit

FIG. 15—Simplified jitter power spectrum

### Timing Recovery

Threshold detection is performed by a form of level detection circuit, in combination with a timing signal that gives the output pulses the correct time relation. Short-term variations of pulses from their ideal position in time are called *jitter*, and arise generally from the difficulty of deriving a precise timing signal from the incoming line signal. The line signal spectrum has a null at the symbol frequency; so, to produce a timing signal at this frequency, a non-linear operation is required. A convenient method is rectification of the equalized signal followed by slicing, the resulting signal being used to excite a tuned circuit, typically with a $Q$-factor of about 50. The required sampling instants can then be derived from the zero crossings of the signal derived from the tuned circuit.

A number of sources of error in timing have been identified, but the significant ones are those that cause timing errors to accumulate rapidly with the number of regenerators. These are inter-symbol interference, and amplitude–phase conversion which occurs because of uncertainty in identifying the zero crossings of the timing signal. Both of these mechanisms are dependent on the character of the pulse sequence being transmitted, as this determines the inter-symbol interference and the amplitude of the timing signal. Consequently, the jitter produced by these mechanisms is correlated in each regenerator of a chain. Each timing-recovery circuit also acts as a low-pass filter to jitter introduced by all previous regenerators, so that low-frequency pattern-dependent jitter accumulates in proportion to the number of regenerators. The "power" spectrum of the jitter at the output of a chain of regenerators, with symbol frequency $f_s$, is then of the form shown in Fig. 15. The term "power" is used by analogy with a noise voltage; the actual quantity is the square of a phase angle, which is dimensionless.



(*b*)

(*a*) Photograph of oscilloscope trace with 5 mV/cm vertical sensitivity and 2 ns/cm horizontal sensitivity
(*b*) Explanatory sketch

FIG. 16—Eye diagram

### Detection

The degree of success achieved in the equalizers can be determined by considering the eye diagram. This is obtained by observing the waveform at the input to the threshold detectors on an oscilloscope having its time base triggered from a symbol-rate clock. If a random signal is being transmitted, successive sweeps of the trace build up a picture of all possible transitions, as in Fig. 16. The intersection of the sampling instant and threshold level should be somewhere within the eye and so, to reduce the probability of errors being caused by noise, the eye opening must be made as large as possible. As the eye can be derived theoretically, the quality of the received eye can be used as a figure of merit for different regenerator parameters. Imperfections in the regenerator are conveniently referred to the eye impairment that results from them, including imperfections in the threshold detector and the preceding output stage.

To achieve a given error-rate performance, the worst-case eye opening must have a certain height compared with the noise present at the threshold detectors. Fig. 17 gives the error probability† plotted against the pulse-amplitude-to-r.m.s.-noise ratio and this shows that a ratio of 22 dB is sufficient to maintain the required error-rate performance of 1 in $10^{10}$ per regenerator. The graph also shows that the error rate is very dependent on the signal-to-noise ratio and that, for a small increase over the 22 dB ratio, the error rate becomes negligible. Because of this, it is generally assumed that the error rate of a digital line section (DLS) is approximately that of the worst regenerator, all others making a negligible contribution.

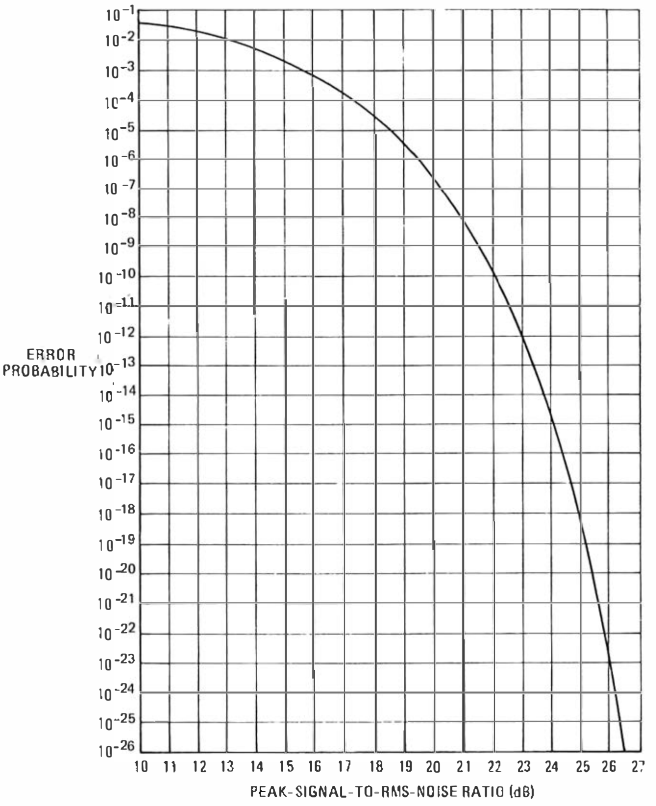


FIG. 17—Error-probability/signal-to-noise-ratio characteristic

To assess the performance of an individual regenerator, a measurement of noise margin is used. The noise margin is the amount by which the basic noise at the threshold detector must be increased to cause a given error rate—usually 1 in $10^6$ for convenience of measurement. Typically, a regenerator may have greater than 10 dB noise margin against an error rate of 1 in $10^6$ for a section loss of 78 dB at 45 MHz. The margin against an error rate of 1 in $10^{10}$, the worst-case performance limit, is theoretically about 3 dB less than this. In most cases, section losses will be somewhat less than 78 dB, so that normal operating margins will be improved due to the reduction in gain required, as shown in Fig. 18.

The threshold detection circuit feeds binary-coded ternary signals to the output amplifier in a similar manner to the output of the encoder in the transmit apparatus of the line terminal equipment.

## RECEIVE APPARATUS

The receive apparatus of the line terminal equipment (Fig. 10) performs essentially the reverse functions to the transmit apparatus except that, as an option, a jitter reducer may be provided. The received line signal is first separated from the power-feeding current and the supervisory telemetry signal by the power-separating filter. It is then detected by a terminal regenerator, which provides the equalization, AGC amplification, timing-recovery and threshold detection functions of a dependent regenerator. The terminal regenerator feeds binary-coded ternary data and 90 Mbit/s timing signals to the decoder for conversion to binary data and 120 Mbit/s timing signals. The binary data signal is descrambled by a self-synchronizing unit, which typically consists of a 9-stage shift

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† An error rate of $m$ in $10^n$ is an error probability of $m10^{-n}$

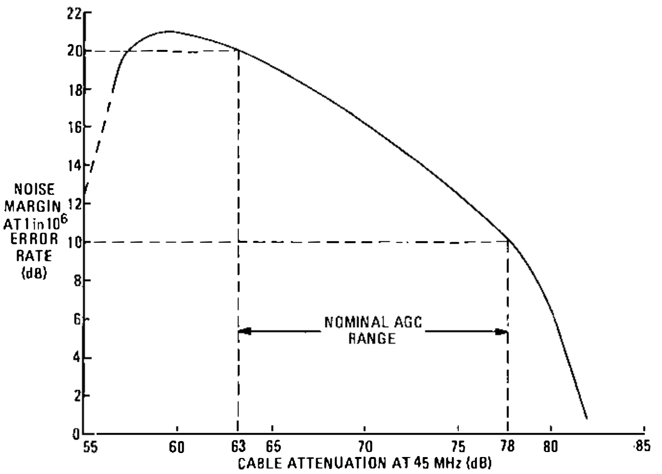


FIG. 18—Typical noise-margin/cable-attenuation characteristic

register with selective feed-forward connexions and which requires the transmission of only 9 bit before synchronism is achieved. The descrambled binary signal is coded into HDB3 to provide the traffic-out interface signal.

## Decoding

Decoding from the line code to binary signals requires that the line-code words can be recognized by the decoder. A number of possible schemes for achieving alignment exist using properties of the ternary line sequence imposed by the encoder. One method used, which is applicable to all forms of 4B3T type codes, is based on the detection of all-zero (illegal) ternary words. Initially, the decoder must assume one of 3 possible phases for the beginning and end of the line-code words, which may or may not be correct. However, it is known that the encoder generates no all-zero words at its output, so that if any such words are detected at the decoder, it is assumed that the initial state adopted was incorrect and another phase is tried. If this also fails, the third position is tried.

Unfortunately, a second possibility exists, which is that the all-zero words are caused by errors in transmission, occurring between the encoder output and the decoder. Thus, when an all-zero word is received, it may be due to an incorrect word alignment phase or an error. To determine which of these possibilities is more likely, the frequency of occurrence of all-zero words is used. If this is greater than a certain threshold value, loss of word alignment is assumed, while less frequent occurrences are assumed to be due to transmission errors. Whatever threshold value is used, there is always a certain probability of the threshold being exceeded by random errors, thereby causing the decoder mistakenly to decide that it has lost word alignment and take appropriate action.

The realignment process consists solely of stepping one time-slot in the ternary sequence. If this is an incorrect phase, further loss of alignment indications will be detected, and the process repeated. Thus, in the case of a spurious loss of alignment due to errors, the decoder steps through all 3 possible phases, arriving back at the original, correct phase. The process is fundamentally different from the frame-alignment process in a multiplex equipment[3], in that no search for alignment is performed, action being taken only when the existing state is found to be incorrect. The decoder assumes that it is in alignment unless indications to the contrary occur and, for this reason, it is desirable that the ternary sequence should contain a sufficient density of such indications for all binary signals. The use of a scrambler ensures that this condition is met for all practical purposes, by giving the binary signal approximately the characteristics of random binary data.

For production systems, a limit is specified for the realignment time of less than 107 μs on 99% of occasions in the presence of an error rate of 1 in $10^4$. This is specified as a percentage because the process is based on randomly occurring events. The immunity against spurious realignments is specified to give a mean time between realignments of greater than 1 year in the presence of a mean random line error rate of 1 in $10^4$. Due to their unpredictable nature, burst errors caused by such effects as lightning may give more frequent spurious realignments.

Once word alignment has been attained, decoding can take place in a similar manner to the encoding process.

## Error Detection

Detection of all-zero words at the decoder is only one of several illegal conditions that can be used for word-alignment and error monitoring. Error monitoring is possible because indications occurring infrequently can be assumed to be due to errors and not loss of alignment. The performance of a DLS can therefore be continuously monitored, while in traffic, without the addition of special signals for this purpose. Detection of the all-zeros word is not a particularly good choice for this application, as error detection can be carried out only where word-alignment circuitry exists. A more general method for error detection makes use of the limits imposed by the encoder on the digital sum. There are 6 possible values that the digital sum can have for the MS43 code, and 8 values for 4B3T code. When an error occurs, the normal range of digital sum is altered in the sense of the error and, when the digital sum touches the limit in that direction, the normal range is exceeded. Hence, if the digital sum is monitored, any overflow of the normal range can be attributed to the occurrence of an error, and the digital-sum count restored to the correct value.

The excess digital-sum count method of error detection can be used at any point in the system, giving the possibility of error detection at the output of each regenerator for fault-location purposes. A word-alignment strategy using this principle would also be feasible, but is not used. Other methods of detecting errors and monitoring word alignment also exist, though all use the principle of monitoring the ternary sequence for illegal conditions; that is, conditions that cannot be generated by the encoder.

These methods of error detection do not detect every error, but are sufficiently accurate for error rates better than, say, 1 in $10^3$, particularly when the result is displayed in decades. This discrepancy is mainly due to bunched errors. Precise error rates cannot be measured on an in-service system; such measurements are possible only by using

(*a*) a comparator between the input and output of a looped system, or

(*b*) a known sequence from a pattern generator.

## Error Extension

A consequence of efficient symbol-rate-reduction coding is that single line errors (that is, errors in the ternary signal) result in more than one error in the binary signal. This can be seen from the code conversion table given in Table 1 (Part 1); for example, one line error, changing the ternary code $+0-$ to code $+--$ gives a binary code 1011 instead of code 0000, an error-extension factor of 3 and an error-extension spread of 4. For a 4B3T decoder, the maximum error-extension factor and spread is 4, although by careful design of the code conversion table, the average error-extension factor can be kept below 2.

Further error extension occurs in the descrambling process, average factors of 3 and maximum spread of 9 being typical; this gives an overall error extension for the receive

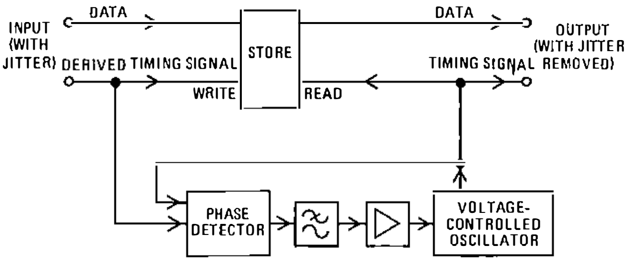


FIG. 19—Simplified block diagram of a jitter reducer

apparatus having an average factor of 6 and a maximum spread of 13.

Due to error extension, the distribution of errors at the system output is not the same as a random error rate of the same value, because of the highly concentrated burst nature of the errors. This has no disadvantage when connected to a digital demultiplexer, but could complicate the design of broadband services such as encoded hypergroups and television.

All error rates measured by built-in system detectors are referred to and displayed as the *equivalent binary error rate* by using an appropriate multiplying factor.

### Jitter Reducer

The function of a jitter reducer is to reduce the magnitude of the jitter that has accumulated in a chain of regenerators. Alternative positions are shown for this apparatus in Fig. 10, operating either at 90 Mbit/s or 120 Mbit/s, although the principle is the same in both cases. Jitter reduction can also be carried out at a 30 MHz stage forming part of the line decoding unit. Fig. 19 gives the block diagram of a typical jitter reducer. The data are read into a store under the control of a timing signal derived from the signal having jitter superimposed, and read out under the control of a signal obtained from a phase-locked oscillator, this being controlled by the recovered timing signal. Short-term variations in the recovered signal are filtered out by the time constant of the control loop of the oscillator, but the mean rates are the same. Jitter frequency components within the passband of the phase-locked loop pass through unattenuated, so that low-frequency jitter can accumulate without bound on tandem-connected systems.

As the phase-locked oscillator in each tributary of a digital demultiplexer[3] is a jitter reducer, the demultiplexer can withstand the jitter generated by one DLS. Therefore, the optional jitter reducer need be fitted in a DLS only when its output is to be connected to another DLS or some other equipment that may be sensitive to jitter.

## SUPERVISORY SYSTEM

A block diagram of the supervisory system is shown in Fig. 20. The system comprises a supervisory control unit in each line terminal equipment, and other supervisory units in each intermediate station equipment and regenerator unit; all are interconnected by a telemetry system working over the same coaxial pairs as the main digital signal, but working in a part of the frequency spectrum below the signal frequencies. Each supervisory control unit can be used to locate most faults, independently of staff at the remote terminal; excessive errors and loss of signal can be located to the nearest regenerator section and power faults to the appropriate power-feeding section.

Normal maintenance practice is that the staff at a terminal are responsible for maintaining their incoming direction of transmission. To enable this practice to be followed, the supervisory control unit sends one interrogation signal over the telemetry path on the coaxial pair carrying the incoming main digital signal to interrogate the intermediate station equipment and regenerator supervisory units. These respond by sending back acknowledgement and fault-condition signals over the same bothway telemetry path. Each supervisory unit responds in turn and, at the same time, sends a further interrogation pulse along the route to the next unit. Thus, by transmitting one interrogate pulse, the supervisory control unit receives acknowledgements from all units along the receive transmission path. Arrangements are made so that, if the distant terminal is unattended and a fault occurs on the transmit path, the local terminal receives a *distant-terminal* alarm and can then also locate the fault in that direction.

### Regenerator Supervisory Unit

A supervisory unit associated with each regenerator in a regenerator unit (Fig. 14) performs the following functions:

(*a*) it monitors the main signal for errors and counts them,

(*b*) it monitors the regenerator for loss of signal and stores the information, so as to record intermittent faults,

(*c*) when an interrogate pulse is received from the regenerator output side, it

(*i*) sends back a pulse to acknowledge reception followed by pulses to indicate if the error counter is full or a loss of signal has been recorded,

(*ii*) sends an interrogate pulse forward to the next regenerator unit or intermediate station equipment, and

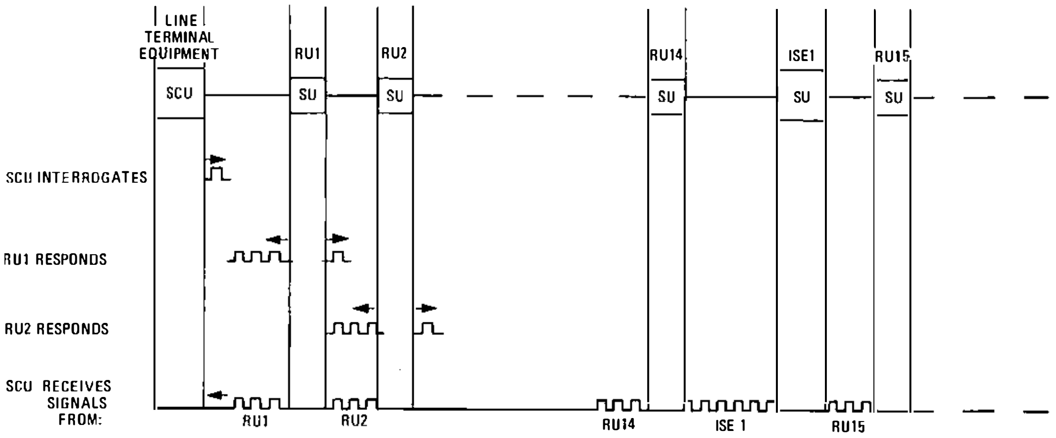
(*iii*) resets the error counter and loss-of-signal store, and

(*d*) when telemetry signals are received from the regenerator input side, they are regenerated and transmitted to the output side; that is, sent back to the supervisory control unit.

The method of error monitoring may be of the excess-digital-sum form already described. However, due to the power restrictions imposed on a regenerator by the power-feeding system, The General Electric Co. Ltd. (GEC) and Plessey Co. Ltd. (PCL) decided that it would be necessary to use a custom-built medium-scale-integrated circuit in each regenerator to implement a system using this error-monitoring method.

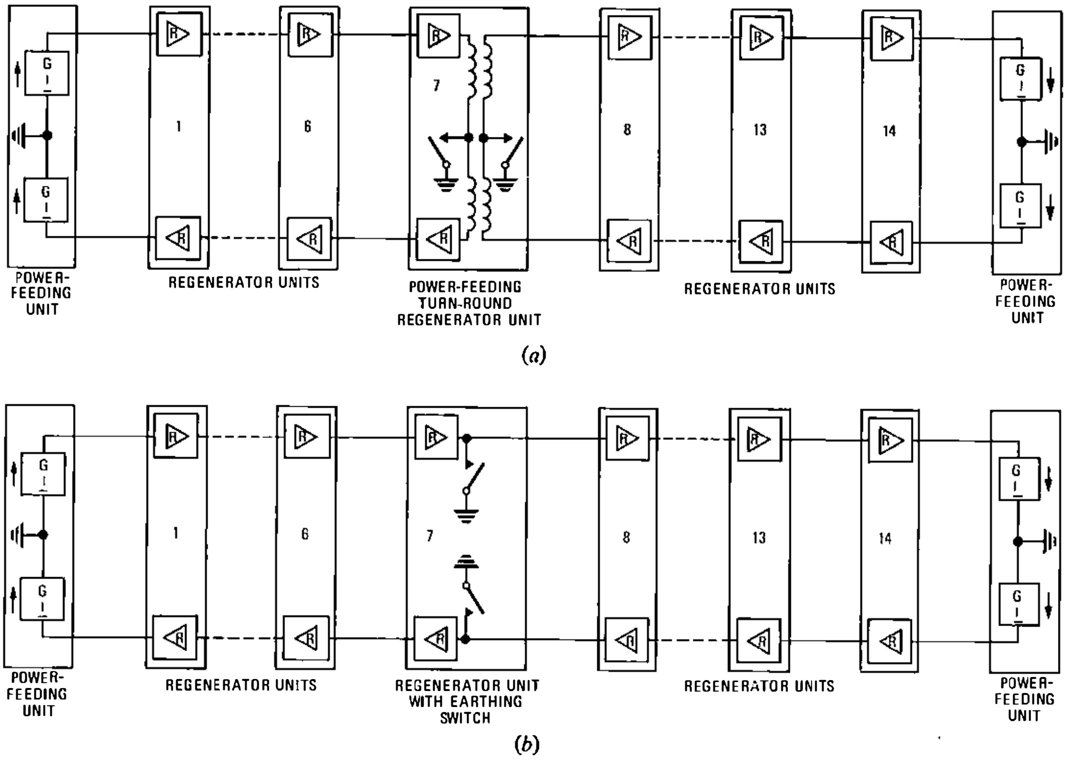
Standard Telephones and Cables Ltd. (STC) decided to avoid the need for a custom-built device by using a different method of error monitoring; this requires less components in a dependent regenerator, but suffers the disadvantage that the normal traffic has to be replaced by a special test pattern and thus is an out-of-service test. The British Post Office (BPO) decided that this method was acceptable because intermittent loss-of-signal faults can still be located in service and lower-error-rate faults (say in the range 1 in $10^5$ to 1 in $10^7$) can be quickly located once the system is taken out of service; with this range of error rate, the system could be left in service until a convenient low-traffic period. This STC system is backed up by in-service excess-digital-sum counters in each surface station, giving an in-service location between 2 stations. The STC method depends on the fact that, if a pseudo-random-sequence is transmitted, having a pattern length $L$ seconds, the line signal would have no spectral components below the frequency $1/L$ hertz, unless errors are occurring in transmission. By using a low-pass filter with a cut-off frequency below $1/L$ hertz and a monostable trigger circuit, error pulses can be detected and counted.

If the error counter in the regenerator has a capacity $C$, and the supervisory control unit interrogates the route periodically with a time $T$ between scans then, if a regenerator returns a signal indicating that the counter is full, the error rate can be assumed to be greater than $C$ errors in time $T$; for example, a count of 45 in a scan period of 5 s with a line rate of 90 Mbaud gives an error rate of 45 in $5 \times 90 \times 10^6 = 1$ in $10^7$. The scan rate can be changed to set error thresholds of 1 in $10^6$, 1 in $10^7$ and 1 in $10^8$.



SCU—Supervisory control unit
SU—Supervisory unit
ISE—Intermediate station equipment
RU—Regenerator unit

FIG. 20—Supervisory system



(a) Looped system
(b) End-to-end system

FIG. 21—Power-feeding systems

### Intermediate Station Equipment Supervisory Unit

The supervisory units in the intermediate station equipment provide the same facilities as in a dependent regenerator; they also transmit power-feeding alarm conditions to both terminals and, in the case of the STC system, an indication that the error counter is full.

### Supervisory Control Unit

The scanning supervisory system results in a very large amount of information being received and stored in the supervisory control unit. To display all this information would be unpractical, and various methods have been developed to reduce the display to manageable proportions. GEC and PCL jointly, and STC independently, developed systems for the experimental field trial that used different approaches. These 2 approaches have been further developed to improve the facilities and reduce the display size for production systems.

The GEC/PCL approach is to use a mnemonic diagram having 2 rows of lamps, each row representing one direction of transmission and each lamp representing a section of the route between 2 surface stations. Then, by manually selecting one particular lamp, all the conditions for that section are expanded out onto a third set of lamps.

The STC approach is to programme a list of priorities into the supervisory control unit so that it automatically selects and displays the most significant fault condition. Certain manual override facilities are provided so that suppressed information can be displayed.

To reduce further the display size, and the power consumption, extensive use has been made of light-emitting diodes, filament lamps being used only for main alarm displays which are used to attract the attention of maintenance staff.

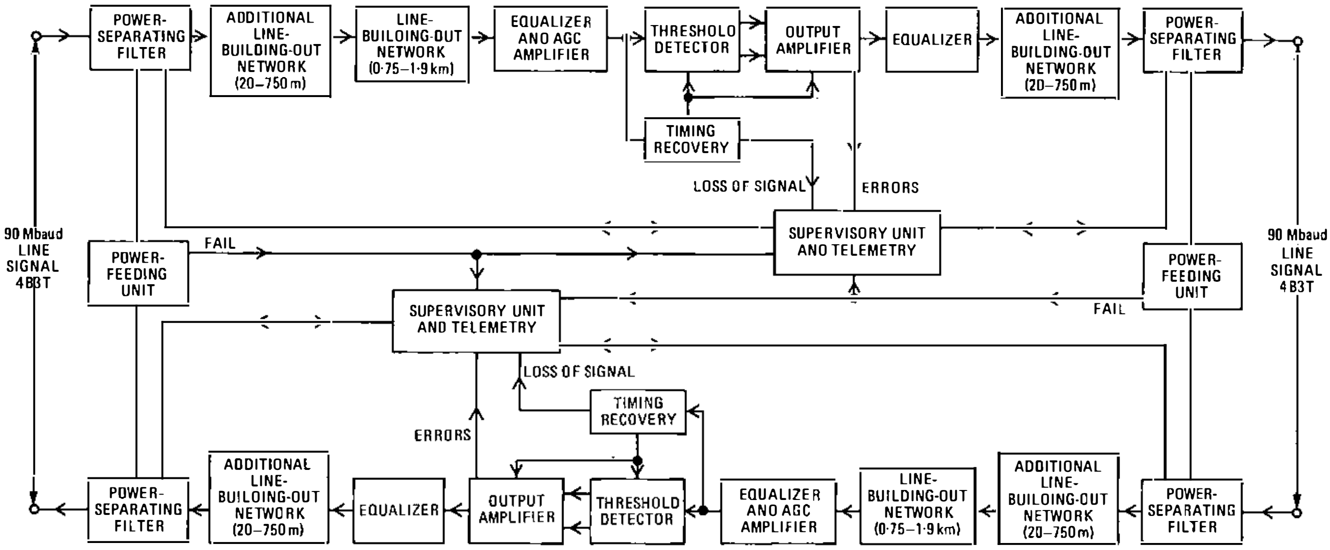


Fig. 22—Block diagram of intermediate station equipment

## LINE POWER-FEEDING APPARATUS

The power-feeding apparatus is essentially as used in Coaxial Equipment Line No. 4000 (CEL 4000) analogue line systems, except that no stand-by facilities are provided. Improvements in power-unit reliability, and the difficulty of obtaining reliable change-over units have made this precaution redundant. Thus, a single power-feeding unit is used, with a simplified power-feeding monitor unit for checking line voltage and current and locating cable faults.

The power-feeding unit delivers a constant current of 49 mA to line, and can supply power to a maximum of 14 regenerators. The power-feeding circuit uses the inner conductors of the coaxial pairs.

Alternative power-feeding arrangements can be used and are shown in Fig. 21. The first is the conventional *looped* power-feeding arrangement used for the CEL 4000 analogue system; each half of the power-feeding unit feeds up to 7 regenerators connected to a coaxial pair, and a low-pass filter (power-feeding turn-round unit) is used to provide a d.c. loop to complete the circuit. The alternative is an *end-to-end* power-feeding system, in which one half of a power-feeding unit is connected via one coaxial pair, feeding up to 14 regenerators, to one half of a power-feeding unit at the adjacent surface station. Under normal conditions, the associated coaxial pair provides the return path, but, under fault conditions, it can be via earth.

Both systems use an earth-switch at the mid-point of the power-feeding section, which applies an earth when the potential to earth exceeds a certain limit, to assist in fault location. In addition, for the looped system, it maintains service over one coaxial pair when the other has an earth or open-circuit fault; this is an advantage with unidirectional services such as television, or with unidirectional service-protection schemes. With the end-to-end system, the earth switch enables a power-fault alarm to be raised at one surface station only, from which the fault location will be made.

The power-feeding unit delivers a maximum voltage of ±242 V to earth and meets the BPO requirements for a safe power-feeding system; that is, the current through a 2 kΩ resistor, connected anywhere in the power circuit, must be reduced to less than 50 mA within 250 ms.

## INTERMEDIATE STATION EQUIPMENT

Fig. 22 is a block diagram of the intermediate station equipment, which is used when the number of dependent regenerators in a DLS exceeds 14. It has the same power-feeding apparatus as the line terminal equipment, but it is duplicated so that the intermediate station equipment can feed power to line on both sides. As the regenerators in an intermediate station equipment are rack mounted and the power-supply arrangements are different, neither a dependent regenerator nor a regenerator unit is used. Instead, the normal practice is to build a regenerator from the terminal regenerator of a line terminal equipment receive apparatus and the output amplifier and equalizer of a transmit apparatus.

## CONCLUSION

Two designs of 120 Mbit/s digital line system have been installed and successfully tested in an experimental field trial. The various equipments have performed well with the systems normally running error free. The exceptions have been a few cable and equipment faults, which produced high error rates and were easily located, and a few isolated bursts of errors which, on checking, coincided with Meteorological Office reports of periods of thundery weather (lightning). Some design changes are being made for production systems, which have a planned ready-for-service date of 1978.

During the field trial, tests have also been made in association with: 2 Mbit/s pulse-code-modulation primary multiplex equipment, 2 Mbit/s to 8 Mbit/s and 8 Mbit/s to 120 Mbit/s digital multiplex equipment, and digitally-encoded broadcast-quality television and sound signals.[5] Evaluation and equipment tests are continuing.

## ACKNOWLEDGEMENTS

The authors wish to thank their colleagues in the BPO, the British Broadcasting Corporation and industry, whose valued efforts have led to these developments and their successful field trial, and GEC and STC for permission to publish Fig. 6 and Figs. 7 and 9 respectively.

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# A Review of the British Post Office Microwave Radio-Relay Network

## Part 2—Performance and Reliability

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UDC 621.37 : 001.1

*Part 1 of this article reviewed the history of microwave radio-relay systems in the UK and described the planning principles adopted. In this part, the performance and reliability of analogue microwave systems are reviewed and the performance objectives for digital systems are previewed.*

## INTRODUCTION

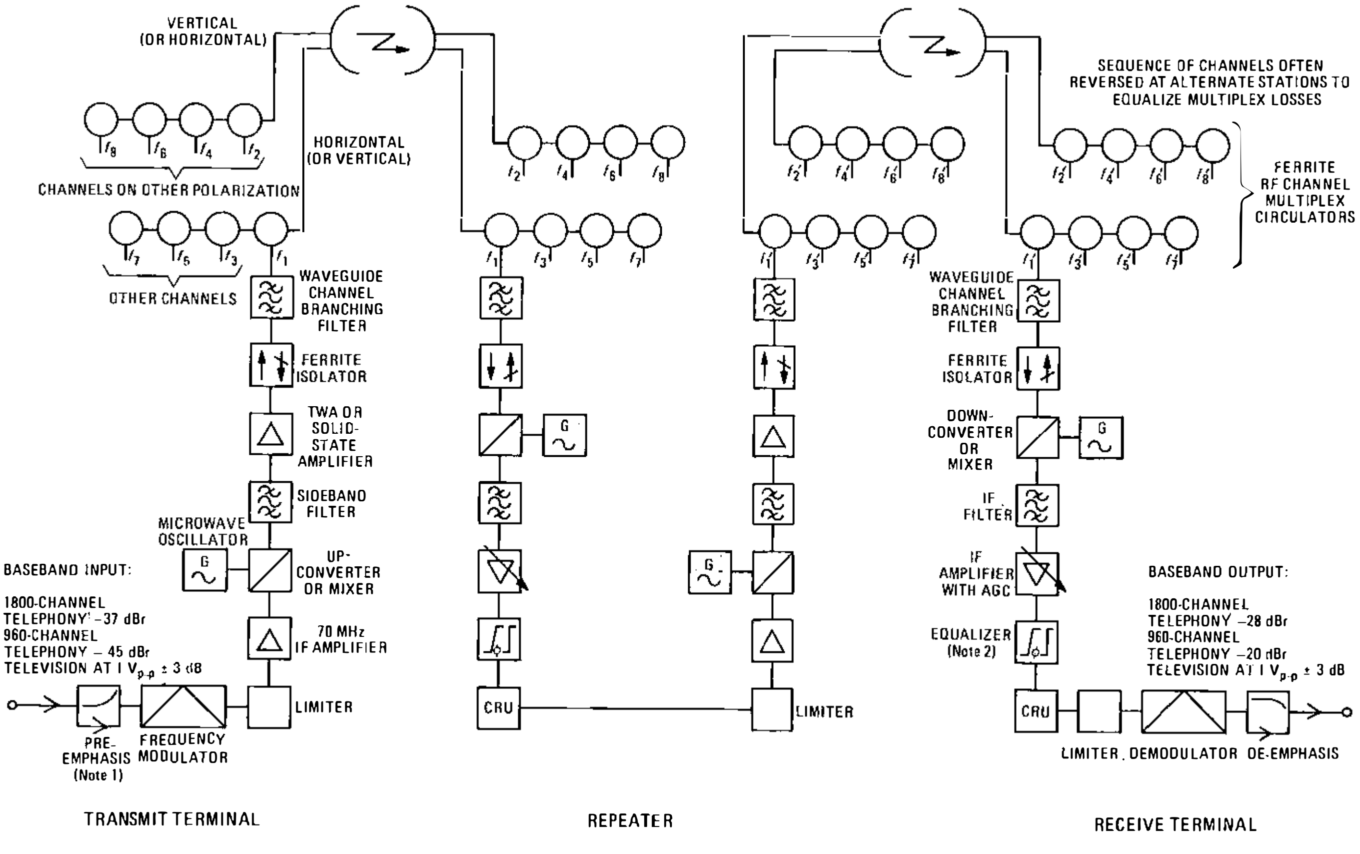
Part 1 of this article[16] reviewed the history of microwave radio-relay links in the British Post Office (BPO), and discussed some aspects of network utilization and planning in the light of over 25 years operational experience. In this part, the performance and reliability of analogue microwave systems are reviewed and a preview given of digital performance objectives, these systems still being at the development stage.

## TYPICAL ANALOGUE AND DIGITAL RADIO SYSTEMS

Before considering performance and reliability, it is useful to describe typical analogue and digital systems.

### Analogue Systems

An analogue microwave channel, in its simplest form, is shown in Fig. 9. The input baseband signal, which can be



CRU—Carrier reinsertion unit, TWA—travelling-wave amplifier

*Notes* 1: Different pre-emphasis characteristics used for telephony and television
2: Although a group-delay equalizer is shown, in some circumstances, amplitude and high-frequency derivative equalizers may also be used

FIG. 9—Typical unidirectional analogue channel

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† Mr. Martin-Royle and Mr. Dudley are in the Network Planning Department, Telecommunications Headquarters, and Mr. Fevin is now in the Service Department, Telecommunications Headquarters

either television or frequency-division-multiplex (FDM) telephony, is pre-emphasized and frequency modulates (FM) an oscillator centred on the internationally-recommended intermediate frequency (IF) of 70 MHz for 960/1800-channel telephony or television systems, or 140 MHz for 2700-channel telephony systems (not used in the BPO network). After suitable amplification and limiting, to remove any residual amplitude variations, the FM signal is applied to a mixer or up-converter circuit, together with a microwave signal offset by 70 MHz from the required transmitter output frequency. One sideband of this up-conversion process is selected by a filter and amplified, either by a travelling-wave amplifier (TWA) or a solid-state amplifier; it is then further filtered by a waveguide channel filter, and fed to the aerial via a circulator and coaxial or waveguide feeder. In some cases, where only low output power is required, the final amplification stage is omitted.

At the receiver, the wanted signal is selected by a waveguide filter and mixed with a locally-generated microwave source, offset by 70 MHz from the received frequency. The 70 MHz signal derived from this down-conversion process is amplified, equalized and then applied to a frequency demodulator to recover the baseband signal, which is then de-emphasized to restore it to the original format. Pre-emphasis and de-emphasis are used to give a more uniform noise distribution on telephony systems, and to reduce distortion on television systems.

A repeater is simply a receiver and transmitter connected back-to-back at IF.

The carrier reinsertion unit in each receiver injects a noise-free 70 MHz signal into the transmission path if the incoming carrier fails. This prevents high noise due to the receiver automatic gain control (AGC) applying maximum gain to the input noise, causing interference or other problems (for example, unnecessary alarms) in the later stages of the system.

Because of the highly directional properties of the aerial, which result in high gain relative to an isotropic aerial, the output power from the transmitter does not need to exceed 10–20 W. To avoid a multiplicity of aerials, several radio channels in a frequency band are multiplexed at radio frequency (RF) on the same aerial and feeder system. To guard against equipment failure, the BPO usually allocates one of the radio channels as a protection for the other main channels, the traffic being switched automatically to the protection channel if a main channel fails.

### Digital Systems

For comparison purposes, it is useful to consider the possible format of a high capacity (140 Mbit/s) digital radio channel.

The first difference is that phase modulation, or more correctly phase-shift keying (PSK), will be used instead of FM. If 2-phase PSK is assumed, one phase of the carrier relative to some reference represents binary 1, and a phase 180° different represents binary 0. For high-capacity systems, however, it will be necessary to use 4-phase modulation. This can be generated as shown in Fig. 10. By selecting alternate bits, the input digit stream can be divided and each stream used to 2-phase modulate a carrier. Both carriers are derived from the same source and are thus identical in frequency, but one of the carriers is phase-shifted 90° relative to the other. After modulation, the 2 carriers are combined, resulting in one signal having 4 possible phases, each phase representing 2 bits. This technique is termed *quaternary phase-shift keying* (QPSK). The symbol rate through the system, which in this case is only half the input bit rate, influences the RF channel spacing.

Various techniques are possible for the corresponding demodulation process. The technique giving the best performance is likely to be coherent demodulation (Fig. 11). The basic requirement is to generate a reference carrier locked in phase with the carrier in the modulator. This is produced by a phase-locked loop, controlled by the incoming modulated carrier, frequency multiplied by 4. This multiplication removes the phase modulation because the 4 phases of the modulated signal are 0°, 90°, 180° and 270°; thus, multiplication by 4 results in phases of 0°, 360°, 720° and 1080°, which represent zero phase shift in each case. The reference carrier is then fed in quadrature to a pair of 2-phase demodulators, together with the incoming modulated signal; the outputs of the demodulators are fed to a decoding logic circuit to recover the original digital input.

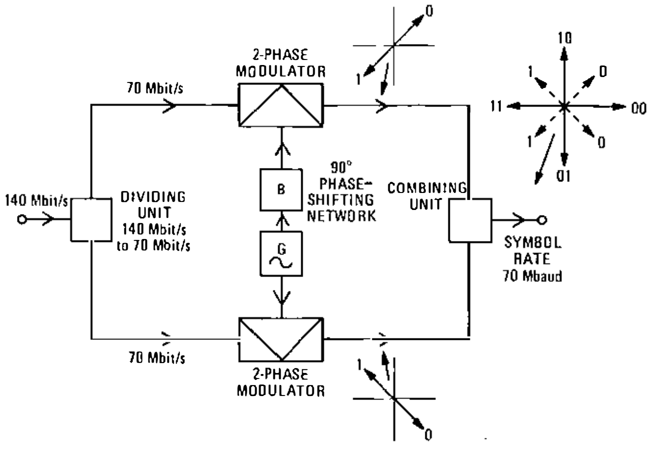


FIG. 10—Principle of a quaternary-phase-shift-keying modulator

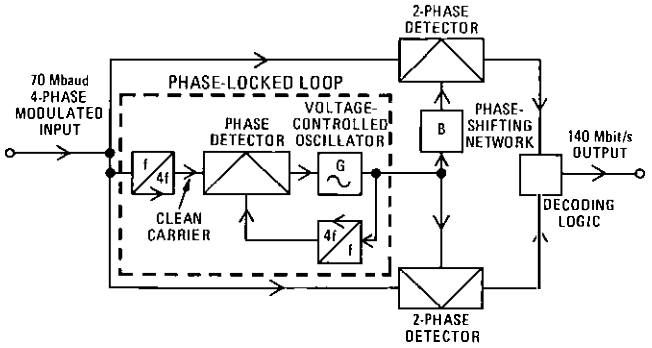


FIG. 11—Principle of a coherent demodulator

Another feature of a digital radio channel that differs from an analogue channel is that demodulating repeaters, and not IF repeaters, will be used. This enables regeneration to take place at each repeater. If IF modulation is used, an adequate number of cycles per symbol interval must be available for the modulation process. An IF of at least 6 times the numerical value of the symbol rate is currently favoured. However, direct RF modulation is still under consideration.

As in analogue systems, a number of radio channels will be multiplexed at RF to limit the number of aerials required. Where propagation difficulties are expected, height diversity with phase combining (described in Part 1) will be used. In addition, protection channels will be needed with automatic switching of the traffic when a main-channel equipment failure occurs.

Digital radio systems are still in the development stage and some features of the final operational equipment may differ from the example described. Research continues into techniques (for example, partial response signalling[17]) aimed at maximizing the digital capacity of the available frequency spectrum.

## PERFORMANCE

Before any new transmission technique is introduced, considerable effort is required in identifying the theoretical

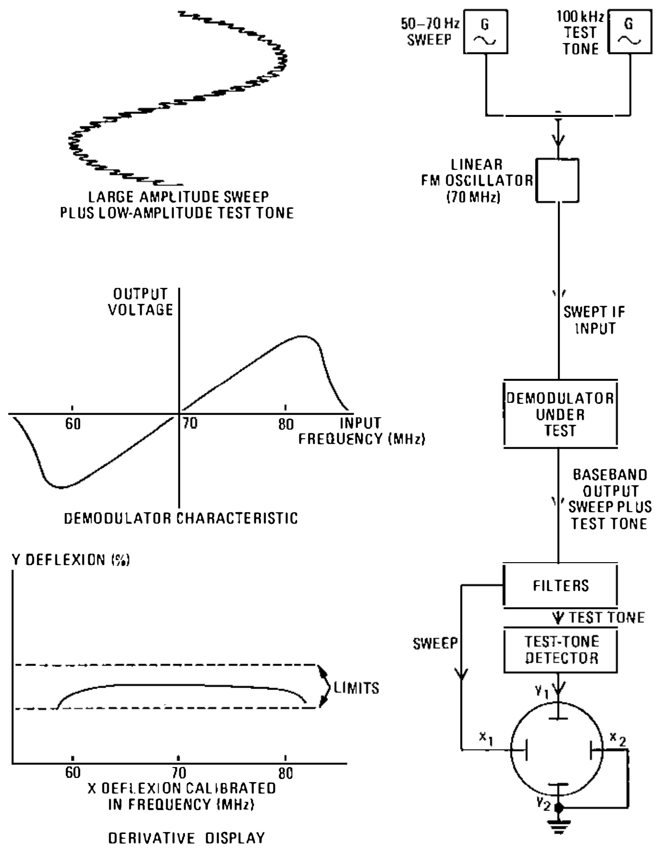
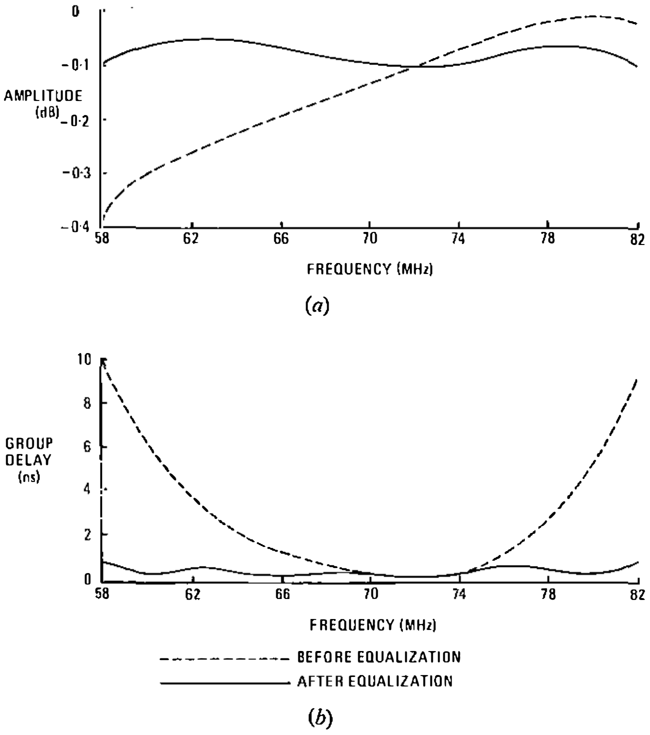


FIG. 12—Principle of derivative measurement



(*a*) Amplitude/frequency response
(*b*) Group-delay/frequency response

FIG. 13—Typical amplitude/frequency and group-delay/frequency responses

distortions introduced by the system. This is tested by experiment and practical experience, and a feedback process refines and improves the understanding of the problems involved. Internationally, meetings of the International Radio Consultative Committee (CCIR) give the opportunity for world-wide experiences to be interchanged, resulting in recommendations for key interfaces and performance objectives. These are generally aimed at achieving common standards for all transmission media since, ideally, whatever routing a telephone call takes, it should not affect the customer. The debate aimed at achieving this objective is well advanced for FDM/FM microwave links, but is still at an early stage for time-division-multiplex (TDM) systems.

### Cause and Effect of Distortion

In passing through the radio system, the signal is degraded by

(*a*) basic noise generated within the radio equipment,
(*b*) interference (noise), as described in Part 1, and
(*c*) distortions arising from the transmission characteristics

The basic noise, which is present whether or not a baseband signal is applied, consists of 2 component parts: fixed basic noise contributed by units within the system, and fade-dependent basic noise arising from the receiver input stages and varying inversely with incoming radio carrier level due to the AGC action of the receiver. The distortion effects in (*c*) give rise to intermodulation noise in telephony systems and waveform distortion in television systems. The effects of (*a*), (*b*) and (*c*) on digital radio transmission will result in errors, but the full extent is being investigated.

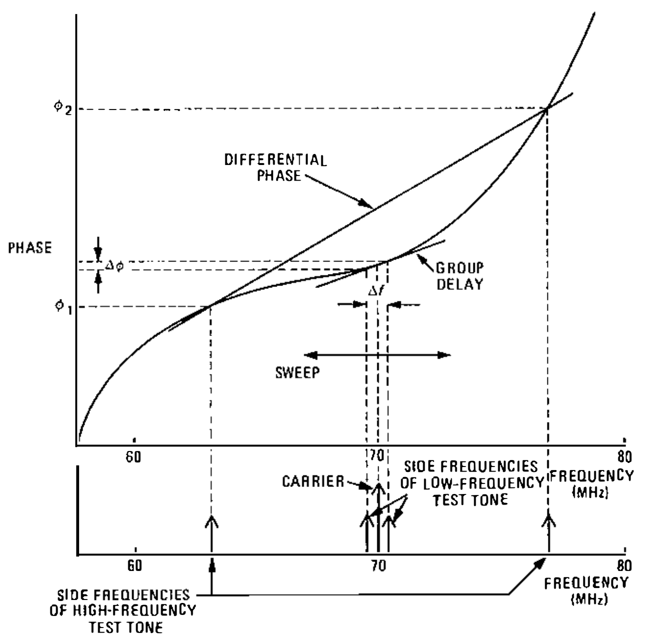
The transmission characteristics of radio-relay systems and their measurement have been described.[18] Modulators and demodulators must have highly-linear voltage/frequency transfer characteristics, and RF and IF stages highly-linear phase/frequency characteristics and uniform amplitude/frequency responses; impedance mismatches must also be avoided, particularly in the waveguide feeders.

Linearity is usually measured by plotting variations in the slope of the characteristics by causing a low-amplitude test tone signal of 100–200 kHz to be swept over the operational range (about 60–80 MHz at IF) by a very-low-frequency sweep signal (≈ 50 Hz). A test receiver monitors variations in the amplitude or phase of the test tone. Application of detected variations to the Y-plates of a cathode-ray tube and the sweep signal to the X-plates produces a plot of the response over the operational band. This method of measurement, applied to a demodulator voltage/frequency transfer characteristic, is shown in Fig. 12; for testing a modulator, the FM oscillator is not required since the sweep and test signal can be applied directly to the modulator input, but a highly-linear test demodulator must be used. The result thus obtained is normally referred to as the *derivative response* of the equipment under test. Overall linearity measurements are also made over the complete link, from modulator input to demodulator output.

Linearity of the phase/frequency characteristic in the IF and RF stages is usually measured at IF, the RF contributions being automatically included; this is called the group-delay response and has the dimension of time.

To measure the amplitude/frequency response of the IF and RF stages, a constant-amplitude test signal is swept over the operational range from about 60–80 MHz, variations after transmission through the equipment being monitored.

All these characteristics must be controlled within very tight limits; for example, the derivative response should not exceed a 1% variation over the operational band, the amplitude/frequency response must be controlled to about 0·1 dB per repeater section, and the group-delay/frequency response controlled to about 1 ns over a single repeater section. Fig. 13 shows typical amplitude/frequency and group-delay/frequency responses for one repeater section of an 1800-channel equipment, excluding distortions from aerials, feeders and path.



*Notes*: For low-frequency test tones, the deviation ratio results in second-order side frequencies being significant; for simplicity only the first pair are shown

The carrier and pairs of side frequencies are swept over the operational frequency range

FIG. 14—Measurement of phase/frequency response using low-frequency and high-frequency test tones

### *Differential Gain and Phase*

Radio channels aligned as above do not necessarily optimize telephony or television performance, and the reasons for this were intensively investigated in the late-1960s. Field experience, coupled with theoretical work,[19] have identified more complex distortion mechanisms involving amplitude-modulation–phase-modulation (AM–PM) conversion. This occurs in amplifiers, limiters, etc., and typical values are 0·5°/dB for an IF amplifier and 3°/dB for a TWA.

These more complex distortion mechanisms are revealed only if high-frequency test tones, of several megahertz, are used for the measurement of linearity characteristics. Tests made using these high-frequency test tones reveal responses termed *high-frequency derivative* or *differential-gain* and *differential phase* instead of group delay.

Fig. 14 shows the effect of measurements, using low-frequency and high-frequency test tones, resulting in the measurement of group-delay and differential-phase response respectively. This shows that using the high-frequency tones does not give a result equivalent to the gradient at any point of the phase/frequency response, but gives the mean slope between 2 extreme points. Nevertheless, this test simulates more accurately the effects experienced by the high-frequency components of the baseband signal. Fig. 14 also shows that the sweep amplitude must be reduced when high-frequency tones are used because the side frequencies produced would otherwise explore regions outside the operational band.

Differential gain and phase cause intermodulation noise in telephony systems and a distortion to the colour television waveforms that will be described later; the effects on digital signals are still being investigated.

The mechanisms producing differential gain and phase are best understood by examination of the following equations.[19]

$$DG(x) = 1 + [a''(x) + K\tau'(x)]\frac{\omega_t^2}{2} - [\tau'(x)]^2\frac{\omega_t^4}{8}, \text{ and}$$

$$DP(x) = [\tau(x) - Ka'(x)]\omega_t,$$

where $DG(x)$ is the differential-gain characteristic,
$DP(x)$ is the differential-phase characteristic,
$a(x)$ is the amplitude/frequency response,
$\tau(x)$ is the group-delay/frequency response,
$x$ is the swept carrier frequency,
$K$ is the AM–PM conversion factor,
$\omega_t$ is the test tone angular frequency,
$'$ is the first derivative with respect to $x$, and
$''$ is the second derivative with respect to $x$.

Differential gain depends on the second derivative of the amplitude/frequency response polynomial, which means that only third or higher-order terms of the response need be considered. Thus, even if the amplitude/frequency response appears well equalized, residual unequalized third or higher-order components will cause differential-gain distortion. The next term is the first derivative of the group-delay/frequency response polynomial, interacting with the AM–PM coefficient of the system. This arises because unequalized group-delay components disturb the phase relationships between the FM carrier and the pairs of side frequencies, thus destroying the constant-amplitude characteristic of a perfect FM signal. The amplitude variations thus produced are converted to phase variations by the offending units. The effects of AM–PM conversion can be reduced by ensuring that minimal AM is produced; this means group-delay/ frequency distortion must be equalized as soon as possible after it arises, and not mopped up at the end of the system. The equation, by identifying the first derivative of the group-delay/frequency polynomial, indicates that second or higher-order terms are particularly important in this respect. The final term also highlights the need to ensure as near to ideal group-delay equalization as possible.

Differential phase depends on the group-delay characteristic, and the first derivative of the amplitude/frequency characteristic interacting with the AM–PM coefficient.

The expressions for both differential gain and phase are particularly sensitive to the test-tone frequency chosen; the higher the test tone, the greater the certainty of revealing hidden distortions of this nature.

Microwave link analysers (MLAs), providing facilities for measuring all the features of the radio link including differential gain and phase, are now available[20]; these have greatly eased the alignment and maintenance procedures for microwave radio-relay systems, and also allowed the full performance potential to be achieved. The BPO is now investigating the use of computer-analysis techniques for optimizing the equalization of microwave radio-relay links.

Laboratory test equipment has been developed which enables AM–PM conversion to be measured directly. This allows the designer to develop new equipment having much lower AM–PM conversion than was previously possible.

## **Telephony on Analogue Systems**

### *Hypothetical Reference Circuit*

The most important considerations for analogue telephony transmission are noise, baseband gain/frequency characteristics and insertion-gain stability. The inherent advantages of FM, coupled with the use of high-grade modulators and demodulators, limiters and IF amplifiers with AGC, ensures satisfactory gain/frequency and gain-stability performance. Table 2 shows the specified value for these and other parameters.

Noise requires most attention from the equipment designer and the system planner, and is measured using white-noise testing techniques.[21,22,23] To recommend noise limits applicable to microwave radio-relay systems, the CCIR relates objectives to a hypothetical reference circuit (HRC), 2500 km in length, and sub-divided into 9 homogeneous baseband sections. Noise targets must be quoted statistically to cater for propagation variations. For links not differing significantly from the HRC, the psophometrically-weighted noise power

## TABLE 2

### Specified Performance for a Typical 3 Repeater-Section Analogue Microwave Link

| Parameter | Limit |
|---|---|
| Telephony (1800-Channel System) | |
| Baseband Spectrum | 0·312–8·204 MHz |
| Nominal RMS Deviation at −37 dBr at zero emphasis frequency | 140 kHz |
| RMS Deviation for Total Baseband at Busy Hour Loading | 1·057 MHz |
| Psophometrically-Weighted Noise Power in any Telephone Channel | −65 dBm0p |
| As Above, but with 30 dB Attenuation on any Repeater Section | −50 dBm0p† |
| Baseband Gain/Frequency Response (0·3–8·248 MHz) | ±0·7 dB |
| Baseband Gain Stability per Day | ±0·25 dB |
| per Month | ±0·5 dB |
| Baseband Signal/Crosstalk Ratio* | |
| Near-End Telephony–Telephony (below 400 kHz) | 65 dB |
| Telephony–Telephony (0·4–8·248 MHz) | 80dB |
| Television–Telephony (4·43 MHz) | 80 dB |
| Far-End | 80 dB |
| Television (625-Line PAL Colour) | |
| Baseband Spectrum | 50 Hz–5·5 MHz |
| Peak-to-Peak Deviation at Zero Emphasis Frequency (1·5 MHz) | 8 MHz |
| Luminance Channel | |
| Signal/Random Weighted Noise | 67 dB |
| As Above, but with 30 dB Fade | 48 dB |
| Signal/Unweighted Periodic or Spurious | |
| Noise Below 10 Hz | 30 dB |
| 10 Hz–1 kHz | 46 dB |
| 1 kHz–5·5 MHz | 58 dB |
| *K*-Rating | 1% |
| Step-Signal Response, Overshoot | 30% |
| Amplitude Non-Linearity | 3% |
| Chrominance Channel | |
| Signal/Random Weighted Noise | 65 dB |
| As Above, but with 30 dB Fade | 40dB |
| Differential Gain | ±1·5% |
| Differential Phase | ±0·75° |
| Luminance-Chrominance Inequalities | |
| Crosstalk | 1% |
| Delay Inequalities | ±20 ns |
| Gain Inequalities | ±5% |

† −50 dBm0p = 10 000 pW0p and is the fade-dependent noise target of 10 pW0p under 30 dB (1000 : 1) fading conditions

*Adjacent radio channels may carry television or telephony

## TABLE 3

### Equipment and Interference Noise Contributions

| Item | Noise (pW0p) |
|---|---|
| 9 sets of modems, fixed basic noise (30 pW0p each) | 270 |
| 63 TWAs and sets of oscillators, fixed basic noise (15 pW0p each) | 945 |
| 63 interference allowances (15 pW0p each) | 945 |
| 9 sets of protection switching equipment, fixed basic noise (10 pW0p each) | 90 |
| Total fixed basic and interference noise | 2250 |
| 9 sets of modems, intermodulation noise (25 pW0p each) | 225 |
| 63 transmitters/receivers, intermodulation noise (20 pW0p each) | 1260 |
| 63 repeater sections of feeder, intermodulation noise (20 pW0p each) | 1260 |
| Total intermodulation noise | 2745 |
| Total Equipment and Interference Noise | ≈5000 |

in any telephone channel at a point of zero relative level (pW0p) must not exceed

(*a*) 3$l$ pW0p mean power in any hour,

(*b*) 3$l$ pW0p 1 min mean power for more than 20% of any month, and

(*c*) 47 500 pW0p 1 min mean power for more than 0·1$l$/2500% of any month,

where $l$ is the route length (kilometres).

The time of 1 min was chosen because it represented the average duration of an international call.

To ensure these objectives are met, a system planner must first find out how the noise build-up will occur, how much the equipment designer needs and how much is dependent on the route planning. It is usual to plan to meet the most stringent requirement, knowing that the others will then be met.

### *Hypothetical Reference Circuit as Applied in the BPO*

In the BPO, the average length of one repeater section is 40 km, and a full HRC (2500 km) would consist of 63 repeater sections. Typical equipment and interference noise contributions for an HRC consisting of 9 baseband sections are shown in Table 3.

To conform to the 7500 pW0p HRC requirement, only 2500 pW0p remains for fade-dependent noise; the equivalent figure required to conform to the 47 500 pW0p objective is 42 500 pW0p.

### *Free-Space Fade-Dependent Noise*

The current BPO method for specifying fade-dependent noise is based on the work of K. W. Pearson,[24] and a full derivation is given in the Appendix. Studies using this method suggest that, for the BPO network, the fade-dependent noise per repeater section, under free-space (that is, no-fade) conditions, must not exceed

(*a*) 10 pW0p if the mean power in any hour objective is to be met, or

(*b*) 22 pW0p if the 1 min mean power for more than 20% of any month is to be met, or

(*c*) 13·5 pW0p if the 1 min mean power for 0·1% of any month is to be met.

These apply only to repeater sections of 40 km length, but Fig. 15 shows the variation with different repeater-section lengths of 40 m roughness.† The fade-dependent-noise target is of vital importance to the system planner since, for a given equipment and aerial, it determines the maximum attenuation that can be tolerated on a repeater section. Prior to Pearson's work, the 20% of the month target was thought to impose the severest constraint, but the above shows that the mean noise power in any hour is the deciding factor for a network such as that of the BPO.

Recently, the CCIR has extensively discussed the hourly mean noise objective, with some administrations wanting its withdrawal.

To achieve 10 pW0p per repeater section in the BPO network requires on most repeater sections a transmitter output power of 10–20 W which, in turn, requires a TWA output stage, since solid-state amplifiers cannot yet deliver this power at microwave frequencies.

## Television on Analogue Systems

### *Hypothetical Reference Circuit*

For analogue systems, the dominant feature for colour-television performance is the control of distortion of the television waveform. The targets for random noise are

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† Roughness factor is taken as the r.m.s. deviation of the path profile at 1·6 km intervals, excluding the terminals

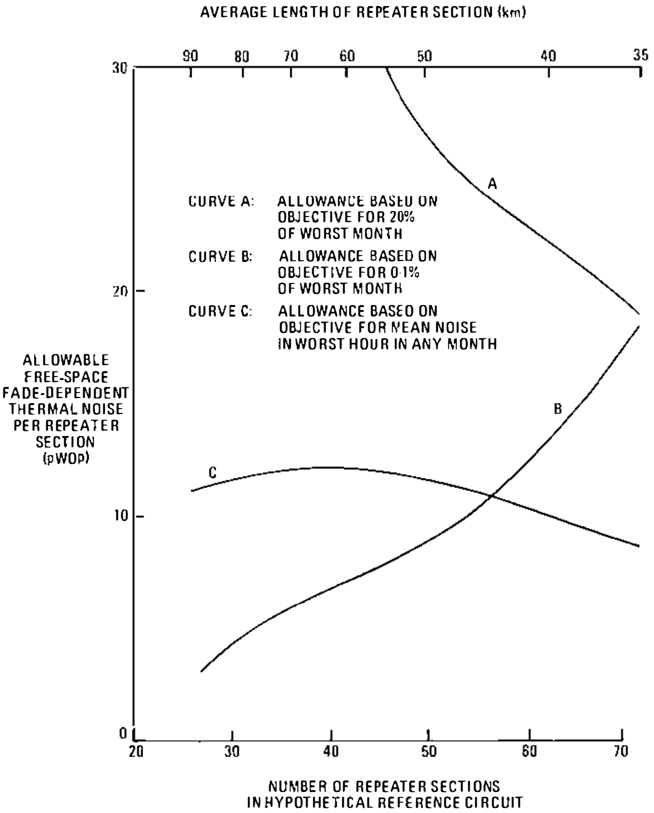

FIG. 15—Variation of fade-dependent-noise allowance with repeater-section length

easily met by radio-relay systems designed to meet the more stringent telephony objective. Periodic or spurious noise can, however, cause problems.

An HRC is again used, defined by CCIR for 625-line PAL colour television as one of overall length 2500 km, with 2 intermediate video points dividing the circuit into 3 sections of equal length.

### *Hypothetical Reference Circuit as Applied in the UK*

The general HRC concept is regarded as too simple to be representative of the UK national network and the BPO have agreed with the British Broadcasting Corporation and the Independent Broadcasting Authority to use a UK reference chain consisting of 4 main links (greater than 40 route kilometres and usually radio) totalling 805 route kilometres, 2 major local links (greater than 6–10 km and usually cable), and 6 minor local links (usually unamplified cable).

The UK national 625-line PAL colour-television service has a baseband signal consisting of a luminance channel extending up to 5 MHz, and a chrominance channel approximately 3·5–5·5 MHz. This does not imply restrictions on the transmission of luminance signal components in the range 5·0–5·5 MHz or of chrominance components below 3·5 MHz. For specification and testing purposes, it is convenient to deal with

(*a*) the permissible distortion and noise impairments in these 2 channels taken separately, and

(*b*) the permissible inequalities of gain and delay of the channels taken in association.

### *Noise*

Random noise is dealt with on a statistical basis for the UK reference chain recommendation and stated in terms of the ratio of the peak-to-peak signal (excluding synchronizing pulses) to the r.m.s. value of continuous random noise read on an instrument having a 1 s time constant. The objectives are

(*a*) for the luminance channel, the ratio should not fall below 52 dB (60 dB for a single main link) for more than 1% of any month, and

(*b*) for the chrominance channel, the ratio should not fall below 46 dB (54 dB for a single main link) for more than 1% of any month.

Table 2 shows the current BPO specification figures for random noise.

Periodic and spurious noise have a serious effect on television pictures, and experience has shown the need for rigid specification of this type of noise (Table 2).

### *Waveform Distortion*

The features of the radio link which cause intermodulation distortion in telephony distort the waveform of colour-television signals. Luminance-chrominance crosstalk is mainly determined by non-linearity of the transfer characteristics of modulators, demodulators and baseband amplifiers. Luminance-chrominance delay inequality depends on the IF group-delay characteristic, normally the parabolic content, and gain inequality depends on baseband, RF and IF gain/frequency response and impedance mismatches. The *K*-rating factor depends on baseband, IF and RF gain and phase characteristics.

A colour-television signal consists of a luminance signal, with a 4·43 MHz colour sub-carrier superimposed. Any unwanted variations in amplitude or phase of this sub-carrier with respect to the colour reference signal causes saturation and hue errors respectively. Variations in sub-carrier amplitude and phase occurring when the luminance signal changes in amplitude are termed *differential-gain* (or more logically *differential-amplitude*) and *differential-phase* distortion respectively.

Distortions must be stable with time for successful equalization. Instability caused many difficulties with the older generations of equipment, but is far less of a problem on modern radio links. Commissioning of the early links was very much a development activity, a problem not helped by the fact that many of the waveform limits were, and still are, close to the limit of measuring ability. A full account of waveform testing of television links is given in an earlier article.[25]

## **Digital Systems**

At present, digital radio-relay systems are under development in the BPO, and performance objectives are still being evolved both nationally and internationally. Also, the CCIR has not yet agreed the make-up of an HRC, but it seems likely to take a form similar to that recommended for analogue telephony.

The 2 basic performance parameters for a digital microwave system are jitter and error rate.

### *Jitter*

Jitter is the short-term variation of significant instants of a digital stream about their ideal position in time. It can be expressed as a function of time or as a spectrum. Jitter mainly arises in the regenerating process[26], either by external noise directly injected into the regenerator output or phase jitter in the frequency generated by the clock circuit. This latter form of jitter stems from

(*a*) noise on the received waveform that disturbs the location of the zero crossings,

(*b*) limitations of equalization,

(*c*) mis-tuning of the regenerator tuned circuit, and

(*d*) variations in the pulse-density patterns in the incoming waveform.

Jitter may prove to be the most important parameter in an integrated digital network. The BPO proposes to use the following objectives for jitter on a radio link.

(*a*) The jitter output, with no jitter on the input signal to the system, should not exceed 100 ps r.m.s. in the frequency range 5 Hz to 10 MHz for a 10-repeater-section system. The spectrum of the jitter should be limited to 100 Hz within a

3 dB bandwidth and should be attenuated at a rate not less than 6 dB/octave up to a frequency of at least 100 kHz.

(*b*) The jitter gain of the system, when there is jitter on the input signal, should be no greater than 0·1 dB for a 10-repeater-section system.

*Error Rate*

The CCIR are considering a recommendation for maximum error rates not to be exceeded for more than small percentages of time. For radio systems, errors will mainly occur during fades. To allow for this, an adequate fade margin has to be designed into the system. Consequently, for most of the time, when the RF signal is at or about free-space level, very few errors will occur. For example, on one digital radio system field trial in the UK, a period of 3 months elapsed before an error was recorded.

The proposed BPO objective is that the error rate should not exceed 1 in $10^5$ for more than $0 \cdot 1l/2500\%$ of any month, where $l$ is the length of the system (kilometres). The allowable error rate therefore applies to any length of link, but for different percentages of time in proportion to the ratio between the actual link length and the probable HRC length (2500 km); for example, on a 40 km repeater section, an error rate of 1 in $10^5$ could exist for only 0·0016% of any month (≈ 40 s). To ensure that this objective is met, fading statistics indicate that a 40 dB fade margin is necessary. Errors can arise from excessive jitter, noise, interference, or from distortions within the radio equipment such as errors in phase and amplitude of the modulation due to AM–PM conversion, group-delay distortion etc. The extent of these problems is still under investigation.

One of the main reasons for the choice of PSK is its immunity to errors due to interference. To illustrate this point simply, the information in Table 4 has been derived,[27] and this shows the level of interference causing an error in a 2-state system.

The level of interference to cause an error in a 2-phase PSK system is higher than that in either the equivalent frequency-shift-keyed (FSK) or AM system. It is dangerous to take this example too literally, because many assumptions have been made; for example, that the bandwidths are equal in each case. Nevertheless, it serves to illustrate the theoretical advantage of PSK.

## RELIABILITY

### Terminology

Reliability of microwave radio-relay systems was treated theoretically in an earlier article.[28] Before discussing it further, it is important to define the terminology used in the BPO.[29] Reliability is measured in terms of failure rate ($\lambda$) and its reciprocal, mean time between failures (MTBF). More precisely, $R(t) = e^{-\lambda t}$, where $R(t)$ is the reliability during the period $t$.

In considering maintainability, there must be an allowance for the mean time to repair (MTTR) faults, and maintainability during period $t$, $M(t)$, can be expressed as $M(t) = 1 - e^{-t/\mathrm{MTTR}}$

Availability combines reliability and maintainability. Equipment availability, $A$, is given by $A = \dfrac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MTTR}}$, and is usually calculated on a per-annum basis. Non-availability is simply $1 - A$.

### Use of Protection Channels

The service availability can be made greater than the equipment availability by providing protection equipment to carry the service when the main equipment fails. The service is then unavailable only when simultaneous failure of both main and protection equipment occurs or when common equipment such as the switch fails. Earlier articles[30,31] reviewed the development of protection switching and supervisory systems. The current BPO standard is the 7 + 1 IF switch (one protection channel for 7 traffic channels). On low-growth routes, however, a parallel-fed 1 + 1 channel arrangement is usually provided, with a simple baseband switch at the receive end. The improved reliability of modems now allows single modems per channel, instead of the pairs previously provided. Recently, multi-channel baseband switches have been developed that are fast to operate, free from transients and an advantage for maintenance testing; these will probably supersede the IF type.

In the BPO, protection channel arrangements are designed to safeguard against equipment failure and not against fading. An excessively deep fade can completely cut off a system and be as serious as equipment failure, but careful route planning and the use of diversity reduces this possibility to very low proportions. Some overseas administrations plan their systems with a form of protection switching designed to operate on detection of fades. It is argued that there is some protection against frequency-selective fading, as well as equipment failure. Some reasons for the BPO not adopting this approach are as follows.

(*a*) For channels to behave differently under frequency-selective fading conditions, the frequency spacing between the channels needs to be greater than 4%.[32] This spacing is not possible between all the main and protection channels within a frequency band.

(*b*) Unless one protection channel is provided for each main channel, the periods when the effects of fading are

**TABLE 4**

**Levels of Interference Causing an Error in 2-State Systems**

| Type of Modulation | Form of Modulated Signal | Interference Needed to Change 1 to 0 | RMS Level of Interference |
|---|---|---|---|
| AM | $1 = E \sin \omega t$<br>$0 =$ no signal | $-E \sin \omega t$ | $E/\sqrt{2}$ |
| FM<br>(FSK) | $1 = E \sin \omega_1 t$<br>$0 = E \sin \omega_2 t$ | $-E \sin \omega_1 t + E \sin \omega_2 t$ | $\sqrt{\left\{\left(\frac{E}{\sqrt{2}}\right)^2 + \left(\frac{E}{\sqrt{2}}\right)^2\right\}} = E$ |
| PM<br>(PSK) | $1 = E \sin \omega t$<br>$0 = -E \sin \omega t$ | $-2E \sin \omega t$ | $\sqrt{(2)}E$ |

### TABLE 5

**Service Availability of BPO Microwave Network**

| Year<br>Item | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|---|---|---|---|---|---|---|
| Total Unidirectional Channel Length (× 100 km) | 141·77 | 161·28 | 191·35 | 276·41 | 333·05 | 368·98 |
| Unidirectional Channel Repeater Sections | 340 | 394 | 479 | 688 | 826 | 904 |
| Service MTBF per 100 km (d) | 331 | 317 | 367 | 493 | 546 | 450 |
| Service Availability per 100 km, Unidirectional (%) | 99·9911 | 99·9966 | 99·9942 | 99·9964 | 99·9977 | 99·9979 |

reduced must be less than optimum; BPO systems often have 7 main and one protection channels.

(*c*) If the protection channel is required to protect against fading, its value for occasional-user traffic is reduced. Protection channels are in great demand for occasional television circuits and Confravision on the understanding that the service is secondary to the traffic on the main channel.

## Availability of the BPO Network

The service non-availability objective for a unidirectional channel in the BPO analogue microwave network is tentatively set at $0{\cdot}06l/1000\%$ per annum, where $l$ is length (kilometres). This recognizes that longer routes have more equipment and hence greater risk of failure. This leads to the service availability objective of 99·994% per 100 km, derived from the original objective of 99·99% per 100 miles. Table 5 records the service availability achievements for the BPO microwave network.

The service availability objective has been met except in 1970 when all-electronic-tube equipment dominated the network. To demonstrate the reliability of modern equipment, Table 6 gives the calculated average MTBF per transmitter-receiver pair for the equipment in the network in 1974–75.

### TABLE 6

**Average MTBF per Transmitter-Receiver Pair**

| Type of Equipment | MTBF† per Transmitter-Receiver Pair (d) | |
|---|---|---|
| | 1974 | 1975 |
| All Electronic Tube | 43 | 39 |
| Hybrid (Solid-State except for TWA) | 199 | 219 |
| All Solid-State | 671 | 636 |

† Average value calculated from $\frac{\text{total days} \times \text{number of transmitter-receiver pairs}}{\text{number of faults}}$

The all-electronic-tube example represents the oldest equipment. Hybrid equipment is the current main line standard. Compared with the all-solid-state figures, the TWA seems to produce a much lower reliability. The TWA, however, is not necessarily an unreliable device. The hybrid equipment is higher powered than the all-solid-state examples and there is strong evidence that the extra heat dissipation lowers the MTBF of other units in the equipment. Also, BPO experience is that the high-voltage power unit for the TWA has a lower MTBF than the rest of the equipment; this may be a feature of its complexity. Nevertheless, an all-solid-state replacement for the TWA offers the prospect of improved equipment reliability.

## CONCLUSIONS

Part 1 of this article discussed history and planning, and this part has discussed performance and reliability of the BPO microwave radio-relay network. Part 3 will describe equipment aspects.

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## APPENDIX

### Derivation of Noise Specification from CCIR Recommendations

This article shows that fade-dependent noise allowances of 2500 pW0p, 2500 pW0p and 42 500 pW0p can be made for the hourly mean, 20% of the worst month and 0·1% of the worst month periods respectively, for a 2500 km link. To derive from these figures readily-applicable planning rules for the free-space fade-dependent noise allowable on each repeater-section, calculations must be based on propagation conditions and fading characteristics likely to be experienced.

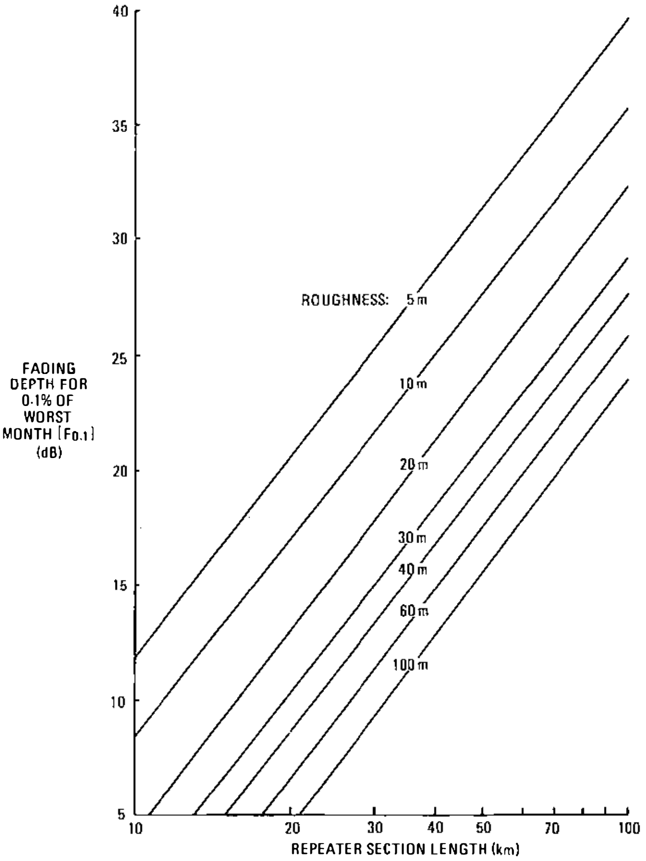

FIG. 16—Fading depth for 0·1% of the worst month ($F_{0.1}$) against repeater-section length and roughness

Measurements on repeater sections in the BPO network,[11] having 0·577 first Fresnel zone clearance when $k = 0·7$, show that for fading depths in excess of 10 dB relative to free-space level, the slope of the fading depth is 10 dB/decade of probability of occurrence. Results vary with length and roughness of the repeater section considered. From these results, K. W. Pearson[24] derived a planning technique which, with slight modification, is now used by the BPO.

*Summary of K. W. Pearson's Work*

(*a*) *Single Repeater-Section Links* Fading can be simulated by the sum of 2 probability distributions: for fades down to 10 dB below free-space level, the probability follows a log-normal curve, while below 10 dB, it has a Rayleigh characteristic, with a slope of 10 dB/decade. A family of curves is produced (Fig. 16), relating fading depth for 0·1% of the worst month to repeater-section length and different roughness factors; this family of curves is termed $F_{0.1}$. For a single repeater section, it is partially derived and partially deduced empirically that, for any hour (including the worst), the average fade depth is

$$8·5 + 0·3\,(F_{0.1}) \text{ dB relative to free-space level. } \ldots\ldots \quad (1)$$

Also, for a single repeater section for any month (including the worst), the relationship between depth of fade and percentage of time such fading exists is derived for different values of $F_{0.1}$ shown in Fig. 17.

(*b*) *Multi-Repeater-Section Links* For multi-repeater-section links, it is concluded that, for small percentages of the month (0·1%) and for $n$ repeater sections of equal length, the noise exceeded for the complete link for $x$% of time will equal the noise exceeded for $\frac{x}{n}$% of time on one repeater section, since high noise peaks are unlikely to occur simultaneously on all repeater sections. For unequal repeater-section lengths, it is suggested that taking $\frac{x}{n}$% of time for the longest path will yield sufficiently accurate results. In either case, for a given repeater section and knowing the value of $F_{0.1}$, $\frac{x}{n}$% can be calculated and the fade depth read directly from Fig. 17.

A similar approach is proposed for the 20% of the month target, except that it cannot be assumed that the other repeater sections make no contribution. By trial convolutions of the distributions in Fig. 17, a fade allowance of 2 dB fade on each of $n-1$ repeater sections is proposed. The fade depth on the remaining repeater section (the longest for unequal sections) for $\frac{20}{n}$% of the time can be read from Fig. 17 for the appropriate value of $F_{0.1}$.

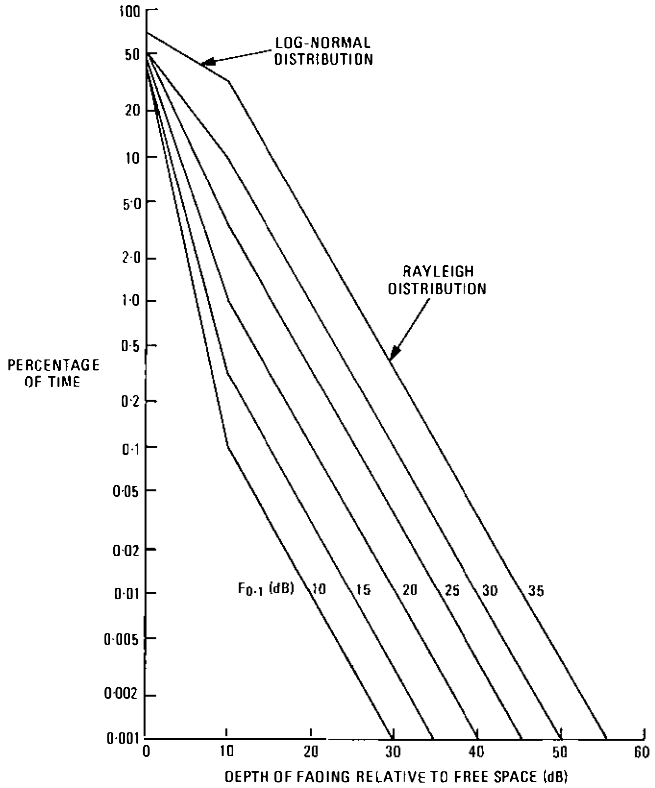

FIG. 17—Relationship between depth of fade and percentage of time such fading exists for different values of $F_{0.1}$

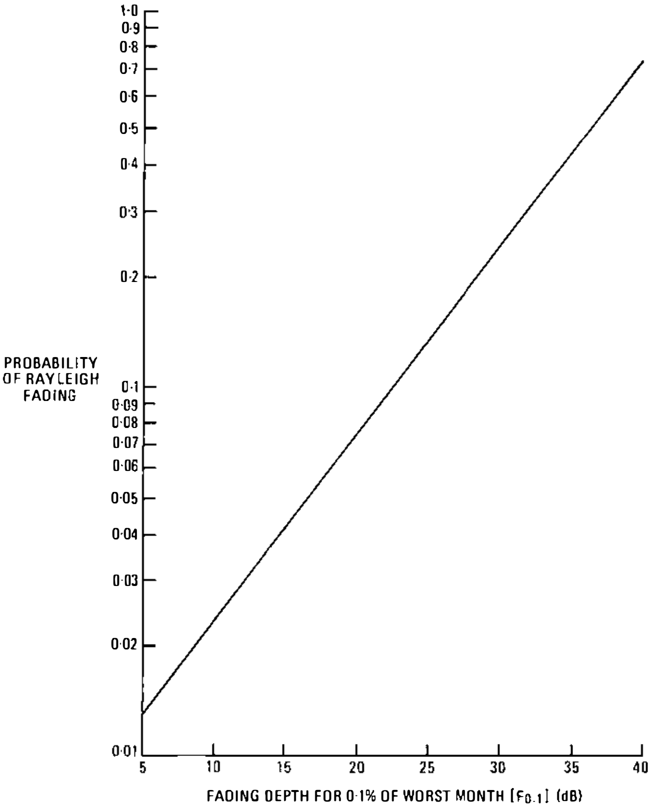

FIG. 18—Probability of Rayleigh fading

The hourly mean fade is complicated to derive for multi-repeater-section links. Fading occurs mainly at sunrise and sunset and for only about 6–8 h/d in the worst month (≈200 h/month). So a new graph is produced (Fig. 18) relating probability of Rayleigh fading and $F_{0\cdot 1}$ values to allow for this factor. For many repeater sections in tandem, it is postulated that the probability of a number of these experiencing Rayleigh fading is a binomial distribution and, for many repeater sections, this approximates to a normal distribution. Thus, for an $x$% certainty that less than $r$ repeater sections are suffering Rayleigh fading, it can be shown that

$$r = np + y\sqrt{\{np(1-p)\}}, \qquad \ldots\ldots(2)$$

where $n$ is the number of repeater sections in the link, $p$ is the probability of Rayleigh fading from Fig. 18, $y$ is the number of standard deviations for $x$% certainty, and $\sqrt{\{np(1-p)\}}$ is the standard deviation.

The remaining repeater sections $(n-r)$ will be suffering non-Rayleigh fading and it is suggested that a 1 dB fade on each is likely.

*Application to BPO Network*

The fade-dependent-noise limits for an HRC, made up of repeater sections of 40 km average length, each of 40 m average roughness, gives $F_{0\cdot 1} = 17$ dB from Fig. 16, and

$n = \dfrac{2500}{40} \approx 63$ repeater sections in the HRC.

(*a*) *0·1% of the Month Objective* To comply with the 0·1% objective the 42 500 pW0p for the HRC is subdivided on a time basis. For $n = 63$ equal repeater sections of 40 km length and $x = 0{\cdot}1\%$, the target per repeater section is $\dfrac{x}{n} = \dfrac{0\cdot 1}{63} = 0{\cdot}0016\%$.

For a repeater section of $F_{0\cdot 1} = 17$ dB and 0·0016% of time, from Fig. 17, the fade depth will be 35 dB (3160:1). Thus, the 0·1% of any month target for free-space fade-dependent-noise per repeater section becomes $\dfrac{42\,500}{3160} = 13{\cdot}5$ pW0p.

(*b*) *20% of the Month Objective* To calculate the free-space fade-dependent noise per repeater section to meet the 20% of the month noise target, one repeater section is taken to experience noise exceeded for $\dfrac{20}{n}$ % of time and the remainder an average fade of 2 dB each. For the one repeater section, the time $= \dfrac{20}{63} = 0{\cdot}32\%$ and, from Fig. 17, with $F_{0\cdot 1} = 17{\cdot}0$ dB, the fade exceeded for 0·32% of the month on one repeater section = 12 dB (15·6 : 1). The remaining 62 repeater sections each suffer a fade of 2 dB (1·6 : 1).

Therefore, total fade $= (1 \times 15{\cdot}6) + (62 \times 1{\cdot}6)$, and average fade per repeater section $= \dfrac{(1 \times 15\cdot 6) + (62 \times 1\cdot 6)}{63} = 1{\cdot}81 : 1$ or 2·5 dB. With the noise for 63 repeater sections equal to 2500 pW0p, the 20% of the month target for free-space fade-dependent noise per repeater section $= \dfrac{40}{1\cdot 8} = 22$ pW0p.

(*c*) *Hourly Mean Noise Objective* To calculate the free-space fade-dependent noise per repeater section to comply with the hourly mean noise recommendation, it is noted that 1 h is about 0·5% of the average fading of 200 h/month. For a normal distribution, in equation (2), $y = 2{\cdot}57$ standard deviations for $x = 99{\cdot}5\%$ certainty. From Fig. 18, for $F_{0\cdot 1} = 17$ dB, $p = 0{\cdot}05$; substituting in equation (2) gives

$$r = 63 \times 0\cdot 05 + 2\cdot 57\sqrt{\{63 \times 0\cdot 05\,(1 - 0\cdot 05)\}},$$
$$= 7\cdot 59 \text{ repeater sections.}$$

If 7·59 repeater sections are suffering Rayleigh fading, there will be 63 − 7·59 = 55·41 repeater sections suffering the average 1 dB (1·26 : 1). From equation (1), the depth of Rayleigh fade for each of the 7·59 repeater sections will be

$$8\cdot 5 + 0\cdot 3(F_{0\cdot 1}) = 13\cdot 6 \text{ dB } (22\cdot 9 : 1).$$

Therefore, the total fade for the 63 repeater-section HRC during any hour will be $(7{\cdot}59 \times 22{\cdot}9) + (1{\cdot}26 \times 55{\cdot}41) = 243{\cdot}9 : 1$ or 23·86 dB. Distributing this evenly between the 63 repeater sections gives the equivalent fade per repeater section $= 23{\cdot}86 - 10\log_{10} 63 \approx 6$ dB.

The 2500 pW0p fade-dependent noise allowance available for 63 equal-length repeater sections gives 40 pW0p per repeater section. But each repeater section must be calculated to assume a 6 dB fade; thus the mean hourly target for free-space fade-dependent noise per repeater section is $\dfrac{40}{4} = 10$ pW0p.

The most stringent parameter for planning purposes is the hourly mean noise, which sets a free space fade-dependent-noise limit of 10 pW0p for an average repeater section of 40 km. Fig. 15 shows how the CCIR targets for free space fade-dependent noise vary for different repeater-section lengths.

Pearson's method is open to some criticism in that it is based on a number of assumptions and some of the rules are empirical rather than derived. Nevertheless, the results for the allowable free-space fade-dependent noise per repeater section are not totally out of step with other methods of interpretation of the CCIR Regulations which, in many cases are not as rigorous as Pearson's method, even allowing for the above criticisms.

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# Book Review

*Scientific Analysis on the Pocket Calculator*. J. M. Smith. John Wiley & Sons Ltd. x + 380 pp. 52 ills. 73 tables. £6·50.

The modern pocket calculator gives engineers, scientists, mathematicians and other practitioners extensive and versatile portable computing facilities. The author states that the aim of the book is to supply a large number of numerical techniques and approximations, tables, useful graphs and flow charts for performing quick and accurate calculations to "help the reader derive the most computing capability for every dollar he has spent". In this useful book, he largely succeeds in this aim.

The book is based on the use of 3 representative hypothetical calculator types: the simple 4-function machine, the engineering/scientific machine, and the programmable pocket calculator. For the 3 types, 10-digit registers with floating-point arithmetic and scientific notation are assumed in the methods and examples given in the text.

The book is in 4 parts. Part 1 examines and compares the characteristics of present calculators, dealing with instruction and data-entry methods, memories, instruction sets, languages and methods of calculation. The evaluation of scientific functions is introduced from 2 approaches: one using the power-series form of functions and the other using curve-fitting polynomials. In both cases, the text lists formulae for the more common functions, expressed in nested-parenthetical form to minimize key operation and enable direct evaluation. Introduction to the topics of accuracy of evaluation and the minimizing of error propagation are well dealt with. A chapter devoted to data interpolation and smoothing introduces difference tables and the interpolation formulae of Newton, Stirling, Bessel and Lagrange.

Part 2 deals with elementary analysis and numerical evaluation of advanced mathematical functions, such as progressions, infinite series, the solution of polynomials, transcendental functions (approximated by Chebyshev polynomials), and complex variables and functions.

Mathematical formulae, coefficients and constants are stated for methods of evaluating: exponential, sine and cosine integrals; the gamma function, error function and Fresnel integrals; Legendre and Bessel functions; confluent hypergeometric functions; and Chebyshev, Hermite and Laguerre polynomials.

Part 3 moves to advanced analysis, with chapters on Fourier analysis, numerical integration (including Bode, Newton-Cotes and Runge-Kutta methods), simulation of linear systems, derivation of Chebyshev and rational polynomial approximations for analytic substitution, determination of roots of functions, statistics and probability.

Part 4 is devoted to methods of analysis using the advanced programmable pocket calculator, and the 4 appendices include matrix analysis for up to 3 × 3 matrices, complex numbers and fractions and, finally, key-operation sequences for complex-variable analysis and hyperbolic functions.

Generally, throughout the text, typical key-operation sequences are given where applicable, and the accuracy and error-magnitude considerations of the methods used are examined. This is an absorbing book, filling a gap in the literature at this time, but contains, in this first edition, too many minor typographical and other errors.

H. A. R.

# Reliability Targets for Telephone Exchanges

P. DEAN, B.TECH.†

UDC 621.395.722:621.3.004.6

*This article outlines some of the more important reliability and quality-of-service requirements that have been applied to recent types of common-control telephone exchange system, and illustrates a simple technique for reliability prediction.*

## INTRODUCTION

As the provider of a public telephone service, the British Post Office (BPO) needs to ensure, on behalf of its customers, that telephone exchange systems for use in the public network are capable of providing reliable service over an extended period.

In seeking to provide the required degree of reliability, the aim is not to develop highly reliable equipment at any cost, but rather to provide an acceptable and economic telephone service to customers. A measure of how successfully this is achieved is embodied in the term *quality of service*, and it is this which is specified in the Post Office Requirements and Strategic Network Plan series of documents, through which the BPO states the facilities it wishes to be incorporated in new developments, and against which offered designs are evaluated.

This article is not intended to be an exhaustive treatment of a complex subject, but does outline some of the more important reliability and quality-of-service requirements that have been applied to recent types of common-control telephone exchange system. A simple technique for reliability prediction is also illustrated.

## QUALITY OF SERVICE AND RELIABILITY

In considering the level of reliability that should be expected of telephone exchange systems, it is necessary to bear in mind all the factors that together influence the quality of service experienced by the customer.

Quality of service is a measure of how effectively service is provided, and includes

(*a*) predictable and planned levels of call-attempt failure, characterized by grade-of-service[1] figures,

(*b*) failures that cause disruption of service and to which numerical limits can be attached (for example, calls for which no tone or number-unobtainable tone is received, or for which the transmission performance is inadequate), and

(*c*) failures that give rise to customer dissatisfaction but whose frequency of occurrence is more difficult to predict.

Equipment reliability is, therefore, only one of the several complementary means by which an acceptable quality of service can be achieved. It is one aspect of *system effectiveness*, which can be regarded in this case as the ability of an exchange to provide services and facilities in a reliable and predictable way.

Other factors contributing to equipment reliability are:

(*a*) *maintainability*, which is the readiness with which an exchange can be maintained in, or restored to, its working state,

(*b*) *availability*, which is the proportion of time for which the exchange is in a working condition, and

(*c*) *integrity*, which is the immunity of exchange operations from errors and corruption.

Definitions of these and other reliability-based terms are contained in British Standards Institution specifications[2], and several have precise statistical meanings.

The reliability of an item is defined in terms of the probability that it will perform its required function for a specified period of time.

## QUALITY-OF-SERVICE DESIGN TARGETS

The types of quality-of-service target described below are examples of those applied to recent designs of common-control telephone exchanges. The requirements have been chosen to limit the kinds of service failure that are especially to be avoided, the intention being that an exchange design meeting the requirements will provide a good general level of service to its users. Exchange systems must be capable, at least theoretically, of providing the required level of reliability, and a later section of this article shows that it is possible to predict whether the requirements will be met by a given design.

The targets are mostly in the form of mean-time-between-failures (MTBF) figures for specified types of failure. Given certain assumptions[3], an MTBF figure can be taken to be the reciprocal of the corresponding failure rate, which is expressed in failures per unit time.

### Complete Loss of Service

MTBF figures are specified with the intention of limiting the frequency with which customers suffer complete loss of telephone service through the action of exchange faults. The general principle adopted is that the greater the number of subscribers or inter-exchange circuits that would be affected by any given fault, the less frequently the fault should be allowed to occur; that is, the greater should be the MTBF figure applied. Although a general and continuous relationship could be devised between the severity of a failure and the MTBF figure to be associated with it, a small number of steps has been used in practice. MTBF figures of between 10–200 years have been applied to the following increasingly severe categories of failure.

(*a*) *Loss of Service to Individual Subscribers* This results typically from the failure of equipment such as line circuits, which are provided on a one-per-subscriber basis.

(*b*) *Loss of service to Groups of Subscribers* A group size of 10% of the exchange's capacity (or 400 subscribers, whichever is the less) has been taken to represent failures that are significantly more serious than those in category (*a*), but which do not constitute an exchange breakdown. Depending on the size and design of an exchange, equipment items such

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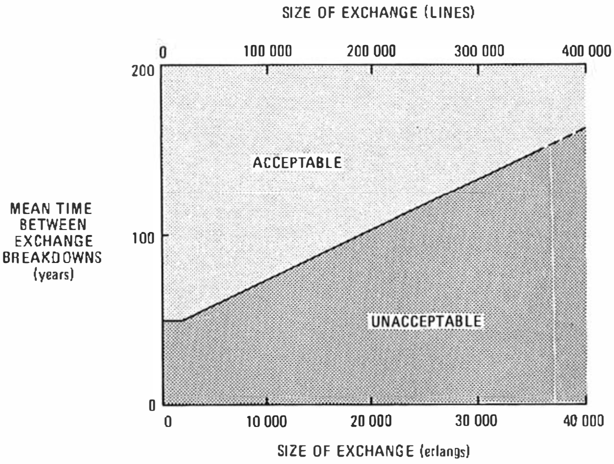


FIG. 1—Limitation of exchange breakdowns

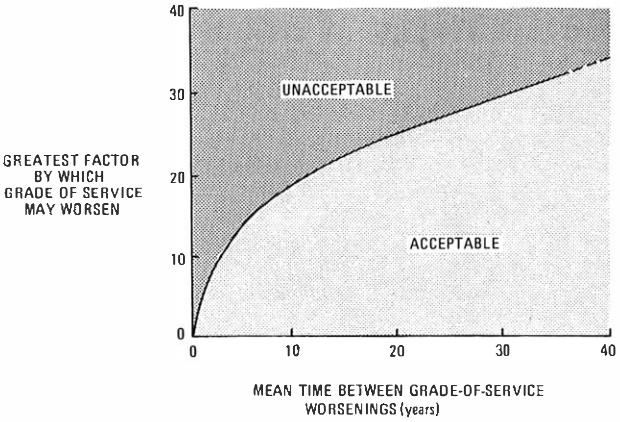


FIG. 2—Limitation of service degradation

as directory-number–equipment-number decoders, and other equipment units dedicated to serving a group of subscribers, may fall into this category.

(*c*) *Exchange Breakdown* For the purpose of failure definition, exchange breakdown is considered to occur when exchange or line faults cause loss of service to more than 50% of subscribers, or to more than 50% of the inter-exchange circuits terminated on the exchange. Again, the principle applied is that the larger the exchange, the less often it is permitted to suffer a serious loss of the ability to switch traffic. There results a size-dependent MTBF requirement that takes the form shown in Fig. 1. The capacity of existing exchanges, both local and main-network, confines them to the lower region of the graph. The loss of a very large quantity of traffic is more relevant to the case of the central control of several exchanges, where the consequences of failure at the central point are much greater.

### Service Degradation

In the case of total loss or denial of service, it is possible, at least theoretically, to determine the number of subscribers or circuits that would be affected by a failure at a given point in the exchange design. However, a rather more general measure of the fault liability of an exchange is the proportion of its designed traffic lost indiscriminately through the action of faults; that is, the proportion of call attempts that fail in the exchange without consistently affecting the service to any particular subscribers. In such circumstances, the exchange is considered to be offering a degraded service rather than denying service to particular users. The term *worsening of grade of service* is often used to describe such a situation, although a grade of service is a design figure and, strictly speaking, cannot vary.

This type of failure is likely to result, therefore, from faults on common equipment; that is, from equipment items provided in sufficient quantities to meet the designed level of traffic. The loss of a proportion of such equipment leaves the remainder less able to handle the traffic, and the result is as though a worse (numerically higher) grade of service is in force. Depending upon the particular exchange design, equipment items that are likely to give rise to this type of failure are those performing the register, supervisory and call-processing functions (the last of which, in the case of TXE4 exchanges[4] for example, is divided on a load-sharing basis between several main control units). In addition, certain types of failure within equipment units that select and allocate such items for use on individual calls can also cause service degradation.

The requirement applied to limit service degradation is shown in Fig. 2.

### Route Isolation

With the exception of accidental and unpredictable mechanical damage to circuits between exchanges, a limit has to be placed on the loss of service on such circuits due to failures within the exchanges they interconnect. This is of particular importance where an exchange gains all but its own-exchange service via the link to another exchange. The limit applied to the loss of service on inter-exchange circuits varies from once in 5 years to once in 20 years, depending on the capacity of the route.

A predictable event with less serious consequences is the loss of some, but not all, circuits on a route. Sufficient circuits are provided to meet a grade of service defined to cover both the switching element and the route. A restriction of access to these circuits effectively reduces the grade of service, and a potentially greater number of calls is lost. This situation may be brought about by faults within such items as supervisory relay-sets and supervisory selectors, with the result that access to a number of circuits on a route is prevented.

Route isolation occurring on a large scale could, therefore, constitute an exchange breakdown.

### Miscellaneous Failures

No less important than those described above is a range of failures that directly affects the service seen by customers, and by which the customer may choose to judge the performance of the system. In consequence, exchange designs are required to be capable of limiting the occurrence of misroutings, false incoming calls, abortive call-attempts, premature clearing-down of calls, metering errors and other specified events.

## RELIABILITY PREDICTION

The need for continuity of service is reflected in the high MTBF figures applied to exchange operation. It is not feasible, however, to test prototype exchanges over comparable periods prior to acceptance of the design, although individual components can be subjected to the equivalent of thousands of hours of operation. Consequently, the long-term performance of new types of exchange must be predicted rather than tested. The main elements of prediction are

(*a*) failure-rate information for the components of the exchange,

(*b*) a knowledge of the structure of the exchange,

(*c*) a set of working assumptions, and

(*d*) a prediction method to relate the above information to give performance figures for the exchange as a whole.

Although reliability estimates are uncertain when applied to individual new designs of exchange, they are probably far less erroneous when used for comparing new and competing designs that use broadly the same technologies.

## Component Failure Rates

In addition to data produced by component manufacturers, the BPO publishes guide figures on failure-rate information (usually expressed in failures per 1000 components per annum) for components of which it has field experience. As well as the tolerance assigned to failure rates, uncertainties can exist due to the assumption of failure rates for components used in a novel application, or to a design including components of which little experience is available. The use of failure-rate information in calculations is based on the assumption of a correct electrical and physical operating environment.

## System Description

Exchange specifications require the designer to provide a sufficiently detailed description of the exchange to allow confidence in the results of the prediction exercise. The following factors must be known:

(*a*) the physical make-up of the exchange,

(*b*) the functions of the sub-units of the exchange,

(*c*) the number of items providing the functions,

(*d*) the physical and functional interconnexions of the sub-units,

(*e*) the nature of any redundancy, or other arrangements included to safeguard exchange performance, and

(*f*) the environmental conditions under which the equipment is to operate; these can affect (sometimes seriously) component failure rates.

## Assumptions

Reliability calculations must reflect the way in which the exchange system is to be maintained. Because of the difficulty in estimating the effect on reliability of a given maintenance policy, a single parameter has been used to characterize maintenance: the *mean time to repair* (MTTR). The MTTR is the average time taken to locate and rectify a fault and, for reliability calculations, is taken to be 5 h. Although this figure is a compromise, since actual equipment-out-of-service times vary considerably, it does play an important part in determining the level of equipment redundancy necessary (for example, duplication or triplication of equipment) to achieve the required MTBF figures.

Quality-of-service requirements for existing systems distinguish between self-healing and permanent faults by adopting the working rule that detected faults which the exchange does not take automatic measures to remedy within a period of 10 min are regarded as permanent and needing manual attention. The change-over of security sections in theTXE2 systems[5,6] is an example of an automatic self-healing action.

## Prediction Methods

Several techniques are available for reliability prediction, and certain approaches are more suited than others to analysing particular systems. For common-control switching systems, a method has been suggested which is aimed at comparing a design directly with the quality-of-service parameters outlined earlier. Since these parameters relate to the service seen by the customer, the prediction seeks to realize a direct measure of this performance. The prediction requires that the exchange be analysed to determine the possible ways in which each part of the system can fail; that is, to identify the failure modes and, for each mode, to estimate the likely influence on exchange performance. For later versions of TXE4, it has not been assumed, as was the case with earlier common-control exchanges, that all components of an equipment unit are series-connected from a reliability point of view so that the unit is critically dependent upon each component (a worst-case assumption). Rather, attention is paid to the real contribution that components and units make towards the various classes of failure. This represents a limited version of a technique known as *failure modes, effects and criticality analysis*, originally developed for space applications by the National Aeronautics and Space Administration as a means of predicting even the most unlikely combinations of events that might lead to system failure.

As a brief example, a particular exchange design may be examined to predict how often a group of subscribers would lose service through the action of internal faults. The general approach would be to identify

(*a*) those equipment items for which a failure of any one could give rise to this level of failure independently of the others, and

(*b*) those items that would give the same failure event by failing in combination.

Representing the first type diagrammatically gives the series-dependent weakest-link-in-the-chain arrangement shown in Fig. 3, in which failure of any sub-unit, A, B or C, is critical for the system. In situations where the failure rate is constant[3], such an event occurs at a rate equal to the sum of the failure rates of the sub-units. The diagram shows how the items are connected from a reliability standpoint, and does not necessarily represent the physical interconnexions.

The second type characterizes the parallel-reliability situation, in which the particular failure event is produced only if a number of similar items fail together (strictly, within the MTTR). Fig. 4 illustrates a case in which failure results from the loss either of sub-unit D or all 3 sub-units of type E. Assuming repair within an average time $T$ years (the MTTR), this combination of equipment items fails at a rate given by

$$\lambda_D + N\lambda_E{}^N T^{N-1} \text{ failures/year,}$$

where $\lambda_D$ and $\lambda_E$ are the failure rates of sub-units D and E respectively (failures/year), and $N$ is the number of parallel units (in this case, 3).

The general form of the second term of this expression for the failure of $F$ out of $N$ parallel units is

$$\frac{N!\lambda^F T^{F-1}}{(F-1)!(N-F)!} \text{ failures/year.}$$

This relationship can be used to determine how frequently a grade-of-service figure would be effectively worsened by failure of a proportion of items such as registers which, from a reliability point of view, are connected in parallel. An additional factor can be incorporated to compensate for the

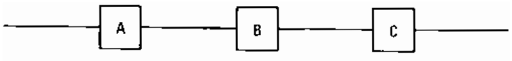


Fig. 3—Series reliability diagram

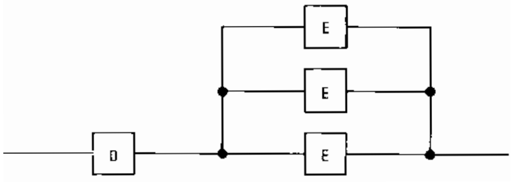
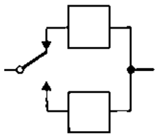
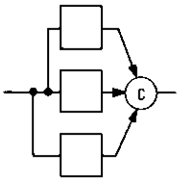
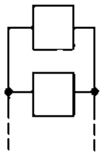


Fig. 4—Series-parallel reliability diagram

**TABLE 1**

**Examples of Equipment Redundancy**

| Type | Block Diagram | Remarks |
|---|---|---|
| Worker-and-Stand-by |  | A form of duplication with only one unit working at any time. Change-over can be periodic (as with the security sections of TXE2 exchanges) or on the detection of failure |
| Majority-Decision |  | Often involves triplication. An extra element, C, is needed to compare the outputs for consistency. An example of the use of a majority-decision arrangement is the pulse generator in TXE4 exchanges |
| Load-Sharing |  | All items are available for use simultaneously (no standing-by arrangement). Examples of this type of arrangement are the registers and main control units in TXE4 exchanges, where the item to be used is selected from a common pool |

fact that only during periods when an exchange is busy do such types of failure put the grade of service at risk. Also, the presence of any built-in escape mechanisms, such as repeat-attempt facilities or the ability to bypass faulty equipment, can lessen the reduction in grade of service, and their effect needs to be assessed.

A further complication involves considering the nearly simultaneous failure of different types of equipment item; that is, considering the effect of a particular failure mode in one item taken with particular failure modes in different items. For this, more complex techniques are necessary to analyse transitions between the various possible failure states to calculate MTBF figures for system failure.

## ACHIEVING RELIABILITY

Quality-of-service requirements must be translated by the equipment designer into suitable measures and procedures and, as a result, a number of different equipment arrangements may be available to meet the target figures. The particular measures adopted in a design are, within limits, of little consequence to the user of the system, provided it can be shown that the required long-term performance will be met. The cost, level of maintenance effort and spares requirements implicit in a design are important factors in assessing its acceptability. Other factors are

(*a*) the selection and use of components best suited to the application,

(*b*) the use of efficient fault-detection techniques incorporated into the design, and

(*c*) the use of various forms of equipment redundancy to add fault-tolerance to the exchange performance.

Table 1 gives examples of 3 different equipment arrangements that are used to perform a particular function in a more reliable way.

## SUMMARY

One of the principal standards by which telephone service is judged is its quality of service, some aspects of which have been discussed in this article. The closer the quality-of-service requirements can be defined to describe the service given to customers, the more likely it is that the design of exchange systems can be influenced towards achieving the necessary degree of reliability.

For new exchange systems, the BPO specifies the quality-of-service targets and agrees with designers the failure rates and methods of prediction to be used. Consequently, estimates of the expected quality of service can be made for particular exchange designs. If the prediction shows that the targets are likely to be met, the service offered to customers can be assured with a fair degree of confidence.

The changing nature of the telecommunications network will require that quality-of-service specifications evolve to cater for new developments, but these specifications must continue to ensure that the essential feature of dependable service to the customer is maintained.

### References

[1] British Standard BS 4727: Glossary of Electrotechnical, Power, Telecommunication, Electronics, Lighting and Colour Terms, Part 3, Group 02.

[2] British Standard BS 4200: The Reliability of Electronic Equipment and Parts Used Therein.

[3] HANSEN, M. G., and STEPHENS, G. G. The Reliability of Coaxial Line Transmission Systems. *POEEJ*, Vol. 65, p. 177, Oct. 1972.

[4] GOODMAN, J. V., and PHILLIPS, J. L. TXE4 Electronic Exchange System, Part 1—Overall Description and General Operation. *POEEJ*, Vol. 68, p. 196, Jan. 1976.

[5] LONG, R. C., and GORRINGE, G. E. Electronic Telephone Exchanges: TXE2—A Small Electronic Exchange System. *POEEJ*, Vol. 62, p. 12, Apr. 1969.

[6] MOON, R. J., BEALE, G. A., and TARRY, D. G. TXE2 Electronic Exchange System: The Evolution from Mark 1 to Mark 3. In this issue, p. 210.

# Audio Junction Cables

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*This article traces the development of audio trunk and junction cables from their inception in the early-1890s to the present day. The electrical characteristics and current installation practices are outlined, and the article concludes by looking at future development and usage of such cables.*

## INTRODUCTION

Audio cables form an important part of the British Post Office (BPO) telephone network. Such cables fall into 2 classes: those between the customer and the telephone exchange (local cables), and those between telephone exchanges (junction cables). This article reviews the historical background, present-day usage, characteristics and practical aspects of provision of the latter. A previous article[1] has described the junction network, this being an administrative classification of circuits with particular traffic-carrying functions. Junction cables carry almost all the junction-network circuits, but, in addition, carry considerable numbers of main-network[2] circuits and private circuits.

The total value of existing junction cables, excluding duct and other external plant, is about £600M, and this is being added to at the rate of approximately £20M/annum. Some 22-million pair-kilometres of junction cable are in existence and about 1–1·5-million pair-kilometres are added annually.

## HISTORICAL BACKGROUND

As the telephone system evolved, the need to interconnect urban centres was first met by overhead-wire routes. Underground cables, using copper conductors with dry paper for the insulant and similar to those of today, were first introduced in the early-1890s for subscribers' lines and, by the turn of the century, were being evaluated for long-distance use. These early telephone cables were based on knowledge that had been accumulated over previous years in dealing with the design of telegraph cables.

Early experiments on long-distance telephone cables dealt with 2 types of construction: one cable type was made up from pairs of wires twisted together (twin type); the other from groups of 4 wires twisted about a common axis (star-quad type), the pairs being made up from the diagonally-opposite wires (Fig. 1). Crosstalk problems occurred between the 2 pairs of a quad and, through lack of knowledge, it was assumed that high crosstalk was inherent in star-quad cables. Development continued, leading to the evolution by 1903 of the multiple-twin (MT) cable, in which 2 pairs of different lay were twisted together with a lay different from that of either of the pairs (Fig. 1). The attraction of cable elements containing 4 wires was that a third, or phantom, speech circuit could be provided on every 2 pairs of wires; a practice successful on MT cables, but now long since abandoned, although phantoms are still used for d.c. signalling on 4-wire circuits.

After investigation, it was shown by 1913 that special testing and jointing operations called *balancing* were needed to reduce crosstalk. The term balancing was later extended to cover methods dealing with resistive and inductive unbalance, but, today, the term has reverted to its first use and is related only to crosstalk aspects.

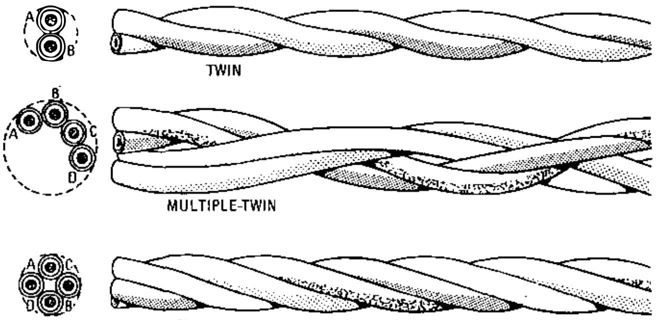

FIG. 1—Make-up of twin, multiple-twin and star-quad conductors

As manufacturing processes improved, experiments with star-quad construction resumed in the mid-1920s, and the original problems of crosstalk were overcome using the knowledge gained from MT cables. Star-quad cables were at an advantage because the compact construction of the quad allowed up to 40% more pairs to be contained within a cable of given overall diameter. Thus, by the 1930s, quad-type cable construction had become standard, the cable being formed by building up layers of quads upon a central core of a single quad or 4 quads.

Another influence on the development of cables was the discovery of loading. As early as 1887, it had been shown that if the inductance of a telephone line could be increased, the attenuation would be reduced. At the turn of the century, it was discovered that the effect could be achieved by adding extra inductance, or loading coils, at fixed intervals. This was a breakthrough because the reduction in attenuation allowed the conductor sizes to reduce over the years from 100 lb/mile or more to the 20 lb/mile (0·9 mm diameter) of the 1930s. The other contributory factor to this reduction was the invention of the thermionic tube and its use during the 1920s in 4-wire repeaters on long-distance circuits.

By the 1930s, audio cables were well established for use between exchanges. Short-distance circuits were 2-wire unamplified, while long-distance circuits were 4-wire amplified. The cables were of quad-type construction with 0·9 mm diameter copper wires, the insulation was paper and the whole cable was sheathed by lead. This type of cable became known as *paper-core quad trunk* (*PCQT*). Loading coils were used on all but the very shortest cables and all cables were balanced on installation to reduce crosstalk. Between 1928–38, numerous technical papers were published, of which a few of the most important are given in references 3–5. Cable construction and installation practices then continued largely unaltered for the next 25 years.

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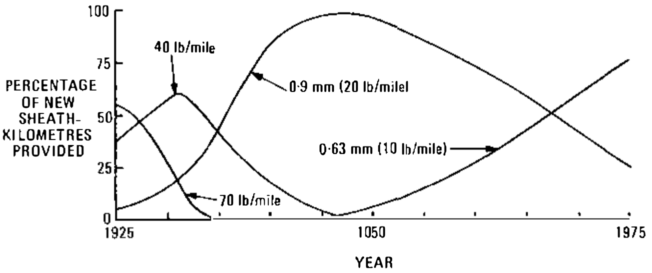


FIG. 2—Changing proportions of conductor gauge provision over 50 years

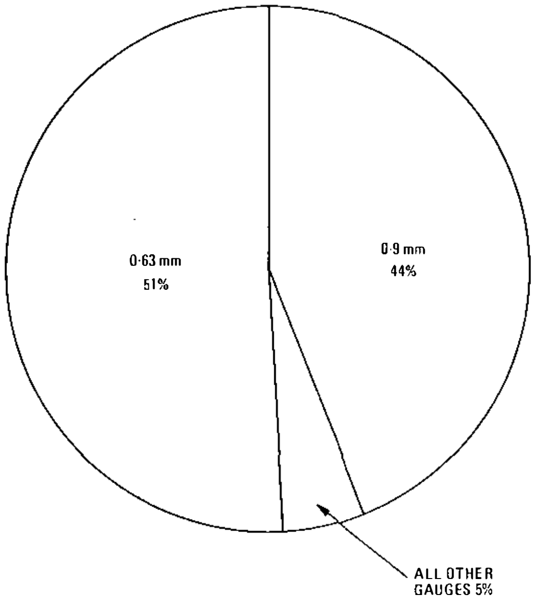


FIG. 3—Proportion of conductor gauges in junction cables existing in 1975

## JUNCTION CABLES TODAY

Post-war developments included the change from lead to polyethylene sheathing, made possible by the development of the aluminium-foil moisture barrier.[6] The other major change was that 0·63 mm diameter copper conductors replaced 0·9 mm diameter copper conductors as the standard for new work in the late-1960s. This was mainly made possible by 2 developments in other fields:

(*a*) the increasing use of high-frequency systems to carry the long-distance circuits that formerly used 4-wire repeaters on audio cable pairs, and

(*b*) the development of cheap, reliable 2-wire repeaters, particularly of the negative-impedance type.

The smaller conductors had greater attenuation and resistance, and thus involved the widespread use of 2-wire repeaters and, sometimes, more complex signalling systems. The extra costs of these were offset by the larger savings from reduced cable costs and, because of the smaller overall cable size, reductions in duct requirements; for example, the largest cable that could be accommodated in a standard 90 mm duct bore was increased from 542 pairs to 1040 pairs.

At about the same time as the change to 0·63 mm conductors, the construction of the cable was standardized on a central core of 4 quads, with one or more layers built around it. The number of pairs in a cable so constructed can be obtained from the formula $2n(3n + 1)$, where $n$ is the number of layers in the cable. This gives standard sizes of 28, 60, 104, 160, 228, 308, 400, 504, 620, 748, 888 and 1040 pairs. An exception is the smallest cable of 14 pairs, in which the core is formed by a single quad.

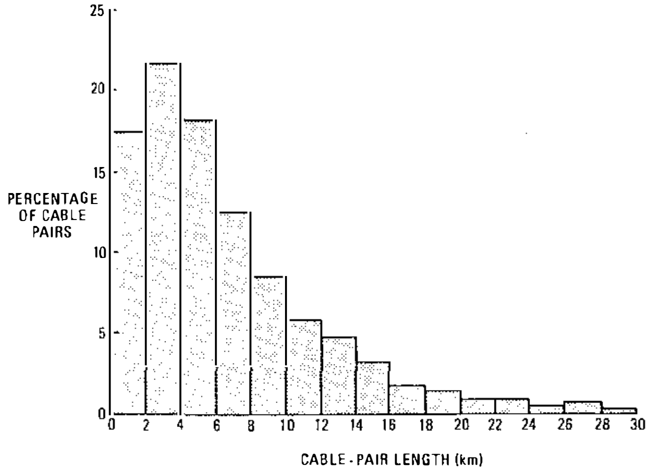


FIG. 4—Distribution of lengths of cable pairs

Although cables containing 0·63 mm copper conductors are now standard for new work, there are still many existing cables with conductors of 0·9 mm, and a few with even larger conductors. Some new cable with 0·9 mm conductors is still provided for spurs to existing 0·9 mm cables and for a few exceptionally long routes in remote areas. Fig. 2 shows how the provision of various gauges of cable has changed over the years, while Fig. 3 shows the approximate proportions of existing cables in 1975.

Junction cables today are used mainly for unamplified 2-wire circuits up to about 10 km long, and 2-wire amplified circuits of between about 10–30 km. There are still 4-wire amplified circuits, but they are almost exclusively for private-circuit use. Long-distance sections of private circuits are carried on high-frequency systems, but sections between the system terminal and the exchange nearest to the customer are still routed on junction cables. A distribution of the lengths of cable pairs in 1975 is shown in Fig. 4.

## CABLE CHARACTERISTICS

The primary line constants of a cable pair are resistance $R$, inductance $L$, capacitance $C$ and leakage conductance $G$, and the secondary line constants are attenuation, phase shift, characteristic impedance and velocity of propagation, with others such as phase delay, group delay and cut-off frequency. The secondary line constants are all dependent on the primary constants but, in practice, the required values of the secondary constants influence the choice of primary constants.

In addition to the above characteristics, the capacitance between pairs, and between pairs and earth, influence the passage of unwanted signals between pairs.

For each cable, the characteristics are established in 3 stages:

(*a*) during manufacture,
(*b*) during the planning of the cable scheme, and
(*c*) during installation.

At the cable-manufacturing stage, the physical properties of the conductors and insulants, together with the way they are assembled, make a major contribution to the primary constants. The manufacturing specification lays down standards for conductor resistance, mutual capacitance (that is, between the 2 wires of a pair) and conductance. Also, limits for capacitive unbalance between pairs, and between pairs and earth, are specified. The variation in resistance, inductance and conductance along a length of cable are insignificant, but capacitance values can vary because of small changes in wire positions.

The characteristics of loading coils are also important, and limits are specified for inductance, d.c. resistance, conductance and crosstalk.

At the cable-scheme planning stage, the engineer carrying out the survey can control, to some extent, the loading spacing and the end-section lengths. This control is fairly limited, given that the length of the cable is determined by exchange locations and that the siting of loading coils within the planning rules is dictated either by the location of existing jointing points or the ability to site new ones.

At the cable-installation stage, little effect can be made on resistance, inductance or conductance. The resistance is determined largely by the cable and, to a lesser extent, by the loading-coil windings. The wire-to-wire contact resistance at joints is very small compared with other resistances. The inductance is determined by the loading coil, which completely overwhelms the inductance of the cable pair and is not affected by installation. The conductance is dependent on good working practices and, if these are observed, is so low as to be insignificant.

The physical relationships between the pairs of a quad, and between pairs and earth, can vary along the cable. This produces an unbalance of capacitance between pairs and between pairs and earth, and leads to crosstalk between pairs. The physical relationship between wires forming a pair can also vary along the cable. Because of this, the mutual electrostatic capacitance, defined as the capacitance between the 2 conductors of a pair when all other pairs are earthed, can vary from cable length to cable length.

## LOADING

From transmission line theory,[7] if $LG = RC$, the line attenuation falls to its minimum or d.c. value. The theory also implies that there will be no frequency or phase distortion, and it is, therefore, called the *distortionless condition*. In a telephone cable at audio frequencies, the value of inductance $L$ must be increased considerably to meet this condition and result in distortionless transmission. Unfortunately, the cost of uniformly distributing the inductance (continuous loading) is prohibitive, and therefore inductance is added at fixed intervals (lumped loading). This has a disadvantage that it gives the characteristic of a low-pass filter having a critical cut-off frequency. To achieve a cut-off not lower than 4 kHz and an acceptable velocity of propagation, the value of inductance that can be added is considerably lower than that necessary to meet the distortionless condition, but most of the benefits are still obtained.

The attenuation up to the cut-off frequency, and the cut-off frequency itself, not only depend on the value of the loading-coil inductance, but also on the intervals between adjacent coils. Most existing loaded pairs, and virtually all new ones, are loaded with 88 mH coils at 1·83 km intervals. With 0·63 mm conductors, this gives an attenuation of about 0·45 dB/km and, with 0·9 mm conductors, about 0·23 dB/km. In each case, the cut-off frequency is about 3·9 kHz, giving adequate performance to 3·4 kHz. Exceptionally, a few pairs are loaded with lower values of inductance at closer spacing to give a higher cut-off frequency for programme (music) circuits. The end section of a cable between the loading coil and the termination should ideally be a half section but, in practice, this invariably cannot be achieved because of physical limitations.

The loading coils are either of toroidal or pot-core construction. For cables requiring up to 104 coils, individual pot-core coils called *unicoils* (Fig. 5) are mounted in specially designed cradles accommodated within a cable joint (Fig. 6). Where more than 104 coils are required, they are manufactured by enclosing either pot-core or toroidal type coils in bitumen-coated steel cases (Fig. 7), with the connexions brought out in stub cables which are subsequently jointed to the main cable.

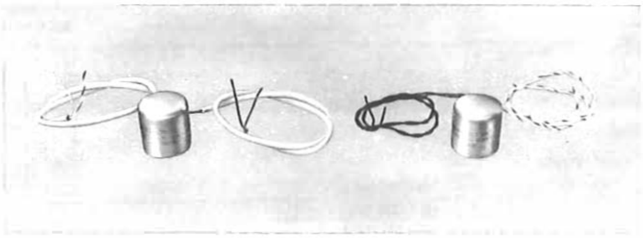


FIG. 5—Unicoil type loading coils

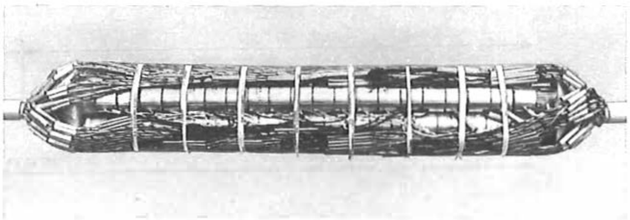


FIG. 6—Unicoils mounted in a cable joint

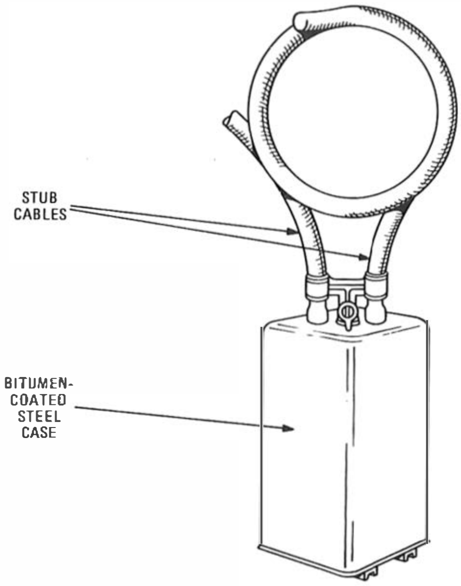
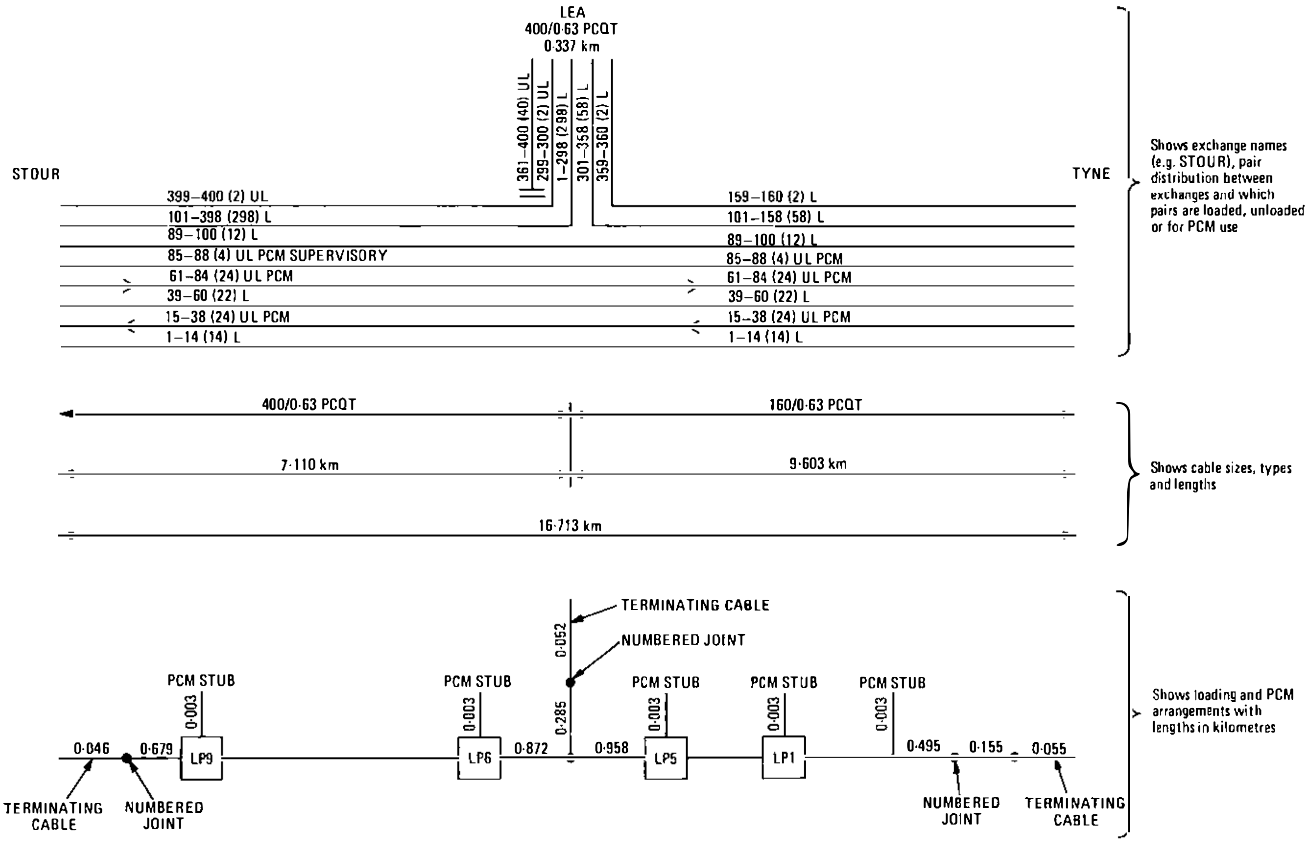


FIG. 7—Typical loading-coil case

The distance between loading coils should be 1·83 km ± 1%, with adjacent sections within 1% of each other. Where this cannot be achieved, a short section can be made to appear to be the correct length by adding capacitance across each pair; a process called *building out*. This is adopted only when severe civil engineering problems prevent the loading coils being installed at the correct point. As with loading coils, small numbers of capacitors can be accommodated within a joint, but large numbers are enclosed in steel cases and connexions brought out in stub cables.

## CABLE PLANNING

Estimates of future public-circuit requirements are published each year in the annual schedule of circuit estimates (ASCE), and planning engineers compare future public-circuit demand and an estimate of private-circuit demand with existing circuit capability. The basic data for the ASCE are held on computer files and the comparison is carried out with computer assistance. Once the possibilities of using existing plant are



UL—unloaded
L—loaded
LP—loading point

*Notes:* Intermediate loading points not shown when at standard spacing (1·83 km ±1%)
PCM stub cables provided to facilitate future jointing to cases housing regenerators

FIG. 8—Diagrammatic representation of a cable

exhausted and the need for new circuit capacity has been established, the planner must decide on the most economic way of providing it. For plant between local exchanges and between local exchanges and group switching centres, the choice usually lies between installing pulse-code-modulation (PCM) systems on existing cables or providing a new cable. Apart from the suitability of existing cables and the practical problems of siting PCM equipment, PCM is usually not economic under about 8–10 km.

If a cable is chosen, the size and layout is determined from the number of exchanges that require pairs and the long-term circuit requirements of those exchanges. It is generally assumed that a cable takes 4 years to provide, because of the time involved in planning, surveying for duct, providing duct, and then manufacturing and installing the cable. It is also most economic to provide a cable to cater for about 6 years' growth, so that cable sizes are based on forecasts of circuit requirements 10 years ahead. If the distances involved would favour PCM economically, but the existing cables are unsuitable or fully exploited for PCM, it is the normal practice to include unloaded pairs in a new cable so that, when the loaded audio pairs have been used for circuits, future circuit growth can be met by PCM provision. A typical representation of a cable of this type is shown in Fig. 8. The upper part of the diagram shows how the pairs in the cable are connected between the exchanges, and the lower part shows how the loading points are spaced. Although the example shows a cable with one spur, it is quite usual to have cables with 4 or more spurs, or no spurs at all. There are also variations in the ways that spurs are derived; for instance, 2 spurs can be taken from the main cable at a common point, or a spur can itself have a spur taken from it.

## CABLE INSTALLATION

### Cabling

Most junction cables are installed in underground ductways and jointed in footway jointing boxes or manholes although, in the centre of very large cities, particularly London, a considerable proportion are installed in deep-level tunnels for at least part of their route. In locations with difficult terrain (for example, rocky ground), it is sometimes necessary to provide aerial cable, in which a steel wire is moulded into the sheath to allow suspension from poles. Although cheapest in initial cost in such locations, aerial cables are vulnerable to damage, both man-made and from the weather. In remote rural areas with very low traffic growth rates, it is occasionally possible and worthwhile to moleplough cable directly into the ground.

The methods of installing cable in duct have improved in recent years with the introduction of mechanical aids, notably the rodding and light-cabling vehicle[8] and the heavy-cabling equipment.[9] The former can be used for cables up to 308 pairs (0·63 mm), whereas the latter will deal with the larger cables.

### Jointing

The jointer identifies the cable quads and wires by coloured cotton whippings and ink marks on the paper insulation. The wires are jointed together by twisting and then soldering, and are insulated with a paper sleeve. Mechanized jointing, using the jointing machine originally introduced for local cables,[10] is now a technically approved method for junction cables and is likely to replace the twist-and-solder technique in the near future. The machine produces a crimped joint with a plastics sleeve.

Some joints can be made to a predetermined pattern, but others are completed only after balancing tests have been made to choose quad combinations that will reduce crosstalk. In these cases, the jointer prepares the distant and testing ends of the cable so that the balancing engineer can carry out the tests.

The completed joint is protected by a polyethylene sleeve, which is sealed to the polyethylene sheath of the cable with epoxy putty or welded with injection-welding techniques. Sections of jointed cable are pressurized temporarily until they can be connected to the exchange pressurization system.

## Balancing

Satisfactory crosstalk performance cannot be achieved by straight jointing of successive lengths of cable and special jointing sequences must be used to avoid the accumulation of capacitive unbalance along the cable. This balancing process can be dealt with in 2 main parts: that for the reduction of within-quad crosstalk and that for the reduction of between-quad crosstalk.

### Within-Quad Crosstalk

The procedures adopted for PCQT cable involve making measurements from a break in the cable section between loading points. Measurements of capacitive unbalance between pairs in a quad are made for each quad in the cable, first in one direction from the measurement point and then in the other direction. From the tabulated measurements, a selection is made of quads to be joined together and a decision taken on the method of joining the wires of the quads so selected. As the unbalance of the second pair in a quad relative to the first pair in the quad can be expressed as a negative or positive reading, the object is to match similar values opposite in sign to achieve a low (or zero) overall value. The measurement process and the choice of quads to be joined together is called *test selection*, and the joint where the operation is performed is called the *test-selected joint*.

Two principal applications of test selection are used in practice: quarter-section balancing and half-section balancing.

*Quarter-Section Balancing*

This is a traditional method which gives consistently good results.

The loading section is divided into 4 approximately equal parts:

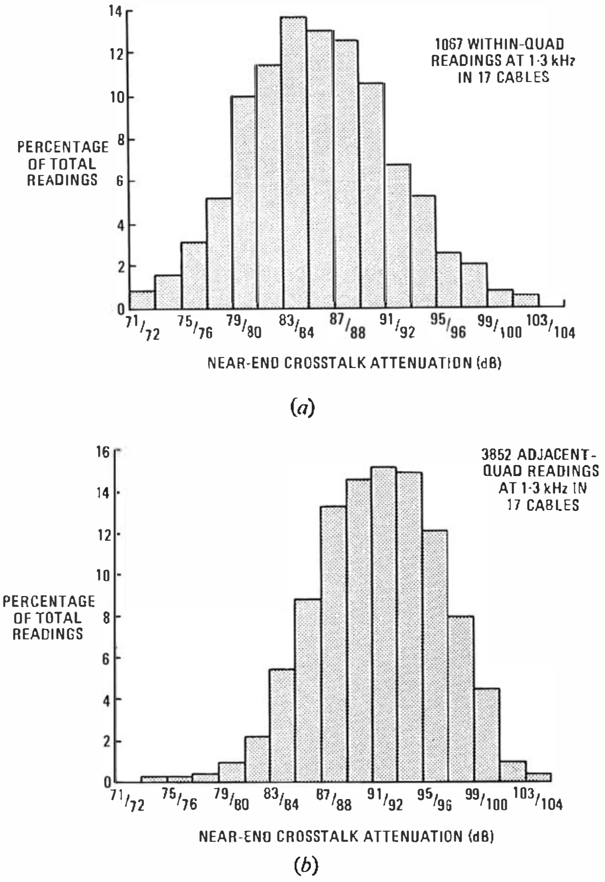
——1—— X ——2—— Y ——3—— Z ——4——

Test measurements are made in each direction from points X and Z. On BPO-installed cables, these tests are made after the cable is installed, but the readings for contract-installed cable are usually based on factory measurements. From the resulting 4 sets of readings, a selection of pairs is made to minimize the overall section unbalance. Jointing schedules are prepared for the joints at X, Y and Z. At point Y, tests are made to confirm the predicted values and any necessary adjustments are made. The joint at Y is then made and an overall section check made.

*Half-Section Balancing*

For this method, the cable section is divided into 2 approximately equal parts, with joints made to a predetermined schedule (systematic joints). A test-selected joint is then made at the centre followed by an overall section check.

Over the years, several trials have been made of balancing systems that do not use test selections at all, commonly known as *no-balancing* techniques. These rely on pair reversals (AB and CD crosses) to cancel out the unbalance between pairs in a quad, or predetermined jointing sequences between quads to introduce a random element in the accumulation of capacitive unbalance. To date, with 0·63 mm conductor PCQT cable, none of these methods has proved reliable and they are not now used. If new types of cable with better capacitive unbalance performance can be designed, it may be that reliance on test measurements can be reduced.



(*a*) Within-quad near-end crosstalk attenuation
(*b*) Adjacent-quad near-end crosstalk attenuation

Fig. 9—Range of values of crosstalk attenuation on modern junction cables

For all balancing methods, the cable is divided into balancing groups corresponding to the cable layers, except in the very centre, and only quads within the same balancing group are allowed to be connected together. This limits the possible combinations of quads to manageable proportions and produces a reasonably tidy joint. The process of selecting quads to be jointed together means that the 2 pairs forming a quad are always in the same quad at any point along the cable and, because of this, the pair-to-pair within-quad crosstalk is the worst crosstalk condition.

The method of evaluating the test measurements and determining how the quads should be interconnected has traditionally been carried out by painstaking inspection and manipulation of the figures, but computer assistance is now available. The object of selecting quads is to achieve a good balance for every quad, rather than a perfect balance for some quads and a poor balance for the remainder.

Typical values of within-quad near-end crosstalk attenuation at 1·3 kHz on recently installed cables are shown in Fig. 9(*a*).

### Between-Quad Crosstalk

Between-quad crosstalk embraces crosstalk between one pair of one quad and one pair of any other quad in the cable, and is due to capacitive unbalances between quads. Because of the design of the cable (for example contra-rotating layers), crosstalk between quads in different balancing groups is insignificant and special measures to reduce it are not required. Capacitive unbalance is large only for adjacent quads and small for all other combinations; thus, it is necessary to ensure only that there is no cumulative addition of capacitive unbalance between adjacent quads. It is unnecessary to resort to test selection to control between-quad unbalance; the problem can be overcome by making joints at regular intervals to ensure that no 2 quads adjacent in one length are joined to quads that are adjacent in any other length in a loading section. This type of joint is called a *systematic joint* and is carried out to a predetermined jointing schedule.

Typical values of adjacent-quad near-end crosstalk attenuation at 1·3 kHz on recently installed cables are shown in Fig. 9(*b*).

### Terminations

Paper-insulated cable is not suitable for terminating on distribution frames and a polyethylene-insulated quad-type terminating cable is used. The terminating cable has 0·5 mm diameter conductors to produce a smaller cable that improves access to congested exchanges. Due to the inferior characteristics, the terminating cable is jointed to the paper-insulated main cable at a point not more than 160 m from the termination to overcome balancing difficulties. At a point near each termination, one joint has each pair clearly identified by a numbered collet and can be used for access to the cable in emergencies. This numbered or emergency joint is usually between the main and terminating cable.

The method of terminating cable on main distribution frames (MDFs) in telephone exchanges has been dealt with in an earlier issue of the *Journal*.[11]

## PRESSURIZATION

A major disadvantage with paper-insulated cables is that entry of moisture at any point, due to sheath or joint-closure defects, can cause major disruption of service. Such defects in dry situations may, in spite of regular insulation-resistance tests, go unnoticed. It is only when moisture finally enters the cable that the defect becomes apparent, by which time the conductor insulation is damaged, resulting in circuit faults.

This type of insulation damage is overcome by filling the cable with sufficient compressed air to raise the pressure above atmospheric pressure. The air pressure in the cable thus retards the ingress of moisture. By using suitable indicating devices, maintenance staff are alerted when sheath or joint-closure defects occur, causing a lowering of the air pressure within the cable. Thus cable breakdowns and insulation faults are reduced, resulting in considerable improvement of service provided by the network.

Over 40 years ago, attempts were made to pressurize cables, but with little success. It was not until the early-1950s that successful trials were carried out on junction cables and, in 1953, it was decided to pressurize all future audio junction cables. In the late-1950s and early-1960s, a programme of retrospective pressurization was undertaken such that, by the mid-1960s, all existing junction cables had been pressurized.

The static system of cable pressurization is used for junction cables. This requires that all sheaths and joints are maintained virtually air-tight. The cables are filled with air either from cylinders or from suitable sources of dry compressed air, connected to the cable at various points (Fig. 10). Pressure is maintained by frequent topping up. Any leaks are repaired as they develop.

Continuous monitoring of the overall pressure condition of the pressurized cable is carried out by installing contact pressure indicators and contactors (pneumatically-operated switches) at strategic points along the cable route. For new junction cables, the nominal spacing between adjacent pressure indicators is generally in the range 1·6–4 km. Contactors are provided at the mid-point of a loading-coil section and a pair from the cable is used as an alarm circuit. Reduction of the air pressure to 50 kPa (500 mbar) absolute operates the gauges and/or contactor contacts and provides an earth on the B-wire of the pair.

On completion of cable installation and jointing, each air-pressure section of the cable is filled with dry air to an equalized pressure of 160 kPa (1·6 bar) absolute. At intervals of 7 d, for a period of 1 month from the time of equalization, measurements are taken to ensure that the cable is virtually air-tight.

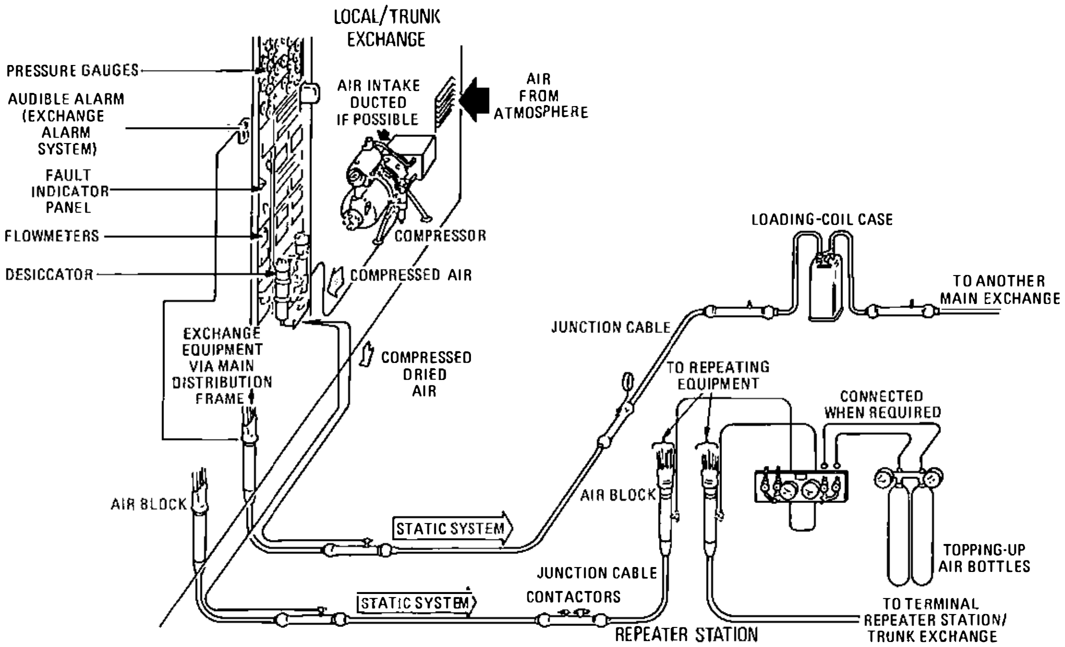


Fig. 10—Pressurization of junction cables

## ELECTRICAL TESTS ON COMPLETION OF INSTALLATION

Before any junction cable can be brought into service, electrical tests are applied between MDFs to ensure that the standards set have been achieved. These tests should be carried out after the completion of all construction work, including the satisfactory equalization of the air pressure systems. The main tests are as follows.

### *DC Resistance and Resistive Unbalance*

(*a*) All conductors are tested for continuity and the resistance of each pair recorded. The difference in resistance between the 2 conductors of a pair must not exceed 0·2% of the loop resistance of that pair or 1 Ω, whichever is greater.

(*b*) The moisture barrier is also tested for continuity between stations and the resistance recorded.

### *Insulation Resistance*

(*a*) The insulation resistance of the completed cable system between any wire and all other wires, together with the moisture barrier, connected to earth, must be greater than 8 GΩ/km.

(*b*) The insulation resistance between the moisture barrier and earth must not be less than 150 MΩ/km, with the conductors free from earth.

**TABLE 1**

**Impedance/Frequency Characteristics**

| Loading (Nominal) | | Test Frequency Range (kHz) | Maximum Deviation of Impedance (%) |
|---|---|---|---|
| Inductance (mH) | Spacing (km) | | |
| 88 | 1·83 | 0·3–2·8 | ±10 |
| 22 | 0·457 | 0·3–9·5 | ±10 |
| 16 | 0·915 | 0·3–9·5 | ±5 |

**TABLE 2**

**Attenuation Limits**

| Conductor Diameter (mm) | Loading (Nominal) | | Maximum Attenuation (dB/km) | |
|---|---|---|---|---|
| | Inductance (mH) | Spacing (km) | 1 kHz | 2·4 kHz |
| 0·63 | 88 | 1·83 | 0·49 | 0·51 |
| 0·9 | 88 | 1·83 | 0·25 | 0·27 |
| 0·63 | Unloaded | — | 1·13 | 1·75 |
| 0·9 | Unloaded | — | 0·75 | 1·12 |

### *Return Loss and Impedance/Frequency Characteristics*

(*a*) At any frequency in the testing range, the return loss of any circuit must not be less than 22 dB, and not less than 24 dB for 90% of the circuits, when tested against a network. The impedance/frequency characteristic of this network represents the average smooth mean impedance/frequency characteristics of 5%, or 10 circuits, (whichever is greater) of the similarly-loaded pairs in the same group at the testing end of the cable.

(*b*) The impedance/frequency characteristic of each pair must not differ by more than the percentage deviation shown in Table 1, at any frequency in the range given, when compared with a smooth mean curve through the actual characteristic of that same pair. This applies for all pairs measured from each end. The impedance concerned is the modulus of the characteristic impedance. The measurements are made with a line current not exceeding 5 mA, with the circuit under test built out, if necessary, to avoid terminal reflections.

### *Attenuation*

Typical maximum attenuation limits, tested with 1 mA send current and corrected to 10°C, are shown in Table 2.

### *Crosstalk*

Typical limits for crosstalk attenuation are shown in Table 3.

## USAGE FOR PCM SYSTEMS

PCM systems[12] are used to provide extra circuit capacity on existing cables by the addition of multiplex equipment at the ends, and digital regenerators at intervals along the line. However, because of the extra cost of such equipment, they are generally uneconomic for circuit routes shorter than about 8–10 km.

PCM signals require a wideband transmission path and a cable pair designed for audio-frequency use seems an unlikely medium. However, digital systems can tolerate very poor

**TABLE 3**

**Crosstalk Limits**

| Conductor Diameter (mm) | Test | Typical Minimum Permissible Crosstalk Attenuation (dB) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Between Loaded Pairs | | | | Between Unloaded Pairs | | | | Between Loaded Pairs and Unloaded Pairs | | | |
| | | All Pairs | | 90% of Pairs | | All Pairs | | 90% of Pairs | | All Pairs | | 90% of Pairs | |
| | | NE | FE | NE | FE | NE | FE | NE | FE | NE | FE | NE | FE |
| 0·63 | 1 | 72 | 74 | 74 | 78 | 80 | 82 | 82 | 84 | — | — | — | — |
| | 2 | 72 | 74 | 74 | 78 | 80 | 82 | 82 | 84 | 76 | 78 | 78 | 81 |
| 0·9 | 1 | 72 | 74 | 76 | 76 | 82 | 84 | 84 | 86 | — | — | — | — |
| | 2 | 74 | 76 | 76 | 80 | 82 | 84 | 84 | 86 | 78 | 80 | 80 | 83 |

NE—Near-end, FE—Far-end
Test 1 is between the 2 pairs forming a quad
Test 2 is between any other 2 pairs in the same balancing group
Pairs loaded with 88 mH coils

signal-to-noise ratios, and 1·536 Mbit/s and 2·048 Mbit/s line systems operate satisfactorily on unloaded pairs that may, typically, have an attenuation of 16–18 dB/km at 800 kHz for 0·63 mm diameter conductors. The signal regenerators inserted along the line have been designed to be spaced at about the same distance apart as the loading coils. On existing cables, the loading coils must be removed from the pairs to be used for digital systems; therefore, it is convenient to site the regenerators at the same place as the loading coils to minimize the amount of jointing work. However, it is sometimes necessary to insert regenerators at other points to counteract the effects of induced noise from exchanges.

Regenerators are housed in cast-iron pressurized cases which are installed in specially-built footway jointing boxes, or occasionally in manholes, and connected to the main cable by a short length of interconnecting cable.

The 2 directions of transmission of PCM systems are separated into different parts of the cable to minimize crosstalk. Each direction is carried in a different balancing group which, except in the centre, corresponds to a cable layer. It is desirable, but not essential, to have one layer spacing between the 2 directions of transmission.

Within any one balancing group, it is permissible to have 50% of the pairs in use for PCM systems, up to a maximum of 24 pairs; the exception to this is the outer-layer balancing group, where only 25% of the pairs up to a maximum of 24 pairs can be used because of sheath proximity effects. For example, a modern 60-pair PCQT cable can have 16 pairs suitable for PCM (that is, 8 systems), while a 1040-pair cable could carry 120 PCM systems on 240 pairs, although there can be jointing limitations that prevent this latter figure being achieved.

Because of the national uniformity in cable design and construction, it has been possible to devise prescriptive planning rules so that there is a minimum of testing at the installation stage. The testing is usually limited to d.c. tests, a pulse-echo test to ensure that discontinuities do not exist (for example, building-out capacitors) and an insertion loss test at 800 kHz.

## THE FUTURE

Experimental quad-type cables having cellular-polyethylene conductor insulant (PEQ) are now being installed. Early results indicate that, with this type of construction, some improvement over conventional PCQT cable is likely in attenuation and crosstalk at 800 kHz. Such an improvement suggests that considerable scope exists for increased use of PCM systems.

If adopted as standard, PEQ cables may be the last major development of audio junction cables (although aluminium conductors may replace copper), for it is unlikely that many cables of this type will be provided beyond 1990. By then, sufficient potential 2 Mbit/s PCM capacity will exist and the need for higher-bit-rate systems in the junction network will have arisen.

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# Book Review

*Computer Technology for Technicians and Technician-Engineers* (Volume 1). R. V. Watkin. Longman Group Limited. ix + 256 pp. 126 ills. £3·25.

This book is the first of 2 volumes to be published. It is the author's intention in the first volume to cover work required for the present syllabi of computer technology included in the City and Guilds of London Institute (CGLI) Telecommunication Technicians' Course; that is, Computers A, Computers B, and the digital subject matter of Computers C.

The current discussions concerning the reorganization of technician education under the control of the Technician Education Council present difficulties when assessing the suitability of such a book. It is, therefore, assumed that the content of the new courses will not differ substantially from that of the present CGLI courses.

The syllabi covering Computers A and Computers B are an excellent foundation for both the study of computer technology and the mathematical knowledge required, particularly at technician level. However, this book not only covers the subject matter for these courses, but will be of value to anybody interested in acquiring an appreciation of computers and their technology.

Chapters are arranged in a logical manner. The earlier sections cover the mathematics of computing (binary arithmetic, Boolean algebra and logic-mapping techniques) and the electronic building blocks (logic gates, multivibrators, registers, computers and storage media). This information is then used to illustrate the operation of sub-units of a digital computer and show how they are interlinked in a processing system. The final chapters cover machine-code programming and an introduction to analogue-computer techniques. Chapters can be read in isolation, as the descriptive text provided by the author considerably aids comprehension of the mathematics and technical detail.

The publication has been diligently prepared and is in an attractive and readable format. Each discrete mathematical step is shown and explained, this being a welcome change from the more common presentation where the reader is left pondering. The standard symbols specified in BS 3939, Section 21, are adhered to throughout.

M. L. J.

# Underwater Duct-Laying in Bristol's Floating Harbour

J. FIELDING†

UDC 621.315.671: 621.315.28

*This article describes the unusual work of providing underwater steel ducts in front of the entrance to a working harbour, recently carried out in Bristol Telephone Area.*

## INTRODUCTION

Bristol, on the river Avon and 11 km from the sea, has been a port from earliest known times, but every vessel that entered on the flood tide had to lie on the mud during the ebb. Between 1804–09, an entirely new tidal channel, known as the *New Cut*, was engineered, leaving the old course of the Avon as a harbour in which the water level was maintained by lock gates. The harbour, which is nearly 5 km long, became known as the *Floating Harbour*, and a large docks complex, the City Docks, grew around it. Fig. 1 is a map of the New Cut and part of the Floating Harbour.

Eventually, the land-locked position of the harbour deterred further development, and a new port was built on the coast at Avonmouth. The functions formerly carried out by the City Docks have been transferred to Avonmouth over a period of years, and the shipyards, timber-yards and warehouses lining the Floating Harbour have gradually run down.

The site is to be redeveloped, and one area, lying between the New Cut and the Floating Harbour, is to be made suitable for mixed residential and business accommodation.

This area is actually an island some 2 km long and varying in width from less than 100 m to 300 m. Because of its position in the heart of the city, the island has great potential. It is connected to the mainland by no less than 7 swing bridges and one suspension bridge. Only one fixed bridge exists, at the end of the island remote from the telephone exchange and on the side isolated by the reaches of the Avon. Hence, the only practicable cable route is under water.

## PLANNING

Two submarine cables, of 75 and 150 pairs, submerged beside Prince Street swing bridge, have served the area well, but they are scheduled for renewal. Each has been damaged several times by vessels passing through the swing bridge at too great a speed, creating a water turbulence that has apparently caused the cables to be lifted into contact with the ships' propellers. In view of the expected development, with a sales forecast of 1600 additional connexions by 1979, it was decided to use steel ducts welded into continuous lengths to link the island with the mainland, and so provide for the initial and subsequent cable requirements.

Prince Street swing bridge is only 500 m from the exchange, and it was therefore logical to carry out an underwater survey to determine the practicability of placing ducts across the mouth of the swing bridge. The bridge spans a channel 13 m wide and 7 m deep, and is set into a stone-built 2-lane causeway linking the harbour walls, the distance between the walls being 62 m. Fig. 2 shows a section of the harbour at the causeway and swing bridge.

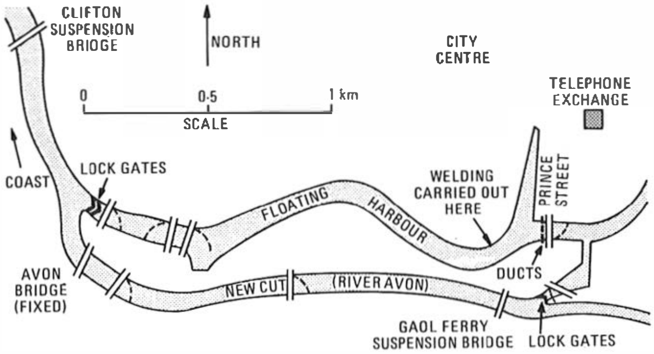

FIG. 1—The New Cut and Floating Harbour

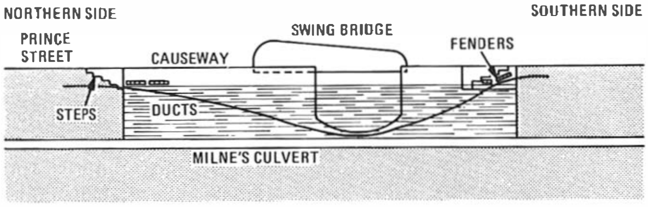

FIG. 2—Prince Street swing bridge and causeway

Lying on the bottom of the harbour close beside the causeway is a large cast-iron pipe, 1·5 m in diameter. This is *Milne's Culvert*, which was laid in 1835 to carry flood water and sewage to the tidal waters of the Avon where it flows through the New Cut. The culvert is still in use, although its function as a sewer will shortly cease and only flood water will be carried.

A self-contained-underwater-breathing-apparatus (SCUBA) diving team was employed to carry out an underwater inspection of the harbour, causeway and culvert. Operations were hampered by a complete lack of visibility in the very muddy water, and by layers of silt varying from 1-4 m in thickness. However, by using long steel probes, the possibility was established of laying ducts along the top of the culvert in front of and below the mouth of the swing-bridge channel.

Duct No. 70A was chosen for the underwater route. This is a mild-steel pipe of 100 mm internal diameter, and has an internal coating of red-oxide epoxy-resin paint and an

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† External Planning Division, Bristol Telephone Area

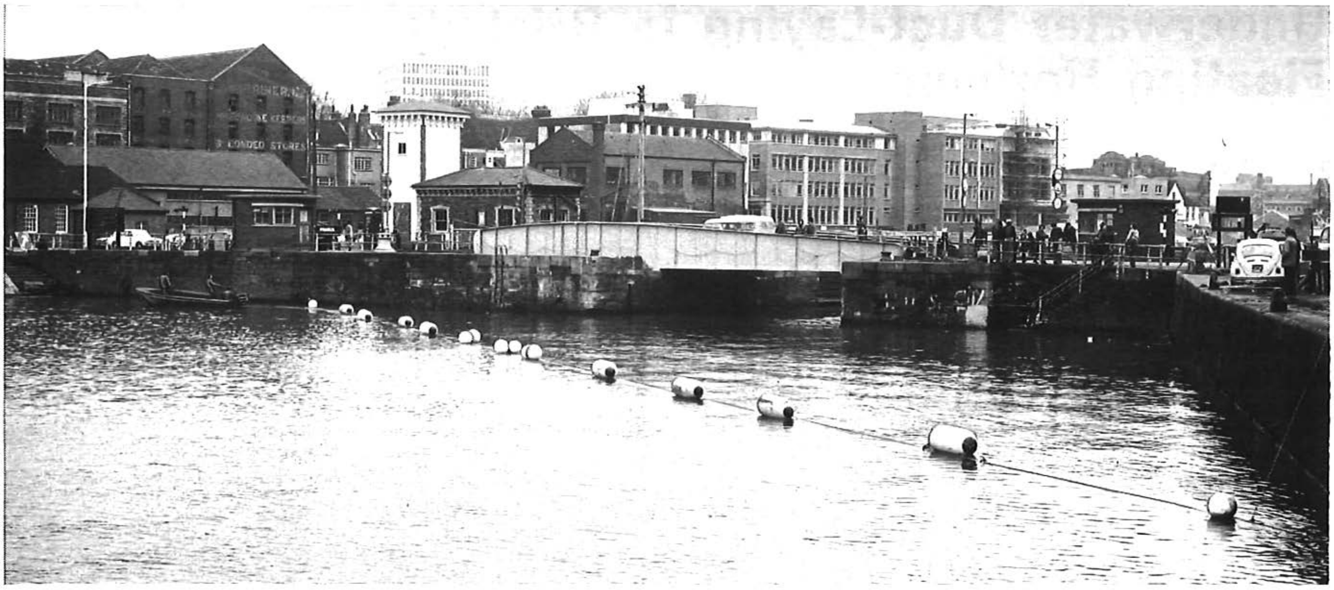


FIG. 3—Towing the ducts into position across the harbour

external cladding of low-density black polyethylene. If a small strip of cladding is removed from around the spigot of one duct and the socket of a second, they can be cleanly and securely welded together to form a water-proof joint. Continuity of the cladding can be restored by a carefully applied wrapping of adhesive plastics tape.

Although the 20-year connexion forecast indicated that 2 ducts would be sufficient, it was considered that 2 more would not appreciably add to the cost once the equipment, boats and men had been assembled. The alternative, of providing extra ducts in the future, would have been much more costly.

In detail, the plan evolved was to construct a manhole at the top of the steps leading down to the water on the northern wall of the harbour, and run the 4 welded duct lengths from the manhole, under the steps, to slant down into the water in vertical formation tightly against the causeway wall. The ducts were to curve gently below the sill of the swing-bridge channel and rise more steeply against the southern section of the causeway, entering the southern harbour wall above the water level through diamond-drilled holes. There, they would link with land-section ducts at a point approximately 2 m inside the wall. Figs. 1 and 2 show the position of the ducts.

## CONSTRUCTION

The underwater and dry-land parts of the operation were let to separate contractors, but overseen by the same works supervisor to ensure co-ordination of the work.

To carry out a detailed survey before the pipes were assembled for welding, the underwater contractors had to time their dives to coincide with periods when no shipping was passing through the swing bridge. The thick deposits of silt were shifted by jetting with compressed air. It was then discovered that, where Milne's Culvert passed in front of the sill, it had been protected right across the channel by a shallow dome-shaped concrete apron. Using underwater compressed-air drills, the apron was lowered to about 0·2 m below the sill, and a 0·3 m square trench was cut in it—no easy task where visibility was nil and repeated jetting was needed to remove the continually returning silt.

The shallowness and shape of the trench were requested by the local drainage authorities, who were apprehensive about the effect of the pneumatic drilling on Milne's Culvert underneath the concrete apron. They had visions of the culvert collapsing and all the water in the Floating Harbour draining out into the New Cut. Their fears, however, were not realized.

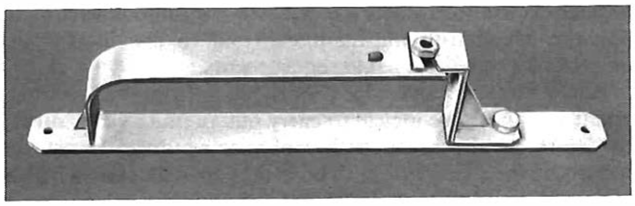
Meanwhile, the dry-land contractors were preparing the approach trenches on each side of the harbour. Also, on one of the disused wharfs, the underwater contractors were assembling and welding the ducts into four 75 m lengths.

Each length was sealed by rubber expansion plugs fitted with air valves, and satisfactorily pressure tested to 41·4 kPa (414 mbar) for 2 h. There were no leaks. Without removing the plugs, the ducts were lowered into the water and floated across to the swing bridge to await the Harbour Master's advice that shipping through the bridge had ceased. The ducts were then towed into position across the harbour (see Fig. 3).

One end of each duct length was first taken through a hole under the steps on the northern side and hauled up a sloping trench to the proposed manhole position. The other end was secured opposite the hole prepared for it in the southern harbour wall. The expansion plugs were then removed and the ducts flooded.

By virtue of the normal flexibility of steel ducts, the divers, using weights, were able to push the central sections down to the bottom of the harbour. At the same time, the southern ends of the ducts were drawn sideways towards the holes in the southern wall. When the inclination caused by the lowering of the central sections reached 25°, it was possible to pull each length through its hole in the southern wall ready for connexion with the land-section duct.

It had been intended that the 4 ducts should lie against the causeway wall in vertical formation, but, because of the obstruction in front of the sill, a change to a square formation was made where they passed through the shallow trench cut by the divers.



*Note:* Bracket is used in the vertical attitude

FIG. 4—Duct bracket

The ducts were allowed to settle for 2 d and were then sealed into the trench by layers of bags of concrete placed up to the level of the sill. In all, 11 t of concrete were used.

Special U-shaped brackets (Fig. 4), with self-locating clips to prevent them re-opening, were designed to hold the 4 steel ducts against the causeway wall. They were made from 12·7 mm mild steel and were heavily galvanized. The brackets were placed over the ducts at intervals of 2·5 m and bolted to the causeway by the divers. Where the formation changed on each side of the swing-bridge channel, differently-shaped brackets were used.

Most of the water was then pumped out, and the ducts were cleared of the remainder and dried out satisfactorily by drawing a mandrel and brush several times through each.

To shield the ducts against accidental contact with small craft, elm-wood fenders were bolted to the causeway above each end of the uppermost duct, extending 2·5 m from its points of entry into the water.

So far, a 66 mm diameter 1600-pair cable has been installed in one of the ducts. The installation was entirely satisfactory.

## CONCLUSION

This project presented an interesting and unusual challenge to the staff of Bristol Telephone Area. The site is still in the process of being cleared, but the Area is ready to meet demands for service arising from the proposed redevelopment.

## ACKNOWLEDGEMENTS

The underwater surveys were carried out for the Area by SCUBA Divers Ltd., Clevedon, and the submarine work was done by Diving International Engineering Ltd., Newport. P. J. Maher Civil Engineering, Bristol, executed the dry-land contract. The brackets were made by the South Western Telecommunications Region (SWTR) Repair Depot to a design specified by the Bristol Telephone Area drawing office. The author would also like to acknowledge the help given by colleagues in SWTR Headquarters and the Operational Programming Department of Telecommunications Headquarters.

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# Book Review

*Telecommunication Networks.* Editor: J. E. Flood, D.SC.(ENG.), PH.D., C.G.I.A., C.ENG., F.I.E.E., F.I.E.R.E. Peter Peregrinus Limited. xvii + 431 pp. 177 ills. £12·60.

In his foreword to this book, which is in the IEE telecommunications series, Professor J. H. H. Merriman draws attention to the expertise that is represented by the authors. In addition to Professor Flood's own contribution as author of 3 chapters and editor, the authors include senior engineers from the British Post Office, the Cable and Wireless Company, the telecommunications industry and the Ministry of Defence's Signals Research and Development Establishment. Their professional knowledge and experience encompasses operations, development and manufacturing. Most books on telecommunications are more or less specialized texts, dealing perhaps with one system or a class of systems. This book, as its title implies, deals with the basic technical and economic factors of interconnected systems, primarily for telephony.

The material is based on several years of vacation schools at the University of Aston that were organized as switching or transmission seminars. Each chapter has an extensive list of references, typically to technical articles in the *POEEJ* or *BSTJ*, and is well supported by figures and diagrams.

The book opens with a short introduction on network concepts. Transmission is dealt with in 3 chapters, on principles, systems and standards. The principles and systems chapters summarize the basic ideas of frequency-division and time-division line and radio systems, concluding with a brief mention of synchronous-orbit communications-satellite systems.

The chapter on transmission standards and planning, and the chapter on numbering, routing and charging, enter into the heart of network planning. The former sets out the criteria and conventions for assessing the transmission performance of telephone circuits and telephone connexions, and hence deriving overall subjective and objective standards as a basis for national and international transmission plans.

A general chapter on network planning describes planning processes and standards, and this is supplemented by a chapter on investment appraisal and 3 case studies in which typical planning problems of telephone networks are analysed, costed and solved. Two of these case studies contrast an urban UK situation with that of a developing island community, notionally in the Caribbean; the third evaluates the economic factors in the introduction of pulse-code-modulation transmission and digital switching in a model network.

Two chapters on switching and signalling describe the broad principles of present switching systems and the requirements and problems of exchange and network signalling.

A valuable chapter on teletraffic engineering explains the basic principles of telephone traffic calculation and the methods of studying teletraffic problems. It concludes with some observations on simulation techniques, traffic measurements and dimensioning standards.

So far, telephone networks have, implicitly, been considered. Two chapters discuss telegraph, Telex and data services. These describe the essentials of the UK Telex system and its international connexions, the Datel services, and the new public services proposed at the time of writing (1974). The recent rapid evolution of international standards for data networks is not, of course, reflected in this review.

An unusual feature in a telecommunications handbook is a chapter on military networks. This explains the different approach to military communications, where invulnerability and mobility are all-important, compared with the relatively static civil networks designed for economic and service objectives. This chapter concludes with some interesting examples of modelling of the complex systems, and analysis by computer simulation. The topic of mathematical models is given more formal and general treatment in a chapter that sets out some of the basic principles of telecommunications modelling, including forecasting models, the use of matrices for describing inter-exchange traffic and network topology, and linear graphs for network analysis.

The book concludes with a broadly-based review of future trends.

Taken as a whole, the book has the virtues as well as the drawbacks of its wide-ranging authorship. The chapters are largely independent and would have been better amalgamated or, at least, grouped together as they have been for the purpose of this review. However, they do represent individual expert opinion of high authority and great practical value. The book can be strongly recommended to the student and to all engineers concerned with telecommunications design and planning.

M. B. W.

# The Millimetric Waveguide System: Terminal and Repeater Equipment

I. A. RAVENSCROFT, C.ENG., M.I.E.E.†

UDC 621.372.8.029.65

*This is the third article in a series describing the main-network waveguide system developed jointly by the British Post Office and British industry. This article describes the terminal and repeater equipment used in a 14·2 km field-trial system that has demonstrated the bandwidth capability of the waveguide system and its stability as a transmission medium.*

## INTRODUCTION

The available spectrum of the 50 mm diameter waveguide, produced for the Martlesham–Wickham Market field trial, covers the frequency range 30–110 GHz;[1] within this band, the attenuation coefficient is below about 3 dB/km and, with quite modest power requirements, repeater spacings greater than 20 km can be accommodated. For the large available band to be used effectively, however, an ordered assembly of carriers, coupled with a diplexing system, is required to allow bidirectional transmissions of signals through the single waveguide tube. Furthermore, great emphasis has to be given to the achievement of high reliability and safety, coupled with ease of maintenance.

In fulfilment of the above requirements, it has been necessary to use solid-state technology to avoid high-voltage and relatively short-lived microwave devices such as klystrons and backward-wave oscillators. But, at the outset, alternative devices were very much in their infancy. For example, although the avalanche oscillator diode was first proposed in 1958,[2] microwave oscillations of coherent form were not produced until 1965[3] and, at the commencement of the repeater development in 1968, satisfactory solid-state sources were not available for use above 30 GHz. Consequently, a co-ordinated research and development effort, on virtually a national scale, was necessary, in which the Research Department of the British Post Office (BPO) played a large part. Problems that had to be tackled included device fabrication, circuit application and engineering to satisfy the needs of an operational system in terms of power requirements, reliability and safety—all within the span of a decade.

At the same time, the problems of matching the requirements of a digital network had to be faced. Because of the large bandwidth available, it was necessary to consider operation at the highest available bit rate and, at that time, switching speeds up to about 300 MHz were considered feasible. Early recommendations favoured a line rate of 120 Mbit/s, which later was increased to 140 Mbit/s. For the field trial of the waveguide system, the former was multiplexed to give a modulation rate of 250 Mbit/s.

The optimum modulation method uses phase-shift keying (PSK), which requires a channel bandwidth approximately double the modulation rate. While the use of multilevel modulation provides an increased information rate in each channel, 4-phase modulation is likely to be the best compromise between effective use of the spectrum and simplicity of operation; the field trial was developed on this premise.

In retrospect, the development of equipment for the waveguide project has had to encompass developments starting at the research stage, and leading through to an outcome as advanced operationally as any system that has evolved through the years.

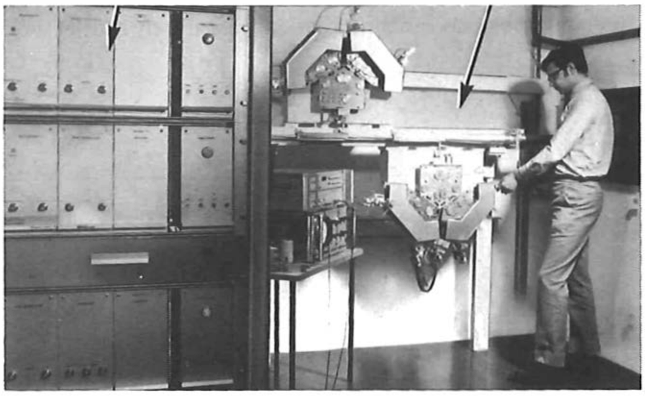

FIG. 1—Field-trial equipment layout

Fig. 1 shows the field-trial equipment layout. A description is given below of the repeater assembly; the terminal equipment consists of the transmitting or receiving half of the repeater assembly, as appropriate.

## REPEATER ASSEMBLY

A block diagram of the repeater assembly used in the waveguide system is shown in Fig. 2; this provides signal amplification and regeneration in a manner similar to other digital systems. Since the repeater is part of a carrier system, modulators and demodulators (modems) are required to transfer information to, and remove it from, the channels allocated to the carriers. Signal amplification is most effectively accomplished at one frequency and, in keeping with conventional practice, the receiving equipment incorporates the superheterodyne principle of translating the incoming carrier to an intermediate frequency (IF), where it is amplified and demodulated. Impairments produced by transmission through the medium or the equipment are removed by a regenerator. The restored signal is then transferred to the transmitter, where it remodulates a fresh carrier for transmission along the next section of waveguide.

A band-branching plan derived for an operational 50 mm waveguide system (Fig. 3) assumes an available bandwidth of 80 GHz, from 30–110 GHz. The GO and RETURN paths each occupy one half of the transmission band, 30–70 GHz and 70–110 GHz, and are separated by a guard band of about 2 GHz. Each of the 40 GHz bands is subdivided into 4 approximately 10 GHz bands, into which the carriers are channelled. The channel bandwidth depends upon the modulation rate chosen for the system and 300 Mbit/s appears to be the highest practical value that can be adopted at present. The optimum bandwidth needed to accommodate a carrier modulated at this rate is about 560 MHz. It is convenient to provide 16 channels per 10 GHz broadband block, allowing 1 GHz as a guard band between each block. Thus, the complete system is capable of carrying 64 channels

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† Research Department, Telecommunications Headquarters

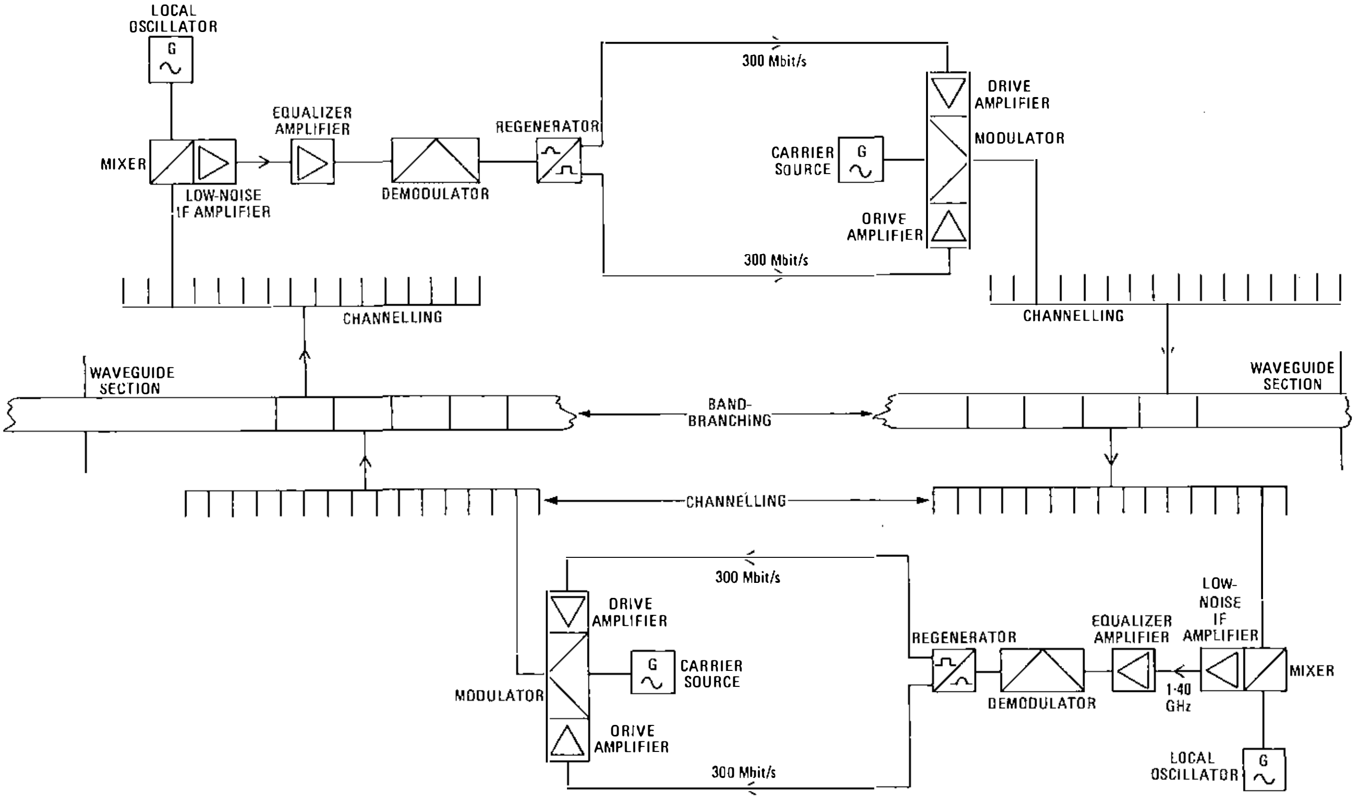


FIG. 2—Block diagram of the repeater assembly

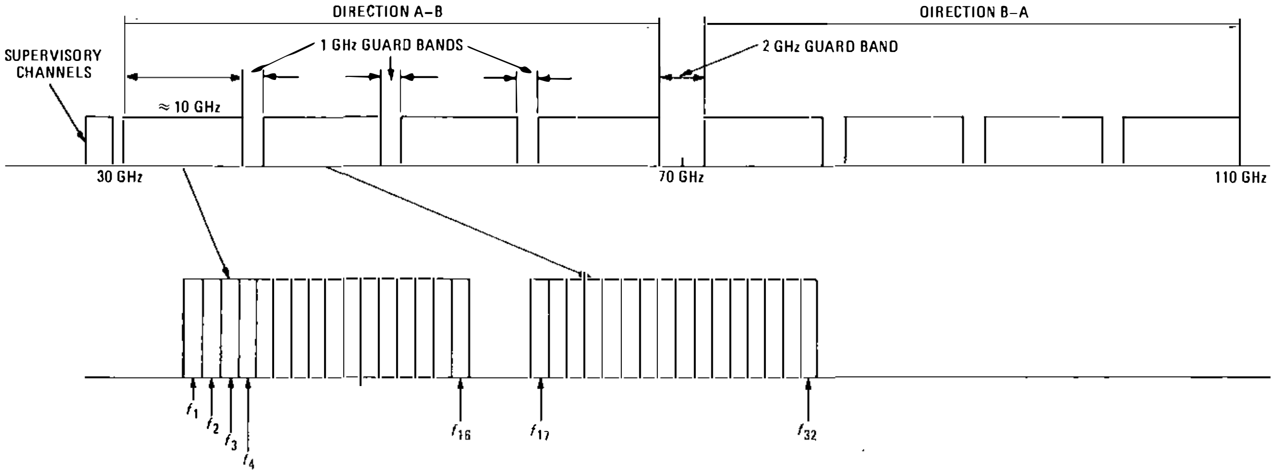


FIG. 3—Band-branching and channelling plan

in each direction, with 4-phase modulation on each carrier; the total information capacity is therefore 38·4 Gbit/s in each direction, equivalent to nearly half a million telephone circuits.

## Modulation

In common with other digital carrier systems,[4] the repeater equipment design is based on PSK of the carrier, in which an incoming binary stream creates phase reversals of the carrier depending on the presence of a 1 or a 0 condition. The modulation can be effected at the IF and frequency converted to the required channel in the waveguide band (Fig. 4) or, alternatively, it can be accomplished directly at the carrier frequency (Fig. 5). Both systems are quite similar in their operation, using path-length switches to change the phase of the signal by the correct amount.

In the case of binary transmission (Fig. 6), the output from an oscillator is routed through a circulator to the switch, which introduces a 180° phase shift in the reflected

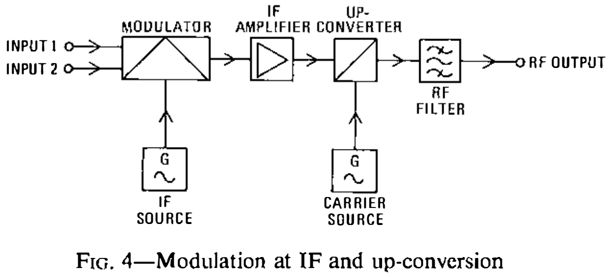


FIG. 4—Modulation at IF and up-conversion

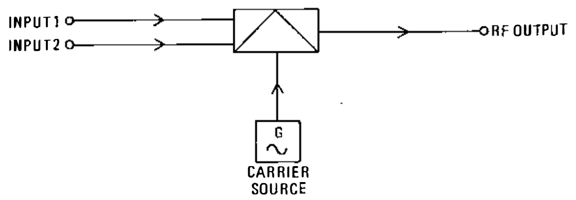


FIG. 5—Direct carrier modulation

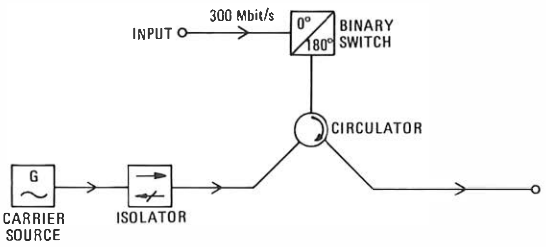


FIG. 6---Binary phase modulator

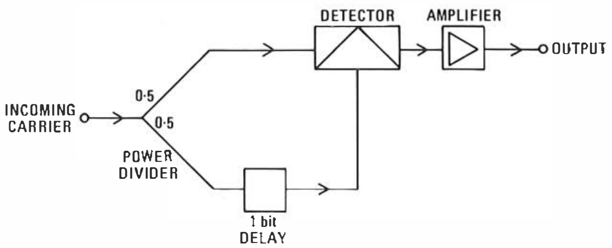


FIG. 8—Binary differential demodulator

signal when operated by one state of the incoming digit stream; for example, a 1 condition. The signal travels back through the circulator and out of the third port. Additional isolation is introduced between the carrier source and the circulator to reduce interaction between the switch and the oscillator through the reverse direction of the circulator. The switching rate of the circuit is largely controlled by the speed of the switching diode and its associated driving circuit; for the waveguide field trial, the modulator operates at 250 Mbit/s and the resultant modulated carrier spectrum occupies a bandwidth of about 500 MHz.

Increased information rates can be obtained either by the use of faster bit rates, or by multilevel techniques. For example, the information capacity is doubled by combining 2 synchronous binary modulated signals in phase quadrature.

In a 4-phase modulator designed in the Research Department of the BPO (Fig. 7), the source power separates into 2 equal-amplitude carriers that are independently switched by 2 incoming synchronous binary streams. The 2 binary phase-modulated signals are then recombined through a quadrature coupler. This type of circuit involves 3 dB loss of signal level through the quadrature coupler, which provides 2 outputs of equal power. With the present state of technology, however, it is preferred because the switches are identical binary modulators and result in adequately low cross-modulation when combined to produce the 4-phase modulated signal. The switches are p i n diodes, which present a resistance of about 0·5 Ω when forward biased and a high resistance shunted by the terminal capacitance when reverse biased. The capacitance across the diode necessitates a circuit manipulation to ensure correct phase shift upon switching; the forward resistance results in signal loss.

In practice, the overall loss obtained through the modulator is about 5 dB (including the coupler). Thus, a source providing 150 mW results in a modulated output power of about 50 mW.

## Demodulation

A binary phase modulator involving phase reversals is an effective means of transferring all the signal energy into the transmitted sidebands, because the resultant signal spectrum contains a negligible carrier component. However, this raises serious problems in a synchronous demodulator, in which a carrier component is required as a fixed reference. An alternative method is to compare the phase of the signal with that in the previous signalling element, so that the demodulator responds to phase changes; in this case, it is necessary to recode the data so that a phase change occurs for a particular state (for example a 1 condition) of the binary stream in a bit interval. The first method is termed *fixed-reference* or *coherent demodulation*, and the second scheme *differential demodulation*.

In the differential system (Fig. 8), the incoming signal is divided into 2 equal-amplitude components and applied to 2 paths, one of which introduces a delay equal to the interval of 1 bit relative to the other path. The 2 signals are then compared; phase opposition between them results in an output voltage corresponding to the 1 condition in the original data: phase similarity produces a 0 condition. The circuit of the differential demodulator is straightforward, and experience has shown it to be very effective for waveguide system applications. However, the differential system is attended by several disadvantages, principally, reduced noise-immunity and more stringent frequency-stability requirements. Since phase detection is achieved by comparing 2 signals each degraded in the system, the effects of noise and system impairments are intensified; because the delay network in the demodulator is phase/frequency sensitive, carrier frequency-stability requirements become very severe.

The waveguide has very stable and uniform transmission characteristics, which result in constant-amplitude signals of low distortion (after equalization). In addition, slightly reduced repeater spacings (to accommodate the extra signal

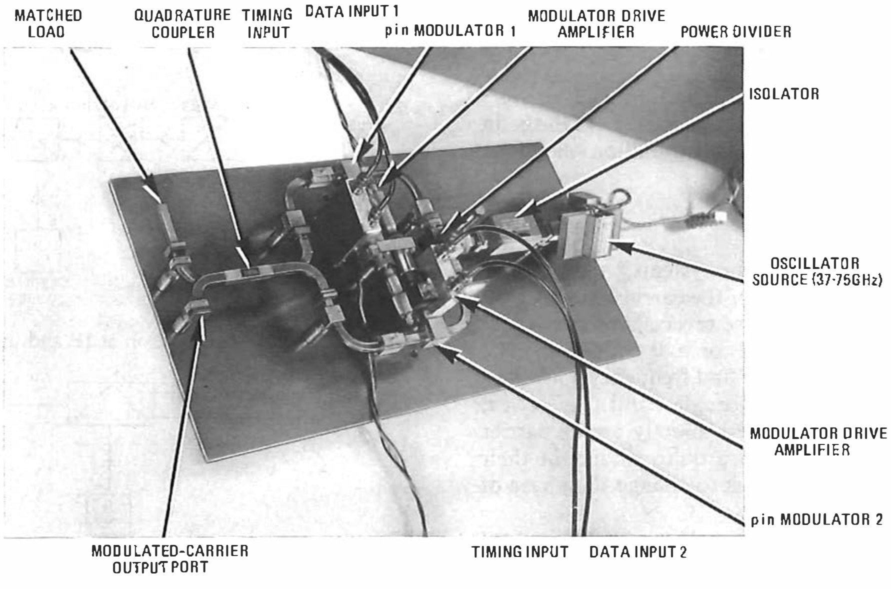
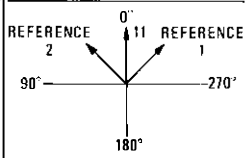
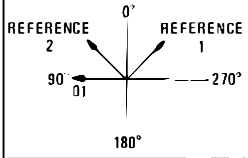
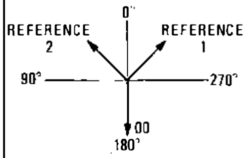
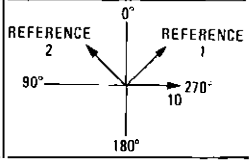


FIG. 7—Experimental 4-phase modulator

### TABLE 1

**Relationships between Binary Input and Output Signals and 4 Phase Changes of the Differential Demodulation System**

| Modulator Input | | Modulator Phase Change | Relative Phase of Reference in Demodulator | | Demodulator Output | | Phasor Diagram |
|---|---|---|---|---|---|---|---|
| 1 | 2 | | Reference 1 | Reference 2 | 1 | 2 | |
| 1 | 1 | 0° | −45° | 45° | 1 | 1 |  |
| 0 | 1 | 90° | −135° | −45° | 0 | 1 |  |
| 0 | 0 | 180° | +135° | −135° | 0 | 0 |  |
| 1 | 0 | 270° | +45° | +135° | 1 | 0 |  |

requirements of the differential demodulation system) have negligible effect on the initial cost of the system, this being very largely dependent upon the waveguide and its installation. Thus, a good case can be made for the use of the differential demodulation system, particularly with the excellent frequency stability obtained from IMPATT† oscillator sources.

As in the differential demodulation system, the data must also be coded in the coherent system to avoid any ambiguity in the polarity of the data stream. In both systems, coding can be introduced by using a bistable circuit; every time a 1 condition is present or maintained, the output of the bistable circuit changes state at each successive bit interval, regardless of the previous state; when a 0 condition is received, there is no change. Thus, the output phase of the modulator alters by 180° for every 1 condition, producing the desired differential signal encoding.

In the 4-phase modulation process, similar principles apply, but the 4 possible states are assigned given changes of phase (Table 1). At the demodulator end, 2 reference signals are extracted and delayed by 1 bit interval as in the binary demodulator (Fig. 8), but, additionally, they are in phase quadrature and oriented in phases of +45° and −45° with respect to zero. The phasor addition of each reference and the original 4-phase signal then provides a phasor of amplitude that corresponds to the condition of the transmitted data; that is, a +45° or −45° phase change yields a 1 condition, and a +135° or −135° phase change a 0 condition. These are basic principles to be found in text books on data transmission.[4]

### Regeneration

The resultant detected signal from each demodulator suffers from effects of transmission impairments due to imperfect modulators and demodulators, amplifier characteristics, terminal mismatches, plus the additional effects of noise in the system. In a digital system, the signal is largely restored by a regenerator; this has the additional function of providing retiming to remove jitter which could, otherwise, build up in the system. Retiming is obtained by referring a signal to the timing content in the demodulated signal and controlling the phase of the signal through a narrow-band phase-locked loop. The timing signal provides gating pulses that coincide with the centre of each bit element. These are applied to the sampling unit and, within the period of each gating pulse, the sampling unit determines whether a 1 or a 0 condition is present in the input. The signal has thus reached a stage where analogue representation of the transmitted original ceases, because the sampling unit produces clean restored elements of rectangular form.

Any excessive degradation of the signal through the transmission path, as a result of noise or any of the impairments indicated above, results in the generation of errors. The error rate in the system is thus a measure of the overall degradation. Typical performance curves obtained from repeater to repeater are given in Fig. 9.

### Oscillator Sources

Oscillator sources for the millimetric waveband provide an absorbing subject that demands special consideration, and cannot be given adequate attention in this article.[5] The IMPATT diode appeared to be the only available solid-state source that had prospects of covering the waveguide band and was, therefore, given most consideration. The device is a p n junction diode, and the avalanche process depends upon a high-enough field being reached in the p n junction itself. A typical microwave oscillator diode avalanches at about 20 V, and it is normally possible to obtain about 200 mW of microwave power at 100 mA driving current.

The junction diode itself can be fabricated from normal semiconductor elements such as germanium or silicon, or from compound semiconductors such as gallium arsenide or indium phosphide. Most of the work on IMPATT diodes to

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† IMPATT: Impact, avalanche and transit time

date has been in silicon and gallium arsenide; while silicon diodes have operated successfully up to at least 110 GHz, all the work on IMPATT diodes in the Research Department has been on gallium arsenide, which has provided better efficiency and more available power at the lower frequencies.[6]

An experimental oscillator unit[7,8] is shown diagrammatically in Fig. 10. The diode is coupled to a rectangular waveguide cavity through a coaxial-to-waveguide transformer. The bias feed to the diode is made through the inner conductor of the coaxial line, and the output power is coupled through an iris in the end face of the cavity to the waveguide feeder. The frequency of the oscillator is controlled by the cavity dimensions, the bias current and the diode parameters. By maintaining the cavity temperature within ±0·1°C by means of a built-in thermostatic control system, a frequency stability of better than 1 part in $10^5$ is obtained. Thus, at 50 GHz, the frequency of the oscillator is kept within 0·5 MHz of the nominal value, a variation that is within the limits required for a 4-phase differential system to maintain an adequate performance. The power available from IMPATT oscillators over the waveguide frequency range is given in Fig. 11.

### Multiplexing

At present, the highest level proposed in the digital hierarchy is a bit rate of about 140 Mbit/s (139·264 Mbit/s). If a binary stream operating at this rate is used to phase-modulate a carrier, the frequency bandwidth required to accommodate the frequency spectrum would be approximately numerically double the bit rate, and about 260 channels would be needed to utilize fully the available bandwidth in the waveguide. To reduce the complexity of the channel-assembly equipment, it is beneficial to raise the digit rate; this also reduces the number of repeater units and makes them more cost effective.

The highest practical digit rate, using currently-available integrated-circuit technology, is about 300 Mbit/s, and 4-level phase operation is the safe limit of practical engineering at present. Thus, taking these factors into consideration in the waveguide system, two 140 Mbit/s tributaries can be diplexed to produce a higher-level signal (highway) operating at about 300 Mbit/s, and two 300 Mbit/s signals can be combined within a 4-phase modulator to produce a 600 Mbit/s channel (Fig. 12). The four 140 Mbit/s tributaries are normally asynchronous and must be synchronized before being multiplexed to the higher levels. Tighter tolerances in the performance specifications of the repeater equipment are also required, but fewer repeater units are needed and the information capacity of each channel and repeater is quadrupled.

Multilevel operation does not affect the modulation rate, and the 600 Mbit/s 4-phase signal can be contained within a bandwidth comparable with the bit rate. In practice, a 560 MHz channel bandwidth is proposed.

A method of channelling, developed for the field trial, operates on the commutating-filter principle, the basis for this having been derived for diplexing in radar systems.[9] The commutating filter (Fig. 13) operates through the interference pattern produced between 2 equal-amplitude signals, derived from the same source, and having a path difference between them.

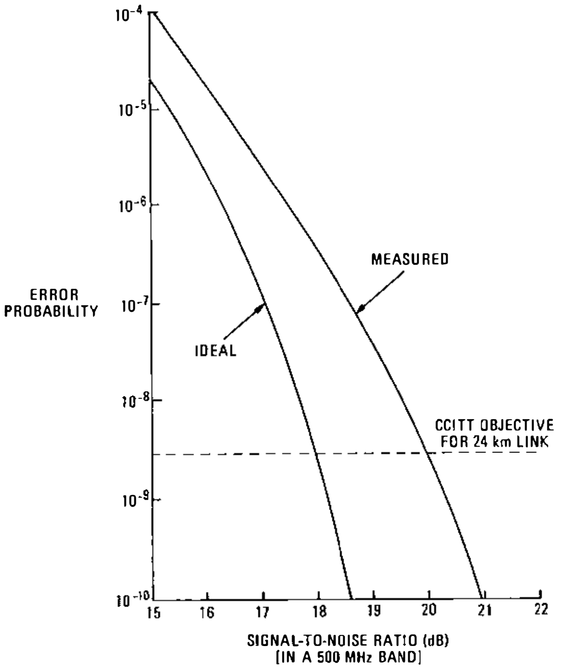


FIG. 9—Error-probability/signal-to-noise-ratio characteristics for 4-phase differential system

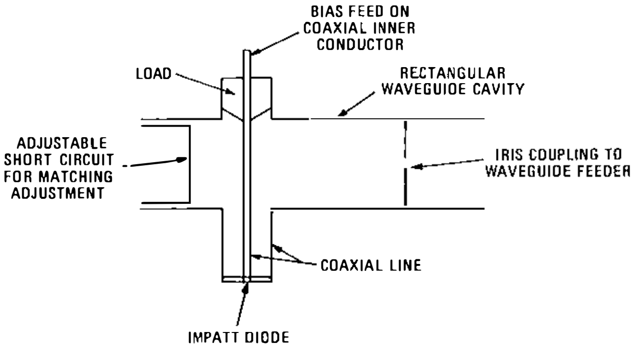


FIG. 10—IMPATT oscillator configuration

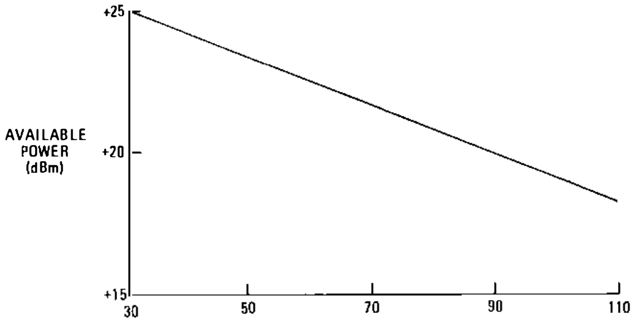


FIG. 11—Available-power/frequency characteristic for an IMPATT oscillator

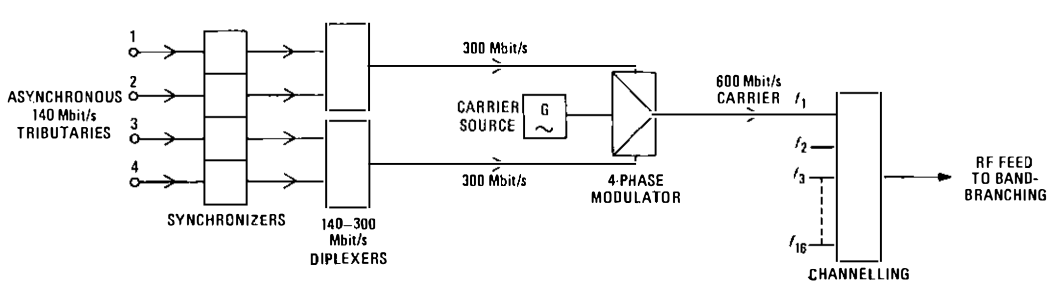


FIG. 12—Assembly of digital tributaries on the RF carriers

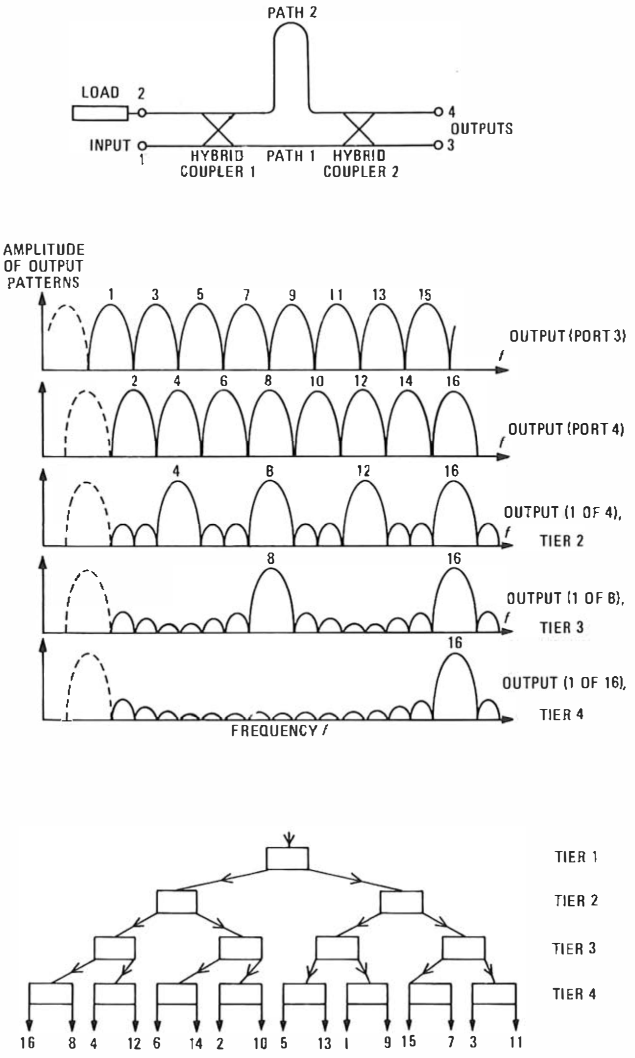


FIG. 13—Commutating filter

A signal arriving at port 1 divides equally into paths 1 and 2 through hybrid coupler 1. As the paths are of unequal length, however, the recombination of the signals through hybrid coupler 2 is dependent upon the relative phases of the 2 signals. When the path difference is an even multiple of half the guide wavelength, maximum output is obtained from port 4. If, however, the path difference is an odd multiple of half the guide wavelength, the maximum output occurs through port 3. A frequency sweep over the bandwidth of the hybrid couplers produces an output that commutes between ports 3 and 4 and, taking the outputs separately (Fig. 13), the maximum output from one port coincides with minimum output from the other; this gives the basis for provision of even channels through one port and odd channels from the other. To extract individual carriers, rather than groups of carriers, it is necessary to follow a hybrid filter with subsequent units each having half the path difference of the previous units.

Multiplexing the 560 MHz channels within the 30–110 GHz waveguide frequency band is effectively accomplished in rectangular waveguide, but for single-moded operation, the bandwidths available in the standard sizes of rectangular waveguide are strictly limited. The circular waveguide band can be covered by the use of 4 rectangular waveguide sizes, but to obtain an optimum balance between the broadband division and the channel multiplexing, the waveguide band has been divided into eight 10 GHz bands, each of which accommodates sixteen 560 MHz channels (Fig. 3). The actual bandwidth occupied by a group of 16 channels is 8·96 GHz. This allows a margin for effective broadband separation. An additional margin is also provided at 70 GHz to permit transmission in both directions through a single waveguide. These proposals are based on the band-branching and channelling equipment developed for the field trial[10] (Fig. 14). This equipment provides rectangular output ports covering the frequency bands 32–40 GHz, 41–49 GHz, 52–68 GHz, 72–88 GHz and 92–110 GHz.

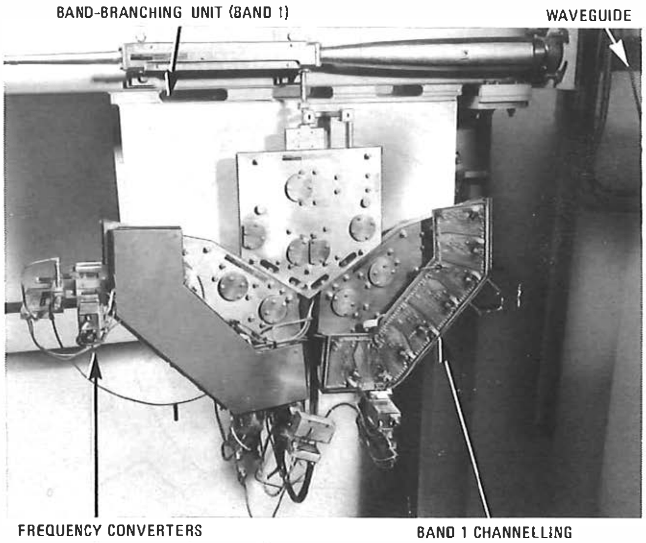


FIG. 14—Band-branching and channelling equipment

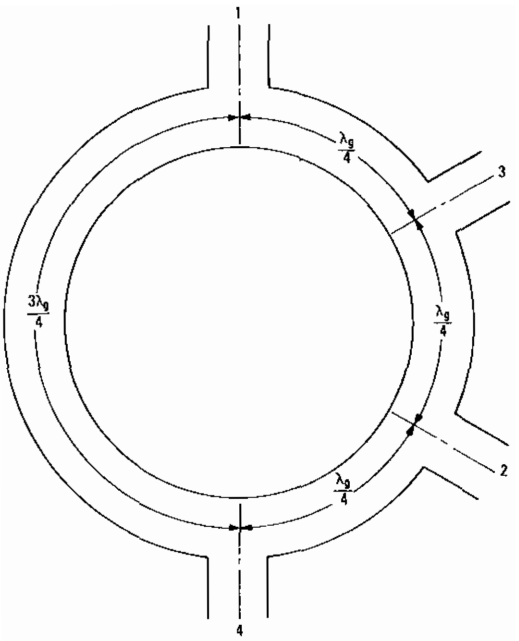
With successive branching units, it is possible to couple out frequency bands in an ascending scale by the use of appropriate reflection filters. Also, since the ports are independent access points to the waveguide, it is possible to build up the system progressively through the frequency bands, without affecting traffic already existing on the waveguide.

## Receiving Equipment

The mixer in the receiving equipment is one of the loss-producing elements of the system and thus needs careful design consideration. In addition, factors such as image-channel rejection, local-oscillator radiation (in this case, transmission back into the waveguide) and adjacent-channel selectivity are problems common to superheterodyne reception, and have to be taken into account. The local oscillator in the receiver operates at a level many orders above the received signal, and it is least harmful if its frequency is situated between channels. This condition is obtained if the IF has a value of $(n + \frac{1}{2}) f_s$, where $f_s$ is the frequency spacing between channels. A value of $n = 2$ provides sufficient separation from the baseband (the band covering the basic spectrum of the data stream) and the IF band. A reasonably low IF is also obtained, facilitating the gain and low-noise requirements of the IF amplifier chain. Thus, a suitable IF for a channel spacing of 560 MHz is 1·4 GHz. The mixer requires local-oscillator injection facilities as well as a signal input port. These can be obtained by means of a directional coupler. One convenient configuration is the hybrid ring (Fig. 15), which is a 4-port device providing independent entries for the signal and local oscillator (ports 1 and 2), and 2 outputs (ports 3 and 4) for the combined signals. The output signals are mixed by non-linear Schottky-barrier diodes and the resultant IF signals are filtered out, combined and amplified. Typical performance figures for this type of mixer are a conversion loss of 6 dB and local-oscillator isolation of about 20 dB.

## IF Amplifier

The IF amplifier incorporates microwave transistors and uses hybrid microwave integrated circuits that enable stages to be cascaded to provide the required gain. The gain for each channel in the field trial has been preset using resistive pads



$\lambda_g$: Guide wavelength

FIG. 15—Hybrid ring

inserted between the low-noise pre-amplifier and the main amplifier. Apart from this preliminary adjustment, no other gain control has been necessary in the amplifier chain, the system as a whole being adequately stable.

## SYSTEM ASPECTS

The overall signal-to-noise ratio, $P_S/P_N$, between repeaters in a waveguide system is given by

$$P_S/P_N = \frac{P_t}{LkTBF},$$

where $P_t$ = power available from the repeater (watts),
$L$ = transmission loss expressed as the ratio of the powers at the transmitter output and receiver input terminals,
$k$ = Boltzmann's constant ($1{\cdot}38 \times 10^{-23}$ J/K),
$T$ = temperature of the waveguide input to the receiver (kelvins),
$B$ = overall effective receiver bandwidth (hertz), and
$F$ = receiver noise factor.

If, for example, the available source power is 100 mW, the receiver noise factor (which includes the mixer conversion loss) is 15·85 (that is, 12 dB), the channel bandwidth is 560 MHz, the signal-to-noise ratio, for a temperature of 290 K, is

$$10 \log_{10} P_S/P_N = 94{\cdot}5 - 10 \log_{10} L \text{ decibels.}$$

Thus, if a carrier-to-noise ratio of 24·5 dB is required, the permissible loss between repeaters is 70 dB. An allowance of 10 dB for the channel filtering equipment reduces this to 60 dB, and an attenuation coefficient of 2·5 dB/km in the waveguide gives a permissible repeater spacing of 24 km.

The proposed design objective for international digital transmission systems allows an error rate of 1 in $10^{10}$ per kilometre; that is, 2·4 in $10^9$ between repeaters having 24 km spacing. Fig. 9 shows that the performance of the differential system allows an adequate margin (4·5 dB) to achieve an error rate of 2·4 in $10^9$ (shown as the equivalent error probability of $2{\cdot}4 \times 10^{-9}$); this margin accommodates such factors as inadequate removal of transmission impairments and performance variations that can occur, for example, through oscillator frequency drift.

In practice, the attenuation coefficient of the waveguide varies with frequency and is likely to increase as each edge of the frequency band is approached. The rising attenuation at the low-frequency end of the band can be accommodated through increased source power and improved equipment performance, but, at the high-frequency end, both equipment and waveguide are likely to show increasing limitations. The overall system parameters must, therefore, have particular reference to the performance in the highest-frequency channel.

However, the group-delay distortion in the waveguide increases rapidly as the lower cut-off frequency is approached, and the lowest channel is the most difficult to equalize. The group delay, $\tau$, incurred in the waveguide is given[11] by

$$\tau = \frac{l}{v_g} = \frac{l}{c\{1 - (f_c/f)^2\}^{1/2}} \text{ seconds,} \quad \ldots\ldots (1)$$

where $l$ = length of waveguide (metres),
$c$ = velocity of light (metres/second),
$f_c$ = lower cut-off frequency (hertz),
$f$ = carrier frequency (hertz),
$v_g$ = group velocity in the waveguide (metres/second).

The lower cut-off frequency for the $TE_{01}$ circular waveguide mode is

$$f_c = \frac{3{\cdot}8317c}{2\pi a} \text{ hertz,} \quad \ldots\ldots (2)$$

where $a$ = radius of waveguide ($25 \times 10^{-3}$ m).

Since the group-delay variation with frequency is monotonic, the major consideration is the slope of the group-delay characteristic over a channel band. This can be obtained from the derivative of equation (1), and is given by

$$\frac{d\tau}{df} = \tau' = \frac{l}{cf}\left[\frac{(f_c/f)^2}{\{1 - (f_c/f)^2\}^{3/2}}\right] \text{ seconds/hertz,} \quad \ldots\ldots (3)$$

from which, the group-delay slope across a channel band $b$ (hertz) is

$$b\tau' = \frac{lb}{cf}\left[\frac{(f_c/f)^2}{\{1 - (f_c/f)^2\}^{3/2}}\right] \text{ seconds.} \quad \ldots\ldots (4)$$

Thus, in a channel width $b$ of 560 MHz and a repeater spacing $l$ of 24 km, the group-delay slope in the lowest-frequency channel ($f$ = 30 GHz) is 97·5 ns.

Removal of this slope by using a group-delay equalizer is simply a cancellation process and cannot be achieved without adequate stability of the medium. The major consideration in this respect is therefore the effect of dimensional changes of the waveguide with temperature, and so the dependency of group-delay slope on the waveguide radius must first be determined. Combining equations (2) and (4) and differentiating with respect to the radius $a$ gives

$$d(b\tau') = b\tau'\left(\frac{2 + (f_c/f)^2}{1 - (f_c/f)^2}\right)\frac{da}{a} \text{ seconds.} \quad \ldots\ldots (5)$$

The waveguide cladding material has a linear temperature coefficient of expansion of $25 \times 10^{-6}$/°C, and the maximum change in temperature 0·6 m below the ground is expected to be 15°C. Thus, $da/a = 3{\cdot}75 \times 10^{-4}$, and $d(b\tau') = 0{\cdot}08$ ns at 30 GHz.

This figure is well below the tolerable group-delay variation and can be amply accommodated, provided other parameters remain stable. The length of waveguide remains constant because the waveguide is under tension at all operating temperatures.

The other consideration is the effect of carrier-frequency changes. This can be similarly determined by differentiating equation (4) with respect to $f$ instead of $a$. With the carrier-frequency stability required for the system, negligible variation of the group-delay response occurs. The remaining principal problem is, therefore, that of matching the group-delay equalizer adequately to the waveguide characteristic to achieve the required performance.

## RELIABILITY

A waveguide system must provide a service, in terms of reliability, at least comparable with existing systems; any new devices introduced into the system need special examination. In the waveguide system, the IMPATT diode falls in this category as it is a fairly recent development, having been introduced since the waveguide was proposed as a transmission medium. However, the considerations that follow apply in general to all the devices used in the system.

The service requirements for a high-capacity transmission system call for a mean time between failures (MTBF) of 20 years/100 km, excluding power supplies, and the non-availability target on any 140 Mbit/s section is 0·01% per 100 km. The nonavailability of a system depends on the mean time to repair (MTTR) or replace a faulty item, relative to the MTBF of the channel containing the faulty component. In quantitative terms, the non-availability is given by $1 - A$, where the availability $A$ is given by

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}.$$

Thus, if the MTTR is 8 h and the MTBF is 20 years/100 km ($1{\cdot}75 \times 10^5$ h/100 km), the nonavailability is 0·005% per 100 km. In general, once the MTBF of a channel is stipulated, the nonavailability is dependent upon the MTTR.

The reliability requirements for an individual channel in the waveguide system can be eased if the system operates on an $n + 1$ basis; that is, $n$ working channels operating with a common spare that is switched into operation immediately any one of the working channels fails. In the waveguide system, since there are 16 channels within each broadband block of channels, it is convenient to make $n = 15$. Under these conditions, the MTBF requirement for each channel reduces to 2 years, which can be expressed as a failure rate of 0·057/1000 h. If there are 50 active devices per repeater and 5 repeaters per 100 km, the failure rate per device is reduced in the ratio of 250, and becomes 0·02% per 1000 h.

This failure rate should be the maximum obtained throughout the life of the system. In the initial period of operation, rogue failures are prevalent, but can be eliminated to a large extent by stress tests carried out prior to the service period. Towards the end of the service life, the failure rate of the devices may rise due to wear-out. The wear-out behaviour of semiconductor devices can be predicted hy batch testing at elevated temperatures, and a family of curves can be obtained showing the increase of failure rate with time for various operating temperatures. Taking the IMPATT diode as the device under scrutiny, it has been found that the predicted failure rate of the device as tested rises to about 0·01% per 1000 h after 20 years' service with junction temperatures of about 210°C. Reduction of junction temperature to 200°C, which is consistent with the system power requirements, gives a substantial margin over the permissible failure rate at the end of a 20-year working period.

Experience to date on the field trial, after 2 years' operation, has indicated that stress tests carried out prior to operation at normal temperature may have yielded pessimistic predictions. Some of the IMPATT devices, whose temperatures have been set to give anticipated failures after 1 year of service, are still operating with no failures recorded. Operation on this form, and with normal junction temperatures, would ensure reliability throughout the life of the system.

A complete study of reliability takes into account failures of passive devices such as resistors and capacitors. It also includes connexions between devices and components which, if soft-soldered, can have a significant effect on reliability. Progress in circuit technology may lead to the production of assemblies and subassemblies in integrated form; this would reduce the number of connexions adequately to meet the reliability requirements.

## CONCLUSION

The repeaters developed for the field trial were produced in sufficient numbers to provide several complete loops through the 14·2 km link, adequate to simulate a system path length of over 100 km. The frequencies of the channels were chosen to provide information on factors such as adjacent-channel and image-channel interference, band protection, and equalization problems; reliability aspects such as oscillator life and frequency stability were also given due consideration. The equipment itself has demonstrated, after several years of operation, that a performance consistent with the operational requirements of high-capacity trunk systems can be met.

The bandwidth capability of the waveguide, and its stability as a transmission medium have been demonstrated. While the waveguide exhibits a larger bandwidth than may be required immediately, it has also been demonstrated effectively that the long-term potential can be maintained by the use of a band-branching plan that provides a progressive build-up of traffic without wastage of spectrum or interruptions to existing traffic.

## ACKNOWLEDGEMENTS

The development of the equipment for the field trial has been a wide-ranging exercise and could not have been successfully achieved without the close co-operation of the many participants in the BPO Research Department and in Industry whose contributions are gratefully acknowledged.

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# The Design of Martlesham Research Centre

## Part 2—Services Provided

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UDC 721.011 : 62.001

*The first part of this article discussed the procedures adopted in the design of the Martlesham Research Centre and described the design of the buildings. This second and concluding part describes the services provided in the Research Centre.*

## INTRODUCTION

Part 1 of this article* outlined the guiding principles adopted in the design of the Martlesham Research Centre, discussed the production of the Schedule of Requirements and described the overall design of the buildings. This second part describes the services that have been provided in the Research Centre.

## THE AIR-CONDITIONING SYSTEMS

### Laboratory Block

The air-conditioning plant serving the laboratory block comprises 5 independent similar installations, one on the lower-ground floor of each of the 5 structural zones that make up the building (see Fig. 6, Part 1). Only one of these need be described here.

A dual-duct system is used, in which up to 90% of the returned air can be recirculated after filtering and conditioning; the remainder is made up from fresh-air supplies. The equipment on the lower-ground floor delivers 2 streams of air, one heated and the other cooled, in a quantity to give an adequate rate of change for ventilation purposes (in the range 4–10 air-changes/h), and in the correct proportions in each individual group of rooms to achieve the required preset local temperature. With this system, the amount of heat supplied to, or removed from, individual groups of rooms is adjusted by altering the proportion of hot-to-cold air in mixer boxes above the ceiling, under the control of a thermostat.

A block diagram of the laboratory block air-conditioning system is shown in Fig. 8. The air circulation starts in the air chamber (which is divided into 2 compartments shown as intake and exhaust) by a diaphragm wall having an adjustable louvred aperture. Air extracted from the building is returned to the exhaust compartment; the required proportion of it is drawn through the louvre into the intake compartment, where it mixes with not less than 10% of fresh air. Air is drawn from the intake compartment through a filter by a 110 kW centrifugal fan having a through capacity of 47 m$^3$/s, and, at a pressure of 1·12 kPa, divides into 2 separate air ducts. The first becomes the hot air stream; the second becomes the cold air stream. The dampers controlling the supply air are continuously variable, and adjust the proportions of recirculating and fresh air according to their relative conditions.

The first air stream goes into a heater battery to emerge dry at a controlled air temperature of 32·2 ± 1·1°C. A heater battery is like an enormous car radiator fed with hot water from the main boilers. The hot filtered air is ducted to the vertical hot riser and passes from the lower-ground floor up through the building to be tapped at every floor.

The second air stream goes into the cooler battery, again in principle like a giant car radiator, but cooled by water at 4·4°C from the refrigeration plant. The cold air is humidified by water spray to near saturation, and emerges from the humidifier at a controlled temperature of 10 ± 1·1°C and relative humidity of 98% (that is, just below dew point) and a pressure of 1·12 kPa; it then enters the vertical cold-riser to pass up through the building.

At each floor level, hot and cold horizontal ducts in the ceiling voids tee out from the vertical risers to carry the 2 air streams to an elaborate system of distribution ducts covering the whole ceiling area, each hot and cold pair terminating in a mixer box. About 800 mixer boxes are provided in the laboratory building, located according to laboratory needs and the amount of heat to be moved. Each mixer box has 2 entry points, one taking cold air and the other hot air. The proportion in which mixing occurs is controlled by flap valves which are pneumatically operated under the control of room thermostats. The present standard room temperature is 20 ± 1·1°C. From the mixer boxes, air at the required temperature is ducted into each room through grills in the sides of the fluorescent-light fittings mounted flush with the ceiling. Stale air is drawn from the rooms, over the fluorescent lamps, up into the void above the ceiling; this lowers the lamps' operating temperature, thereby increasing lamp life and raising the temperature of the returning air for recirculation. Heat from the lighting makes a useful contribution to heating the building.

Extracted air is drawn back from the ceiling voids into the return-air shaft running down through the central zone core, the suction being provided by a 55 kW extraction fan in the lower-ground-floor plant room. This fan delivers the stale air to the exhaust-air chamber from which it is drawn for cleaning and recirculation as already described. If it becomes necessary to isolate a zone on the lower-ground, ground or first floors to prevent an undesirable gas entering the air-conditioning system, electro-pneumatically-released safety flaps operate to close the entry to the return-air risers. These flaps, when released by wall-mounted emergency buttons, prevent recirculation of bad air; simultaneously, large fans in the main outer wall are started and these exhaust into the open air.

Although complex, the air-conditioning system is fully automatic once basic adjustments have been made. It is fairly flexible in application and will deal with a wide range of local heat dissipation in the laboratories. It can remove a continuous maximum average heat load of 150 W/m$^2$ over all floors at any season of the year. Heat from lighting accounts for 50 W/m$^2$, solar gain can produce up to 50 W/m$^2$ depending on the sun's elevation, and equipment can produce the

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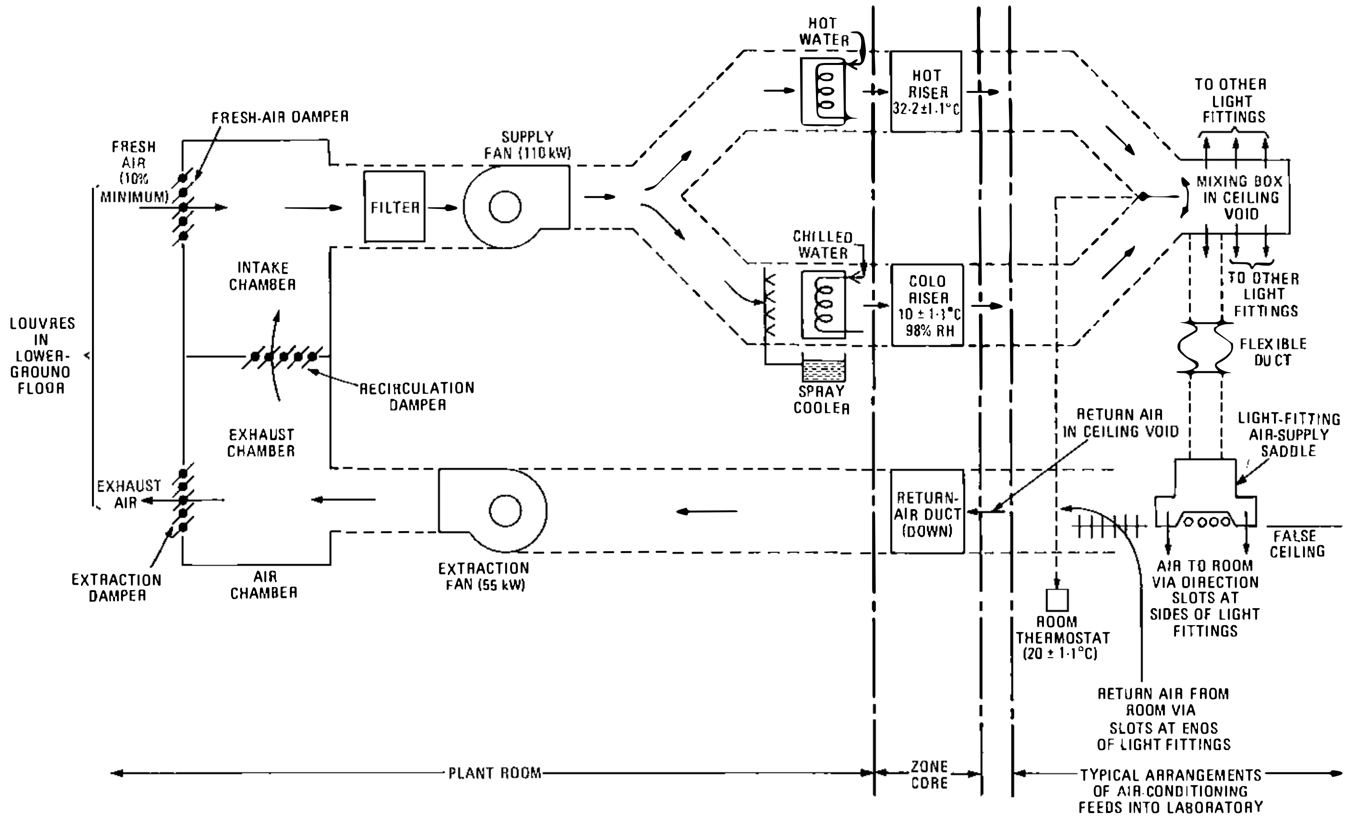
† Mr. Floyd was Head of the Division responsible for the planning of the Martlesham Research Centre and for organizing the move from Dollis Hill, from the beginning in 1964 until his recent retirement

* *POEEJ*, Vol. 69, p. 146, Oct. 1976.



RH—relative humidity

FIG. 8—Block diagram of air-conditioning system for one zone of laboratory block

remainder. Locally, equipment dissipation can be allowed to rise to 100 W/m$^2$ without causing any disturbance to air conditions. Each of the 5 zones has a humidifier at the main cold-duct output in the basement plant room, and automatic controls ensure that this gives an average relative humidity of 50–70% everywhere in the building. This is not adjustable locally.

Most of the controls in the air-conditioning system are pneumatically operated by compressed air supplied from a centrally-situated air-compressing plant on the lower-ground floor.

The acoustic attenuation between adjacent rooms and the noise level of air emerging from the ceiling units is acceptable for normal laboratory conditions; frequently, the effect of noise from the ceiling units is completely masked by other noise contributions in the room.

To most people, the air noise level is unnoticeable in a laboratory or a laboratory-office.

## Administration Block

There are 11 air-conditioning units in the administration building, each serving separate floors or individual rooms; 6 of these units are in the basement, underneath the entrance hall. The remaining 5 small air-conditioning units are in the plant room on the roof; these all serve the top floor, main dining room, coffee lounge, and parts of the kitchen. This multiple-unit system has been remarkably successful in preventing the rest of the building from being aware of the proximity of the kitchen on the top floor.

Some elements of the administration building (for example, the lecture theatres) are used only intermittently, and it would be uneconomical to heat and air-condition them continuously. The multiple-unit air-conditioning system permits selective economy. A block diagram of one of the air-conditioning units in the administration block is shown in Fig. 9. Hot water is supplied from the main boilers and cold water supplied from the refrigeration plant to vary the temperature of the supply air under the control of a wet-bulb sensor at a cold point in the supply duct. This provides "standard air" at a temperature of 10 ± 1·1°C and 100% relative humidity. The room temperatures are jointly monitored by a thermostat in the exhaust duct which controls the reheating of the incoming supply to give the desired average room temperature.

## Refrigeration Plant

A large amount of cooling is needed by the air-conditioning plants, and especially by the dual-duct air-conditioning system in the laboratory block. Cold water for all the buildings is produced by 3 refrigeration units, each of 650 short tons refrigeration capacity,† using centrifugal compressors each of which is driven by a 670 kW 3·3 kV 3-phase motor. This commercial cold-store type of refrigerator uses softened water to minimize pipe corrosion, and the total plant can produce a cooling effect equivalent to extracting the latent heat of water to manufacture 1950 short tons of ice in 24 h. The heat produced by the compressing of the refrigerant gas is dissipated in 3 cooling stacks on top of the water tower.

These large refrigerators are very noisy machines because of their enormous centrifugal compressors. Each machine is on isolated mountings on the ground floor on the west side of the cruciform, but air-borne noise enters the main girderwork of the research services block, which was not designed against noise of this intensity. Additional walls are being built on 2 sides of the refrigerator room to increase the sound attenuation in the inward direction. The source of noise is believed to be at the blade tips of the centrifugal compressors which move at a velocity approaching the speed of sound. It is not surprising that, even with a perfectly-balanced rotor, noisy operation is endemic in this type of machine. This is,

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† A capacity of 1 short ton refrigeration is the ability to produce 907 kg of ice in 24 h from water at 0°C

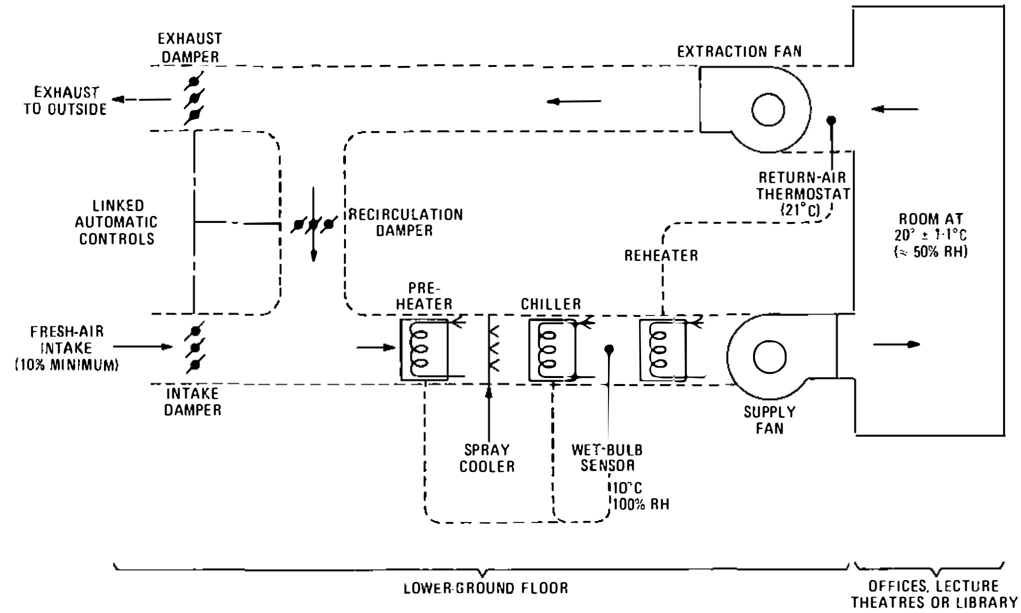
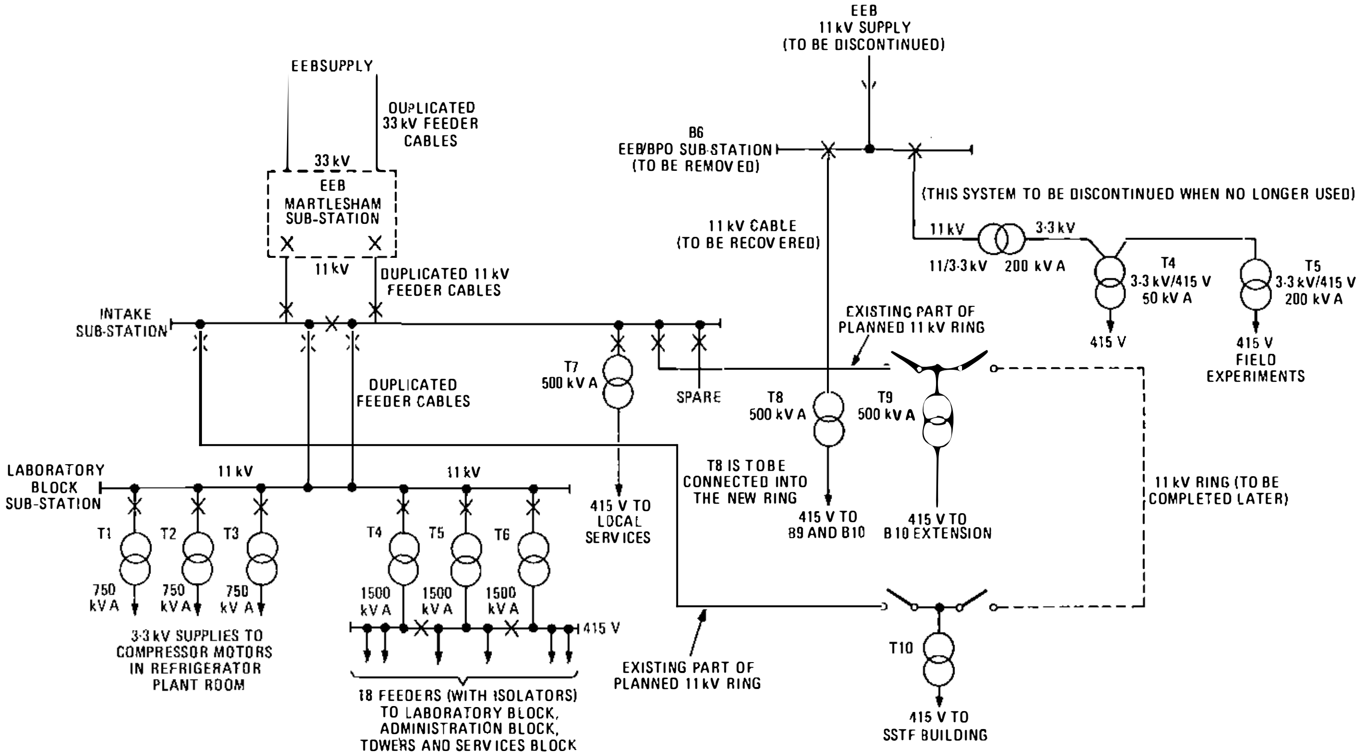


Fig. 9—Block diagram of administration block air-conditioning unit



SSTF—Switching Systems Test Facilities Building
EEB—Eastern Electricity Board

Fig. 10—High-voltage distribution to buildings

however, the most efficient type of large refrigerator, especially when well loaded.

## Bench Equipment Cooling System

An additional cooling facility that can be provided at any laboratory bench is a supply of softened chilled water for cooling local equipment. Chilled water tapped from the main refrigerated supply is used as a source and this is connected to a network of 12·5 mm bench feeders that can be connected wherever needed. At present, this system has a maximum total heat absorption capacity of about 15% of one of the large refrigerator machines. It may prove uneconomical to operate this bench service in cold weather when the main refrigerator plant will not need to run for air-conditioning purposes. It could be advantageous to install a small refrigerator unit specifically for bench equipment cooling duties, so that the main refrigerators can be shut down during winter.

## Boilers

The heat for all the main buildings is supplied by three 2930 kW (10 MBtu/h) natural-gas-fired boilers, with oil stand-by, accommodated in one large boiler house; there is room for a further two 5860 kW (20 MBtu/h) units in the future. The heat is carried away at 115°C in softened and de-mineralized water at 620 kPa and imparted to air at the many heat exchangers for heating the buildings. It is also used to produce hot water for the washbasins in the 2 tower

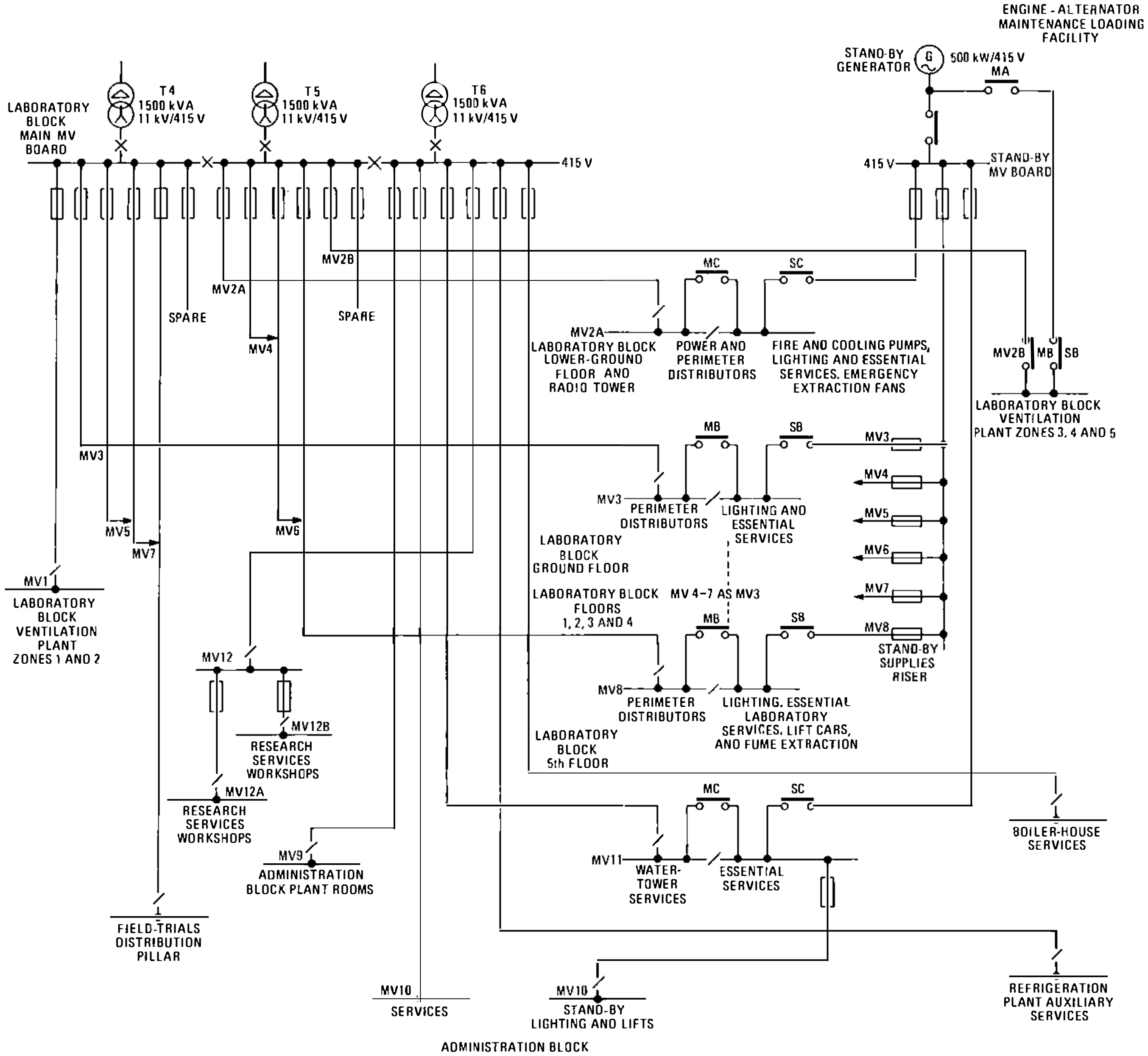


FIG. 11—Medium-voltage (MV) 415/240 V 3-phase network

blocks and the restaurant kitchens. The boiler house is situated on the lower-ground floor in the north wing of the cruciform below the water tower. Pump noise can be troublesome in rooms in the research services block near to the boiler house because it is difficult to damp down this noise at source.

## ELECTRICITY DISTRIBUTION SYSTEM

The Research Centre receives its electricity supply from the Eastern Electricity Board (EEB) on duplicated 11 kV feeders from an EEB open-air sub-station just outside the north boundary fence of the site. The maximum design load for the Centre is 7 MW; the normal running load is expected to be about 4·5 MW.

From a main sub-station alongside the gatehouse of the research site, an 11 kV distribution network feeds

(*a*) a sub-station alongside the laboratory block,

(*b*) a 500 kV A transformer feeding the road lighting system and adjacent building, and

(*c*) an 11 kV ring main that is being installed round the whole site.

Fig. 10 shows the 11 kV power distribution to the buildings, and Fig. 11 shows the medium-voltage 415/240 V 3-phase network that carries power into and within the buildings.

The laboratory block sub-station houses 6 oil-cooled distribution transformers, T1–6 in Fig. 10, any 3 of which supply all the new buildings at 415/240 V 3-phase. This sub-station is in an isolated building, located between the laboratory block and the water tower, with the 6 transformers in individual brick cubicles open to the air for ventilation. Three of the transformers, each of 750 kV A rating, provide 3·3 kV 3-phase supplies to the three 670 kW refrigerator motors in the refrigerator plant room. The other 3 transformers are each 1·5 MV A rating and supply 415/240 V busbars, from which 16 circuits radiate to medium-voltage switchboards; 9 of these are in the laboratory block, 2 are in the administration building, 4 in the research services block and one feeds a field circuit.

A medium-voltage distribution system to individual floors was decided upon because a study showed that it would be more economical than a high-voltage system with transformers on each floor. The fire risk is also reduced because the oil-cooled transformers are outside the laboratory building.

Figs. 10 and 11 show that every opportunity has been taken to operate units in parallel so that out-of-service time due to power equipment failure is cut to a minimum. For example, the 11 kV–415 V transformers T4–6, which feed the laboratory block, are paralleled to the busbars from which all the laboratory distribution springs. Two can handle the maximum load; the third acts as a stand-by.

Power for the courtyard single-storey buildings, B9 and B10 on Fig. 2, and the many small buildings on the site is fed from an 11 kV ring main that is being installed round the periphery of the grounds. Spurs can be run to switchboards and step-down transformers wherever necessary, whether in isolated buildings or outdoors. There is no doubt that the ring-main system is technically the best way to provide the flexibility in the power distribution network that is necessary on a complex experimental site such as Martlesham.

The road lighting system uses Ministry of Transport standard mercury fluorescent road lamps on 7·6 m columns, and on 10 m columns in car parks. It operates from a 415 V–240 V transformer in the gatehouse sub-station. At present, each lamp is fitted with its own time switch so that lamps can be selectively operated. This will be changed to a system of batch switching, which is preferred from experience gained over the first whole season.

As is now usual with engineering buildings in the BPO, the Accommodation Services Section of the Operational Programming Department was responsible for the design of the electrical services and lifts in the new main buildings.

### Stand-by Diesel-Alternator Set

A 0·5 MW self-starting diesel-alternator set, generating 415/240 V, has been installed as an emergency stand-by supply. This engine set gives full output voltage on full load 25 s after the operation of the NO-VOLTS relay. The question of how best to provide electricity in emergencies presents a problem in this large air-conditioned complex because the water-circulating pumps and the air-circulating machinery are all electrically operated. The lighting load is also large. At least 2 MW stand-by engine capacity will probably be needed to keep the Research Centre functioning under minimal conditions if the EEB supply fails. Such a large capital investment for a rare fault condition was not thought to be justified when the project was in the planning stage and, as a result, electrical circuits are arranged so that only 10% of the lights and a few selected laboratories are connected to the diesel-alternator set when the EEB supply fails. None of the air-conditioning motors is on the emergency supply because the electrical load would be too great for the diesel set. Experience has already shown that a larger stand-by capacity is essential and that diesel-alternator sets to give at least 2 MW capacity may, after all, have to be installed to cover EEB power failures.

## LIGHTING

Much attention has been paid to lighting in the laboratory block where deep rooms and windowless laboratories rely on efficient artificial light. An average illumination intensity of 600 lx was specified from the outset, using fluorescent lamps and lighting fittings flush with the ceiling. The spacing of the fittings had to be compatible with the dimensions of the module on which partitions were to be located. A total of 7700 flush ceiling light fittings with a total power consumption of about 1·5 MW is required in the main building.

### Ventilation through Ceiling Fittings

It was also decided at the design stage to place all air entry and exit grilles in the ceiling and to combine these with the light fittings, thus ensuring that wherever there was light there could also be ventilation and heating. As a result, the partitions were freed from any complications involving air-conditioning. Not all the flush light fittings had to convey air, but those that did were equipped with an air saddle; this connected the incoming air streams with longitudinal slots on the side of the fittings, and vented the stale air from the room through end slots and over the fluorescent lamps back into the return-air void. The combined air-handling capacity of a saddle and air grilles in the light fittings, estimated at 170 m$^3$/h, has proved adequate. A sound-absorbing device was incorporated in the air saddle to reduce sound transference from room to room via the air ducts. A test figure of 26 dB attenuation between adjacent laboratories is attained against this source of sound transference. The unusual requirements and large number of fittings needed made it economic to place a development contract for a special design of combined lighting/air-grille fitting for the Martlesham laboratory block.

### Low-Voltage Lighting Control

The control of lighting presents problems when demountable partitions are involved, because it is undesirable to have to alter 240 V mains wiring when partition walls are moved. A system of 50 V d.c. control is used, with a relay in every light fitting and all the ceiling light circuits permanently wired to the 240 V supply. Switches operating at a voltage of 50 V can be inserted into wall partitions and can be safely moved when partitions are changed. No light fitting need be touched when partition walls are altered. All the 50 V relay coils and the wall switches are wired back to one of a number of large matrix boards situated in plant rooms on each floor and, by using a system of cross patching, any combination of lights can be wired to any room switch. A diode matrix is arranged so that, in the event of a mains power failure, about 10% of the ceiling lamps operate from the diesel-alternator set as stand-by lighting. This matrix system of lighting control, using 50 V d.c. to operate mains switching relays, has proved satisfactory and flexible in room planning. The lighting intensity measured on test from the new flush fittings is well above that specified, even giving rise to complaint in some laboratories; using the patching matrix, alternate fittings can be cut out of circuit to reduce the intensity if it proves undesirable locally.

It has also been noted that lighting intensity should not be uniform over a large area nor along a corridor, but should vary from place to place. The eye finds uniformity tiring and ultimately objectionable when the lighting is too bright.

## LIFTS

An efficient lift service is essential for the smooth running of buildings the size of the Martlesham Research Centre. There are 16 lifts in all: 11 for passengers, 3 for goods and 2 light-load service lifts. Six are in the radio tower, including a 5 t goods lift and one with 22 stations including all mezzanine floors, the tower laboratories and aerial galleries. Six are in the water tower, including a 5 t goods lift and one with stations at all the mezzanine floors in the water tower. Four are in the administration building, including one main passenger lift, one goods lift to the kitchen, a book hoist in the library and a light-load kitchen service lift to the Director's dining room.

Each of the 8 main passenger lifts is driven by a variable-voltage d.c. motor, having a useful power output of 15 kW, and take a load of up to 900 kg (13 passengers) at 1·5 m/s. Each bank of passenger lifts operates on a group control system, whereby selected lifts are brought into operation according to the traffic demand. Every lift has 2 home stations, one at each end of its travel. After its passengers have emerged, a lift continues in the same direction to its home station (usually the top or bottom floors), and waits there until its next instruction from the control unit, which must be in the reverse direction from the last journey.

## TABLE 6

### Main Performance Features of Lift Installations

| Lift Number | Location | Speed (m/s) | Number of Floors Visited | Duty | Maximum Load (kg) | Type of Lifting Motor |
|---|---|---|---|---|---|---|
| A1 | Administration building | 1·0 | 5 | Passenger | 900 | Induction motors, 2-speed |
| A2 | | 0·5 | 2 | Goods | 760 | |
| A3 | | 0·15 | 2 | Service hoists | 25 each | Induction motors |
| A4 | | | | | | |
| R1 | Radio tower | 1·4 | 7 | Group control, passenger | 900 each | DC motors |
| R2 | | | | | | |
| R3 | | | | | | |
| R4 | | | | | | |
| R5 | | 0·3 | 8 | Goods | 5080 | Induction motor |
| †R6 | | 1·0 | 22 | Passenger | 680 | Induction motor, 2-speed |
| W1 | Water tower | 1·4 | 7 | Group control, passenger | 900 each | DC motors |
| W2 | | | | | | |
| W3 | | | | | | |
| W4 | | | | | | |
| W5 | | 0·3 | 7 | Goods | 5080 | Induction motor |
| †W6 | | 1·0 | 11 | Passenger | 680 | Induction motor, 2-speed |

† Fireman's facility

The d.c. for the lift motors is supplied by 13 kW motor-generator sets using 3-phase squirrel-cage driving motors. The lift control gear operates at 110 V d.c., supplied by a 3-phase rectifier. Six wire ropes in parallel are used for hoisting each lift cage. The total length of suspension rope used is over 4·8 km. The 5 t goods lifts are much slower than the passenger lifts and are driven by 2-speed induction motors, rated at 18 kW. However, a smaller motor takes over just before the destination floor to give fine control over the stopping level, which is accurate to 6 mm. Loaded trolleys can then easily enter or leave a lift without having to negotiate a step. Table 6 gives the main performance features of all the lift installations.

## FUME CUPBOARDS

Many Research Department projects involve chemical processes that use noxious, or even dangerous, gases and this work must be restricted to fume cupboards with efficient ventilation systems. Such gases must not be allowed to leak into the air-conditioning system of the building, and so careful attention has been given to the engineering of the ventilation. Fume cupboards are tools of the trade in the research divisions concerned. They are likely to be used for a variety of purposes and substances, but probably operate intermittently.

For operational reasons, all the chemical work in the laboratory block has been located on the lower floors of the building. Fume cupboards may be needed anywhere on these floors and must, therefore, be treated as movable items, not part of the building.

To prevent exhaust gas from one fume cupboard feeding back through the exhaust flue of another cupboard not in use, every cupboard must have its own independent flue rising to at least 2·4 m clear above roof level. The vertical flues were installed as part of the building contract, and are located over the 5 zones in 10 stacks of 8 (that is, 16 flues per zone). Each permanent vertical flue is then joined as required by a horizontal run below a laboratory ceiling to the fume cupboard in the desired position. The flues are of 230 mm inside diameter plastics-coated asbestos pipe, with sealed spigot-and-socket joints.

For safety reasons, air must be drawn into a fume cupboard, not blown; so substantial 300 mm suction fans with motors having an effective output power of 1·12 kW, and able to create a reduced pressure of 622 Pa at throat entry, are mounted above roof level on each flue. With this low pressure, which is necessary because the flues are over 30 m long, an air input to a fume cupboard approaching 0·38 $m^3/s$ could occur. If this quantity of air were extracted locally from a laboratory, the air-conditioning stability could be upset. So each fume cupboard can be provided with a conditioned fresh-air input, ducted from beneath the nearest balcony by a standard packaged unit consisting of input fan, electric heater, filter and control louvres. This unit is installed unobtrusively underneath the balcony overhang and is easily accessible from below. It is estimated that 70% of air entering a fume cupboard can be drawn from fresh air with considerable saving in air-conditioning costs. A fresh-air intake for each fume cupboard presents no location problem as balconies run continuously round each floor.

It is probable that only about half of the flues will be in use, as fume cupboards are expensive and will be installed only as required.

Since the time of the design of the laboratory building, there has been a considerable increase in the amount of toxic substances used by Research Department, notably in semiconductor research. There is now also a need to increase the amount of clean-room accommodation beyond that envisaged when the Schedule of Requirements was being drawn up. It has, therefore, been decided to convert some of the single-storey buildings B9 and B10 (see Fig. 2) on the north-west part of the site into clean-room accommodation with, close by, a number of special fume chambers in laboratories reserved for highly toxic work. Certain toxic materials are now excluded altogether from the main laboratory air-conditioned building and must be used only in the fume chambers in building B9.

## THE ACOUSTICS COMPLEX

A feature of the new laboratories is the specially-designed acoustics block, situated just outside the main laboratory building and with a connecting corridor into it. It is designed to give complete acoustic isolation, with massively constructed double concrete walls on isolated foundations. This complex contains 2 anechoic chambers and a reverberant room with associated control laboratories, and a microphone calibration room.

The anechoic chambers absorb all internal sound on the walls without reflection. This is done by linings of sound-absorbing wedges, over 1 m in depth, completely covering all surfaces; a trampoline-type wire-mesh floor is used to support test equipment. Both rooms, one large and one smaller, have massive double doors to give acoustic isolation, the inner one being trolley mounted and motor operated. Equipment can be controlled from outside these rooms.

The reverberant room, about 200 m$^3$ in volume, is lined with hard surfaces to reflect all sound. No two surfaces are parallel, and a reverberation time of not less than 5 s has been achieved. Construction is again double-walled, the inner room being on rubber mountings.

## FIRE PRECAUTIONS

All the main buildings, especially the laboratories, have a minimum main-structure fire resistance of 2 h, being protected by a Pyroc dry-clad treatment. The laboratory floor duct covers also give 2 h fire protection. The partitions are of steel and give zero flame spread. Smoke doors are provided in corridors as required by the fire authorities to limit smoke and flame spread. Those gas cylinders that must be kept in the laboratory block are held in fire-resistant cupboards.

An extensive fire-alarm system has been installed in all 3 main blocks, the 2 towers and the gatehouse. The operation of an alarm sounds a *clear-out* signal (a loud warble) in the block in which the alarm originates and a *preliminary-warning* signal (short bursts of single-tone pulses) elsewhere. The signal is repeated in the gatehouse with a location indicator, and on mimic panels outside main entrances to blocks.

Alarms can be set off by

(*a*) breaking the glass of a red fire alarm, located on all floors of all blocks,

(*b*) automatic operation of heat detectors,

(*c*) automatic operation of smoke detectors in extract ducts of all the air-conditioning systems, and

(*d*) breaking the glass of a chemical alarm, painted yellow. These are located on the lower ground, ground and first floors of the laboratory block only.

In addition to the audible and visual warnings, operation of the fire alarm in the laboratory block disconnects the power supply to the perimeter trunking of the affected floor.

As stated earlier, the operation of the chemical alarm starts up extractor fans exhausting into the open air in the affected zone and floor, and closes a trap in the air-extraction duct for that floor and zone. This prevents any gases from returning into the air-conditioning system by recirculation. The incoming air continues to flow to give a scavenge effect.

## CONCLUSIONS

This article has outlined the principles that formed the basis for the planning of the new Research Centre at Martlesham, and has briefly described the laboratory services provided in the original contract. Some interesting new developments in laboratory design are incorporated, with a view to achieving economy and flexibility when the buildings have to be adapted to future technologies that cannot, at present, be specified.

The engineering design of the Research Centre was a complicated and fascinating task. But, in many ways, the organization behind the move itself, and the Move Committee, by which the unions and staff were kept informed and regularly consulted, was equally important. This more human aspect of the project will be the subject of another article in a future issue of the *Journal*.

## ACKNOWLEDGEMENTS

The author wishes to thank the many people who have been engaged in the Martlesham Research Centre project during its 10-year period, and also the colleagues who have assisted in the preparation of this article.

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# Book Review

*Microwave Devices: Device–Circuit Interactions*. M. J. Howes and D. V. Morgan. John Wiley & Sons Ltd. 402 pp. 249 ills. £13·00.

As implied by the subtitle of this book, difficulties exist when semiconductor devices are operated at frequencies or speeds that are sufficiently high for the package and circuit parasitics significantly to affect and limit the inherent performance of the basic semiconductor chip. Thus, above about 1 GHz, the combined problems of device physics and technology, and device-circuit interactions, require a new breed of specialist with expertise in both areas. In the past, each of these subjects was tackled by a separate group of scientists, often with little understanding or appreciation of the other's problems. Stemming from this new approach is the tendency for semiconductor manufacturers to provide microwave-amplifier modules rather than individual transistor chips and, in the case of power transistors, to provide input-matching and output-matching networks within the transistor package itself.

This new book, the first of a series, is intended primarily to meet the needs of this new specialism, although the last chapter has an extensive survey of the applications of solid-state microwave devices and brings into context the wide range of solid-state microwave devices that are now available.

The editors are to be congratulated on bridging this gap between basic device physics and device-circuit interaction by bringing together a number of accepted authorities in these areas. Each has dealt admirably with the developments leading up to the current state of the art in his particular subject. However, with such a fast-moving subject as semiconductor research, one cannot hope to publish a definitive work, but this volume manages to update a number of classics in the field. Even in such a well-known device as the bipolar transistor, there are still mechanisms that limit the gain and frequency performance and which are far from being fully understood. High-frequency noise in both bipolar and field-effect transistors is still not adequately described, and even in such basic equations as bipolar noise formulae, there is still confusion over the use of the transition frequency (normally referred to as $f_T$) and the frequency at which the common-base short-circuit current gain falls to 3 dB below its low-frequency value (normally referred to as $f_\alpha$).

However, these criticisms do not detract from the general usefulness of the work, and it is to be recommended as being an up-to-date account of the subject.

The level of the text is designed to be suitable for the graduate student or research worker wishing to enter the field. Basic physical concepts in semiconductors and elementary circuit theory are assumed as a starting point, and the text covers such items as Gunn and IMPATT diodes, microwave transistors, and applications such as radar, line-of-sight microwave relay, millimetric-waveguide and optical-waveguide systems.

If further volumes in the series maintain the standard set by this book, they should readily find a place as useful sources of reference.

J. C. H.

# Portable Coin-Collecting Box for Renters' Use

M. B. MOORE, C.ENG., M.I.E.E.†

UDC 621.395.663.6

*A new design of portable coin-collecting-box telephone for use in renters' premises is described.*

## INTRODUCTION

Before 1966, coin-collecting-box (CCB) telephones used by the British Post Office (BPO) for both public call offices and renters' installations were immobile, generally being fixed to a wall.

Public call offices are usually available for anyone to use throughout the day and night, and money deposited in them is collected by the BPO. Renters' CCBs are fitted in customers' premises, so that access to them is usually restricted and they can be of lighter construction than public call offices. The customer is billed for rental and call charges but retains any money deposited in the cash box.

In 1966, a need was seen for a portable CCB for use in such locations as restaurants, hairdressing *salons*, garage forecourts, shops and public houses. CCB facilities were therefore combined with portability at short notice in the CCB No. 735, which was essentially a standard public-call-office pay-on-answer CCB cut down and painted red. It lacked a carrying handle and stowage for the connecting cord, although these were improvised in the later 1/735 version shown in Fig. 1; the capacity of the cash box was very limited.

In 1972, it was decided to embark on a new design that would be more purpose-built and would not have the deficiencies of the earlier model. The task was to improve the ergonomic features and appearance, make good the deficiencies and, at the same time, use as many parts as possible of the existing pay-on-answer CCB mechanism to minimize the cost and the number of spare parts needed for maintenance purposes.

The development was carried out in co-operation with industry, using the services of industrial design consultants. The resulting product, the CCB No. 725 (shown in Fig. 2), is the subject of this article.

## PHYSICAL ASPECTS AND MOBILITY

The case is in 2 main parts: front and rear. For the prototype model (shown in Fig. 3), both parts were aluminium castings, and there was an integral carrying handle. A fixed cord-stowage reel was mounted on the rear part of the case. On the final version, however, the construction was simplified and costs reduced by making the rear part of the case in sheet steel and dispensing with the integral handle and fixed cord-stowage reel.

This has resulted in a unit that could, if desired, be wall-mounted. For use as a portable unit, it is attached to a tubular-steel frame (Coin-Box Holder No. 1), which provides the carrying handle and cord-stowage space, as illustrated in Fig. 2.

It will be possible to stock separately the CCB and its frame to cater for the wall-mounted and portable options. For the portable mode, an 8 m connecting cord is needed, and the CCB is screwed to the frame using the same holes as for securing the CCB to a wall. The frame and CCB together weigh 14 kg.

FIG. 1—Original portable CCB (CCB No. 1/735D)

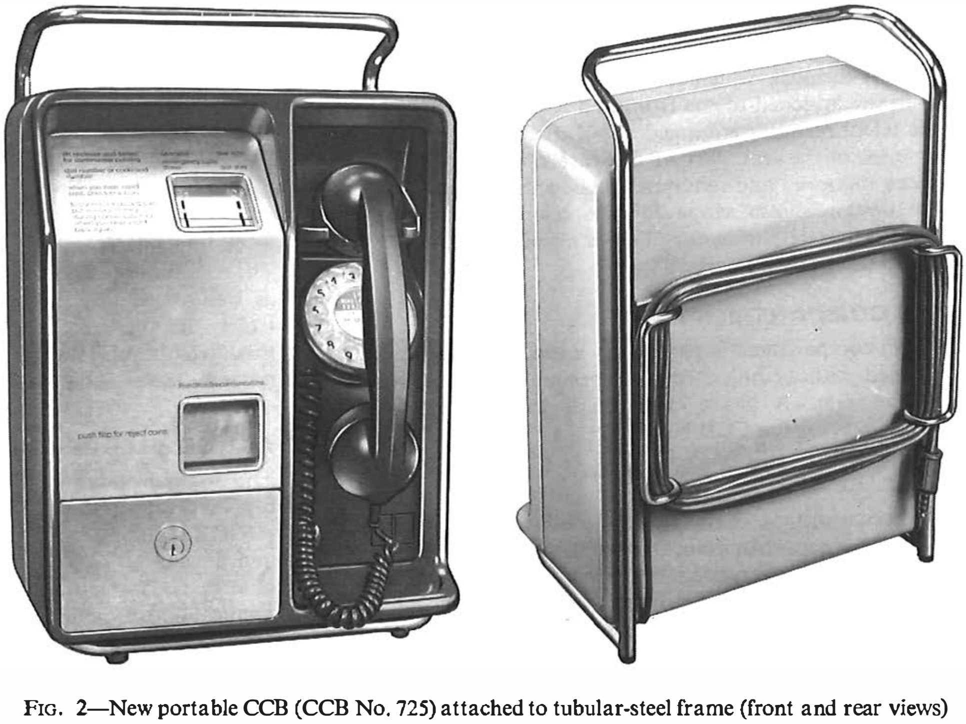

FIG. 2—New portable CCB (CCB No. 725) attached to tubular-steel frame (front and rear views)

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† Telecommunications Development Department, Telecommunications Headquarters

FIG. 3—Prototype, showing integral handle and fixed cord reel

FIG. 4—Trolley-mounted CCB

FIG. 5—View with front removed and telephone unit swung to one side

A trolley is available to which the CCB can be bolted through holes in its base (see Fig. 4). This enables the CCB to be wheeled about; for instance, to be taken alongside a customer's table in a restaurant, or a patient's bed in a hospital. The trolley also provides stowage for directories and the connecting cord.

The painted parts of the case are yellow. This colour was chosen for its distinctiveness. It is also the international colour for telecommunications and the BPO Telecommunications Business house colour. The left-hand side of the front is clad in a stainless-steel plate that carries the operating instructions.

## TELEPHONE UNIT

The telephone unit is a separate sub-assembly. A moulded-plastics chassis carries the bell-set and a printed-circuit board similar to that used in the standard type-746 telephone. Provision is made for 2 press-buttons for extension-plan working.

The chassis also carries the lock that secures the front part of the cover. The lock is arranged so that it is not subjected to any strain if an attempt is made forcibly to remove the front of the case. Any such strain is taken by an extension tongue on the lock which is in double shear between steel parts firmly attached to the front and rear parts of the case.

The telephone unit is hinged about its right-hand edge to swing clear of the rear part of the case once the front part has been unlocked and removed, as shown in Fig. 5.

The design allows scope for the telephone unit to be mounted separately in its own box as a wall-unit, or recessed into a suitable space in a wall.

## CASH COMPARTMENT

The cash compartment is secured by a separate lock, and can be opened without unlocking the mechanism compartment, and vice versa. It has a capacity of 1800 cm$^3$ compared with 390 cm$^3$ for the CCB No. 735.

## MECHANISM

The mechanism is basically a standard pay-on-answer mechanism (Mechanism No. 24), the lower part of which has been rearranged to reduce the height by about 115 mm. Any functional parts thus displaced have been relocated or redesigned. Wherever possible, existing parts have been used to minimize stocks of spare parts and to aid maintenance, but the ductways for both accepted and rejected coins are completely new.

Accepted coins pass directly from the runway assembly and mask unit to the cash compartment via separate short guides. Rejected coins fall directly into a hopper from which they can be retrieved by pushing back a counter-weighted flap. Currently, the hopper and flap are of stainless steel, but the use of moulded plastics is being explored.

The detecting relay (relay SU) for the line reversal that unlocks the coin slots has been repositioned vertically at the rear of the mechanism, just behind the coin-selection link, and has a new curved-wire linkage with the coin-acceptor interlock. The *mask* contact has been made a microswitch. A sheet-steel guard is provided to protect relay SU and the mask unit from damage should the mechanism be removed from the case and laid on its back.

The separate plugs and sockets used to interconnect the pulsing and coin-accepting parts of a standard mechanism with the telephone circuit have been replaced by a single flexible cord; this is permanently connected to the mechanism and terminated in a 12-way plug, which is inserted into a socket on the telephone unit. When the mechanism has to be removed, a dummy plug with strapped terminals is inserted in the socket on the telephone unit to complete the telephone circuit, thus enabling emergency calls to be made if necessary. When not in use, the dummy is parked in a clip on the telephone unit.

A detailed description of the pay-on-answer system, and the mechanism and its functions, has been given in an earlier article.†

## CONCLUSION

The results of the field trial are encouraging. The development, as well as meeting the objectives of providing portable and trolley-mounted CCB facilities, has resulted in a wall-mounted option. The new CCB may thus become the universal pay-on-answer equipment for use at renters' installations.

## ACKNOWLEDGEMENTS

The original design work on the case, frame and trolley was carried out by David Carter Associates, Warwick.

The adaptation of the mechanism and other internal parts, and the change from cast aluminium for the rear part of the case to sheet-steel construction, was carried out by Aeronautical and General Instruments Ltd., Croydon.

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† BASTOW, F. J., COLLINGWOOD, J. D., NEWELL, E., and PRICE, C. K. The Pay-on-Answer Coin-Box System. *POEEJ*, Vol. 51, p. 343, Jan. 1959.

# Regional Notes

## SOUTH WESTERN REGION

### TXE2 Cabling

An interesting field trial of plug-and-socket methods of interconnecting racks in TXE2 exchanges is being carried out at Milton Abbas TXE2, in the Bournemouth Telephone Area. For the purposes of the field trial, 3 areas of application of plug-and-socket cabling methods are being explored; their principles are illustrated in the block diagram of Fig. 1.

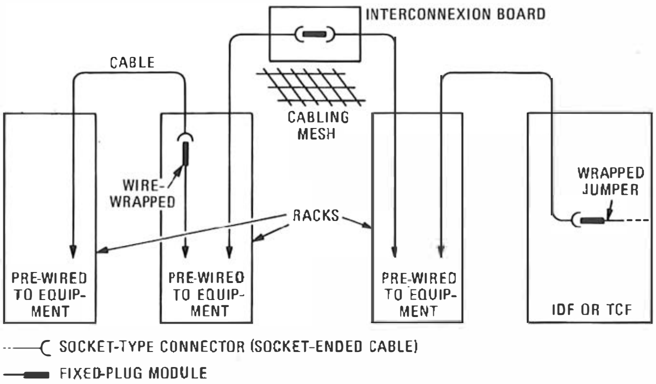

Fig. 1—Principles of plug-and-socket cabling

In one mode, shown in detail in Fig. 2, socket-ended cables, which are pre-wired to the racks, are joined at double-sided fixed plugs (known as *fixed-plug modules*) on an interconnexion board mounted on the cabling mesh above the equipment. In another mode, pre-wired socket-ended cables from one rack are terminated on fixed-plug modules at the top of another, the fixed-plug modules being connected to the rack equipment by conventional wire-wrapping techniques. Fig. 3 shows socket-ended cables terminating on a fixed-plug module at the top of a rack.

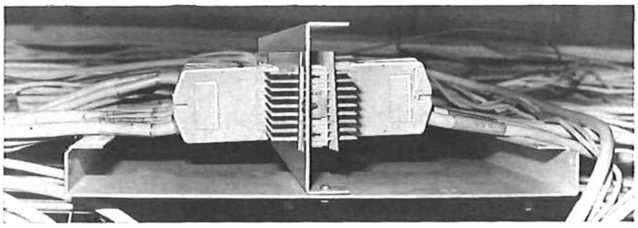

Fig. 2—Socket-ended cables and doubled-sided fixed-plug modules on interconnexion board mounted on cabling mesh

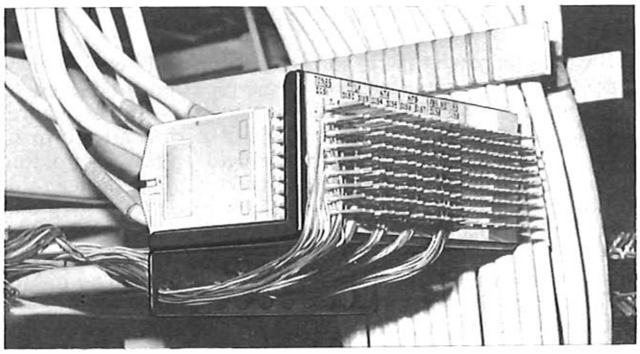

Fig. 3—Fixed-plug module and socket-type connectors at the top of a rack

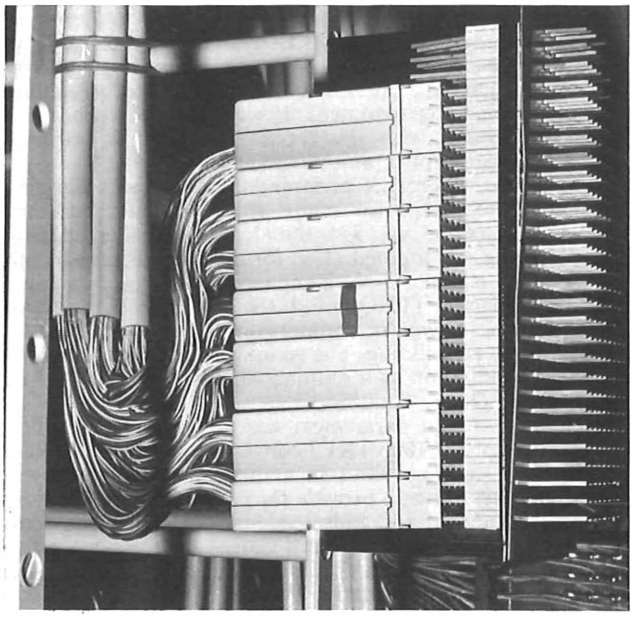

Fig. 4—Fixed-plug module and socket-type connectors on the IDF

(Photographs by courtesy of A. E. Burland, Bournemouth)

The third mode caters for cables from a rack to the intermediate distribution frame (IDF) or trunk connecting frame (TCF); most of the cabling in a TXE2 is in this category. Pre-wired cables, again provided with socket-type connectors, are terminated on fixed-plug modules fitted to the IDF or TCF. Fig. 4 shows socket-ended cables terminating on a fixed-plug module on an IDF. Wire-wrapped jumper connexions to the other side of the module are made in the factory; that is, the IDF/TCF is pre-jumpered.

Each fixed-plug module has 28 × 9 pins and can accommodate a number of sockets; 18-way, 27-way and 36-way sockets are used. The cables are, therefore, typically 20-wire or 40-wire types, and each is specially marked to indicate its terminating position on a fixed-plug module. All the pre-wiring is carried out in the factory. Power-distribution and common-services cables are, at present, terminated in the conventional manner.

The primary object of the field trial is to evaluate the savings in installation costs that arise from using plug-and-socket methods. Great care is being taken to ensure that the design of the connectors and fixed-plug modules, and the materials used in their construction, meet the requirements of installation and maintenance, and that the cabling methods are appropriate to the type of connector used.

The benefits that should be derived from using the plug-and-socket method are as follows.

(*a*) The time taken to provide inter-rack connexions on-site should be reduced.

(*b*) The time taken to perform on-site cable-continuity and other commissioning tests should be reduced. Certain of the testing procedures could be transferred from the site to the factory, where better facilities would be available to speed up testing. The equipment should therefore be brought into service earlier.

(*c*) The procedure for carrying out direct-labour works should be simplified. Fully-tested racks could be supplied to the site, complete with cables terminated on socket-type connectors, ready for plugging in.

The advantages of plug-and-socket methods over traditional site-cabling techniques can be evaluated only over a long period, but once a satisfactory method has been established, the benefits could be of great value in reducing installation costs.

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### The Q-Type Building for Small TXE2 Exchanges

In 1972, the South Western Telecommunications Region developed, in conjunction with the Department of the Environment's Property Services Agency (PSA), a simpler building than the standard types H, L and M26 then existing. It was a single-storey building of a cheaper, more traditional construction, having a pitched roof and capable of sustaining a variety of cladding treatment. It was designed to house a single TXE2 unit, with the capability of being extended ultimately to cater for more than 5000 connexions.

Nevertheless, it became apparent that even this building could prove too large for many unit automatic exchange conversion cases and, in 1974, the idea of a smaller building of similar style was mooted. This fortuitously coincided with an approach on similar lines being made by Telecommunications Headquarters (THQ), and their backing and active co-operation was given in commissioning a private architect to develop such a building. The resulting design was accepted by THQ for adoption as a national standard building, to be known as the *Q-type* building.

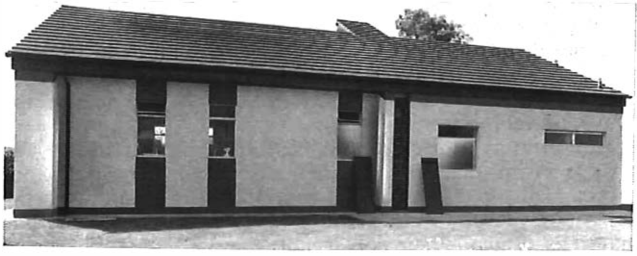
Briefly, the design parameters were to provide an initial nominal capacity of 1000 TXE2 connexions, with an ultimate capacity of 3000 connexions in a single building extension. The building was also to provide for power plant, a stand-by engine-generator set and pulse-code-modulation equipment. There was to be welfare accommodation on the basis of an unattended exchange. A basic design of domestic appearance, capable of receiving alternative external cladding treatments, was required so that local-planning requirements could easily be met and site requirements would be less onerous. The aim was to reduce superstructure construction costs and bring the building within the capacity of the average local builder.

A prototype has been erected in 6 months at St. Dominick, in the Plymouth Telephone Area, for approximately half the cost of its predecessor, and was handed over to the British Post Office in June 1976.

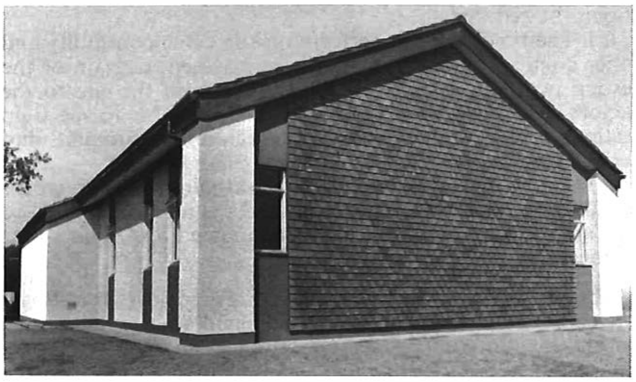
It has since been evaluated by both regional and national representatives of the Council of Post Office Unions, and by the THQ Accommodation Research Division. As a result, certain modifications to detail will be incorporated in the drawings to be issued, and others may be incorporated later. Visits have also been arranged for representatives of other telecommunications regions and boards, and the PSA.

The photographs give a better idea of the appearance and scale of the building than would a tedious written description, but one feature is perhaps worthy of special mention. This is the adoption of overhead feeding of external cables to the main distribution frame (MDF). Although the TXE2 installation is not due to start until later this year, for evaluation purposes, an MDF section and temporary cable lengths were successfully fitted to prove the principle. The cables were fed from a simple footway-type box through a vertical ventilated external riser, which is shown with the covers removed. Although some changes may now be made to the form of the riser, it is hoped that its successful use in this building may lead to a wider application of the principle.

E. J. Harris (0272 295251)



General view of Q-type building, showing vertical riser (centre)

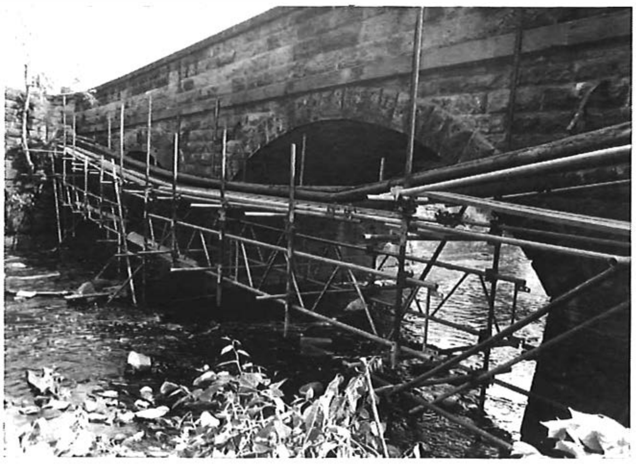


End view, illustrating different claddings

## SCOTLAND

### Collapse of Pipes over North Calder Water

A 6-way duct route containing 3 coaxial cables and 6 low-capacity carrier-system cables crosses the North Calder Water 2·5 km north of Uddingston repeater station. Six steel pipes were clamped to, and supported by, 102 × 45 mm I-section steel beams set into the wall of a bridge. Following a maintenance report, investigation revealed that the beams had collapsed, leaving the pipes sagging, supported by the cables over the 30 m span of the bridge. No appreciable movement of the cables was detected in the adjoining manholes, and electrical tests revealed no faults. The first thought was to raise the pipes and fit new supporting beams. On close examination, however, it was seen that, where the pipes had been pulled apart at their mid-span joints, they were so damaged as to preclude proper restoration. After consultation with the local bridge engineer, it was decided to lay new pipes in the carriageway over the bridge between 2 manholes, 50 m apart, and change-over the cables.



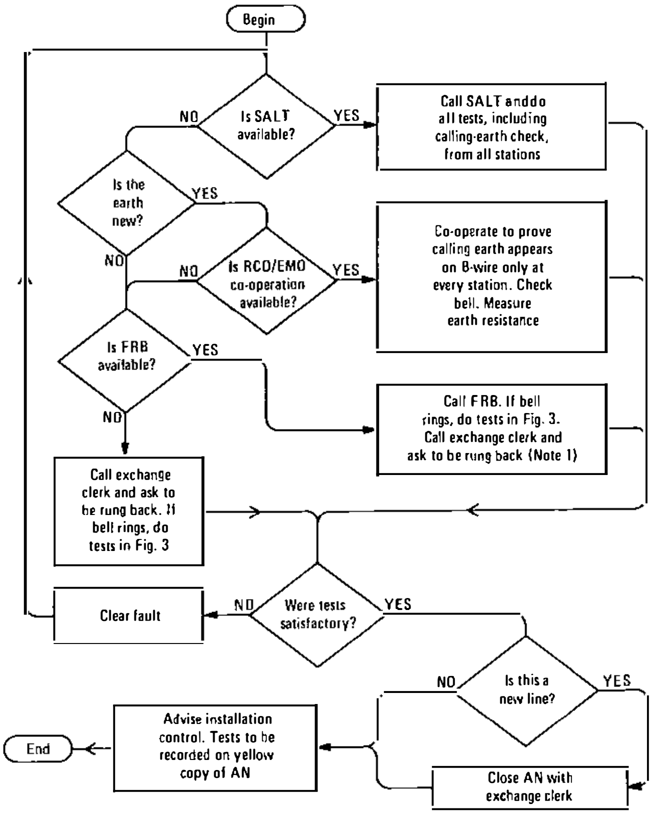
It was anticipated that, at some point during the change-over there would be a total collapse of the pipes into the river, so that some form of support would be necessary. For structural reasons, the bridge engineer would not permit any form of support to be attached to the bridge, and a scaffolding contractor was quickly engaged to erect supporting scaffolding from the bed of the river. The new pipes were then laid over the bridge and the cables changed-over without mishap.

An examination of the beams revealed the weakness to be in the webs, which had corroded and collapsed. The photograph shows the sagging pipes supported by the scaffolding. The collapsed beams, with their corroded webs, can be seen in line with the tops of the arches. The beams were provided in 1954.

W. Bennett (041-242 2390)

## SOUTH EASTERN REGION

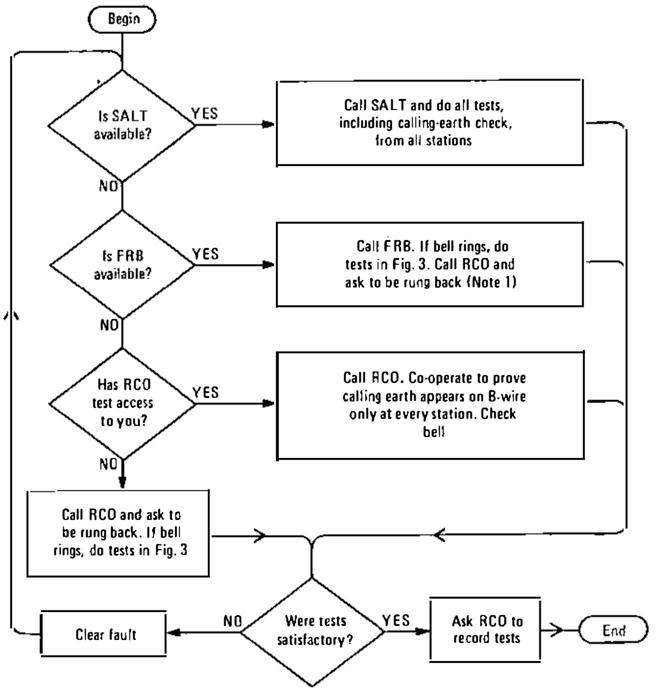
### Shared-Service Polarity Tests



AN: Advice note
EMO: Exchange maintenance officer
FRB: Faultsmen's ring-back
RCO: Repair control officer
SALT: Subscribers' automatic line tester

*Note 1:* FRB does not detect reversals

FIG. 1—Shared-service tests (installation staff): obverse side of card



*Note 1:* FRB does not detect reversals

FIG. 2—Shared-service tests (maintenance staff): obverse side of card

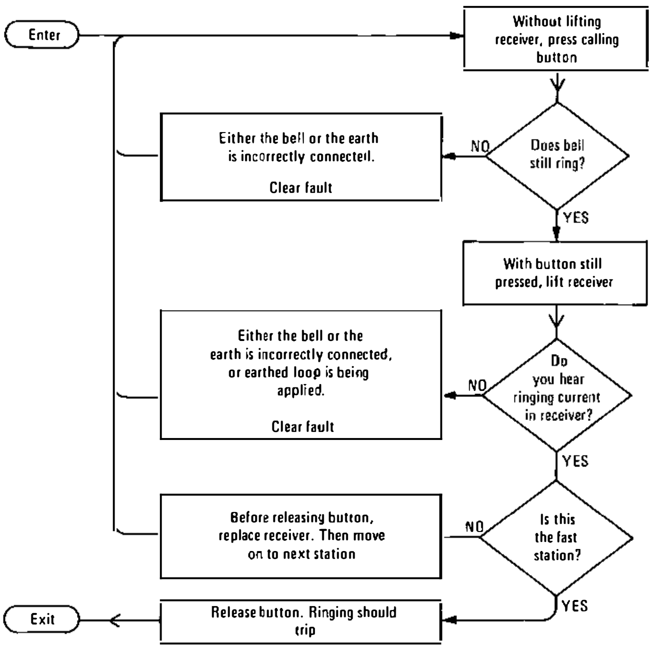


FIG. 3—Reverse side of both cards: polarity tests

Telecommunications Instructions (TIs) C4 C1003 and E5 B1003 call for installation and maintenance staff to perform certain tests when they visit a shared-service installation, to verify that the calling earth is correctly connected.

To simplify this task, the South Eastern Telecommunications Region (SETR) has produced 2 pocket-sized plastics cards that explain the sequence of tests in flow-chart form. One version of the card (shown in Fig. 1) is for installation staff, and the other (shown in Fig. 2) is for maintenance staff. Both cards have the same reverse side, shown in Fig. 3.

The tests in Fig. 1 are done (in accordance with TI C4 C1003) following any work on a shared-service installation. Those in Fig. 2 are done (in accordance with TI E5 B1003) before leaving any shared-service installation, unless the repair control officer indicates that they have already been done. Even then, they are repeated if the wiring has been disturbed.

The procedure given in Fig. 3 differs slightly from that required by the TI to avoid the co-operating officer having to make a separate call to test each station. Since, in the SETR procedure, ringing is not tripped until the last station is tested, there is a risk that a telephone with a disconnected loop at one of the earlier stations will escape detection, but it is assumed that such a serious defect would already have come to notice before the tests start.

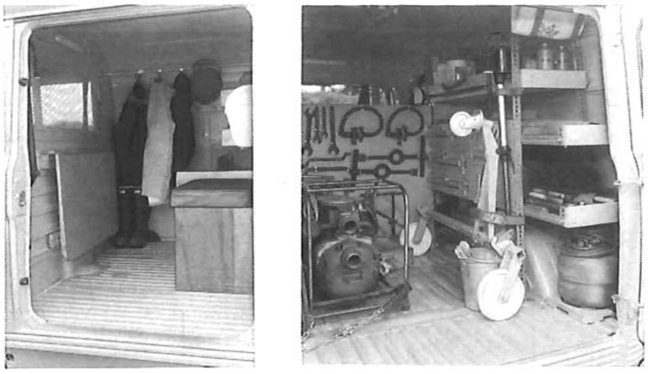
The final step of Fig. 1 is designed to ensure that the installer's tests are recorded on the yellow copy of the advice note. This copy circulates to the repair service control, where maintenance records can then be suitably annotated. This is felt to be a more positive step than simply assuming all new work to have been tested after a certain date.

R. BAYFIELD (0273 201477)

### Design for an External-Planning Survey Vehicle

External planners have always needed a purpose-designed vehicle to meet their surveying requirements. The lack of such a vehicle has created safety hazards and led to a general loss of efficiency. As the result of recommendations made by the Guildford Telephone Area efficiency-studies duty, the Area Productivity Committee appointed a sub-committee to design a suitable interior layout for an existing type of vehicle to meet the needs of external-planning survey duties, and to subject a vehicle so modified to a field trial.

A 615-type (Commer Stores Carrier) vehicle was selected for the trial. The carrying compartment was divided into 2



The personnel compartment (left) viewed through the side door, and the equipment compartment (right) viewed through the rear doors

parts using a 15 mm sheet of marine plywood, this being used so that secure fixing points could be obtained from either side, and because this material is not unduly affected by damp from tools or clothing. Access to the forward compartment so formed—the personnel compartment—is obtained from the near-side door. The personnel compartment is designed to provide facilities for records and written work of short duration, the safe custody of test equipment and the accommodation of protective clothing.

The rear, or equipment, compartment is purpose-designed to accommodate all the items needed to meet any demands likely to face an external planner engaged on survey work. A feature of the design is that it ensures that items required at the commencement of a survey are those most readily accessible.

The field trial has now reached a satisfactory conclusion, and 2 vehicles modified to the trial design will be made available to external planners in Guildford Telephone Area. Each vehicle will be in the care of a Technician 2A driver.

W. Le G. Rushton (0483 65239)

## WALES AND THE MARCHES

### New Tower for Swansea Radio Station

A Tower No. 5A has successfully been erected by the British Post Office (BPO) rigging gang headquartered at Carmarthen, assisted by the Bridgend rigging gang. This was the first erection of such a tower by BPO personnel.

The Tower No. 5A has been described in an earlier issue of the *Journal*.† It is based on prefabricated column modules, 4·57 m square and 6·1 m high, each consisting of 4 vertical 610 mm square welded-rod lattice columns, with solid-rod diagonal and plan bracing and rectangular hollow-section horizontal bracing. The tower at Swansea uses 4 such modules surmounted by 1·83 m column stubs, giving a total height of 26·23 m.

On the acquired site, the tower's centre and a north–south line were marked out to enable the base and building line to be accurately positioned. The peaty nature of the site necessitated a massive reinforced-concrete raft foundation measuring 9·57 × 14·14 × 3·50 m to cater ultimately for a 6-column tower, although only 4 columns were provided initially. The foundation block was installed by the contractor responsible for the radio-station building, who was supplied with a special template to locate accurately the holding-down bolts, which have a positional tolerance of ±3·18 mm. This operation was closely supervised, with measurements being taken before and after the block was poured to check that the template dimensions remained within limits.

As soon as the foundation block had cured, the four 356 kg column bases, which had been obtained in advance of the main tower components, were placed in position using a locally-designed mobile hoist. A final screed was then placed on top of the foundation.

Before delivery of the 40 t of tower steelwork, a railway-sleeper road was laid to allow a mobile crane access to the site to off-load the steelwork and place it on supporting timber as close to the tower base as practicable. Since it was initially intended to use the "climbing-derrick" method of erection, a sleeper ramp was also laid for access to the top of the tower base. A hired crane was used to erect the first tower module with its face bracing omitted on one side to enable the derrick to be lifted into position and secured to the 4 columns prior to its first lift. On delivery to the site, the derrick was found to be in need of repair and, as time was short, it was decided to continue erection using a 38·4 m lattice-jib crane. This length was necessary to allow the crane to be positioned on the hard-standing beside the radio-station building, since the ground around the tower base was too soft to support the weight of the crane. The photograph shows the crane in operation.

The erection proceeded. Each column joint used 100 nuts and bolts with load-indicating heads, each bolt being tightened until 4 projections on the inside face of its head had been compressed to leave a pre-determined gap between the head and the tower, as measured by a feeler gauge. The use of 2 pneumatic wrenches, kindly lent by the South Eastern Telecommunications Region, greatly eased this operation.

The perpendicularity of the tower was checked as erection proceeded, and corrected where necessary by adjustment of the face bracings before finally tightening the bolts. As the tower grew, platform supports and a ladder were fitted. The erection was completed by fitting the mounting rails, the aerial mounting and the aerial itself—a 3·66 m diameter focal-plane bipolar aerial.

The waveguide gantry was installed and the rather cumbersome flexible 4 GHz elliptical waveguide run from the aerial, down the tower and into the building, where it was terminated and tested. Final panning of the aerial took place a few weeks later.

Throughout the work, special attention was paid to safety precautions, and extensive use was made of fall-safe devices

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† Clow, D. G. Steel Masts and Towers in the British Post Office, Part 2. *POEEJ*, Vol. 67, p. 49, Apr. 1974.

and safety belts. The line of a fall-safe device was attached to the top of each column prior to hoisting, thereby ensuring that, as each column was landed and secured, a safe means of access to the top was available to allow the lifting attachment to be unhitched. The expertise and experience gained by the staff concerned will be put to good use when the towers at Coldwell, near Hereford, and Gwaenysgor, near Prestatyn, are erected.

J. C. Tye (0222 391219)

## NORTHERN IRELAND

### Rathlin Island's new Exchange and Radio Link

On Wednesday 25 August 1976, the existing modified mobile automatic exchange (MAX) on Rathlin Island was replaced by a unit automatic exchange (UAX).

Rathlin is Northern Ireland's only sizable island, and is situated about 5 km from the coast of County Antrim. In 1898, Marconi set up one of his first over-sea radio links between Rathlin and Ballycastle, a distance of 13 km. That equipment was later replaced by a British Post Office system and, in 1901, a telegram service was opened between the mainland and the island. The island's first telephone service opened in 1953. A single-channel radio link connected a modified Switchboard CB 935 (a customers' cordless PMBX having a capacity for 3 exchange lines and 9 extensions), installed in the island's Post Office, to a standard UAX 13 exchange line on the mainland.

In reply to a written parliamentary question in 1969, the Postmaster General of the day, Mr. John Stonehouse, stated that Rathlin would have an automatic service by early-1971.

To provide automatic service in the limited time available, and because of building costs, a modified MAX 12 was provided in 1970 as an interim measure. The MAX was dependent on Coleraine group switching centre (GSC) and auto-manual centre (AMC), and provided service for 23 customers and one pre-payment call office. Three Transceivers No. 3A were used for a very-high-frequency radio link between Rathlin and Ballycastle, and the junctions were extended to Coleraine over 4-wire circuits. The link used an out-of-band signalling system (Signalling System AC8), and the power supply on the island was derived from heavy-duty car-type batteries charged from a privately-owned generator.

In 1976, work commenced on providing a permanent installation. A new non-standard building, 15·9 m × 4·9 m, was constructed to house a UAX 13 exchange, and radio and power equipment. In addition, welfare facilities, which include sleeping accommodation for 4 people, have been provided.

Rathlin's new exchange, overlooking Church bay

The UAX 13 discriminating satellite exchange has a 5-digit numbering scheme and provides full STD and ISD facilities for the island's 23 customers and 2 pay-on-answer call offices.

A new radio system has increased the number of channels to the mainland to 6. These channels are multiplexed, and only one carrier frequency is used for each direction of transmission. The system operates in the ultra-high-frequency range at 450 MHz. Duplicate radio equipment has been provided and, in the event of transmitter failure, automatic change-over occurs. The radio circuits from Rathlin to Ballycastle are extended to Coleraine GSC and AMC over pulse-code-modulation channels.

As the island has no public electricity supply, it was necessary to provide a reliable power supply to ensure the security of the system. Twin air-cooled 9·5 kW diesel generators with automatic change-over facilities, rectifiers and batteries were provided. The batteries are able to supply the load for 5 d should both engines fail.

The design and layout of the power and radio equipment used was based on experience gained during the planning of the Scottish Highlands and Islands scheme. With the exception of the diesel generators, all the equipment was installed by Belfast Telephone Area staff. The work was carried out during the summer months, when weather conditions were unlikely to interfere with transport arrangements for staff and equipment between the island and the mainland.

J. McD. Cooke (0232 20309)

# Associate Section Notes

## ABERDEEN CENTRE

The 1976–77 session began in September with a visit to the power station under construction at Peterhead, Aberdeenshire. Also in September, the Aberdeen Centre met the Edinburgh team in the Regional Quiz and, after a close contest, Edinburgh came out the winners by 31 points to 29½.

A visit to Aberdeen University television studios was made in November, and this was followed in December by a talk by Mr. R. C. Blundell, General Manager, Aberdeen and North of Scotland Telephone Area.

I. Booth

## DUNDEE CENTRE

Our 1976–77 programme commenced on 14 September with an interesting and informative lecture entitled *Pulse-Code Modulation—Principles and Practice*, given by a member of the Centre, Mr. D. Gibson. Before the lecture, Mr. A. F. Dollman, General Manager, Dundee Telephone Area, presented the Trainee Technician (Apprentice) (TT(A)) awards, given annually to the TT(A) in each year who has shown the best all-round improvement.

The first round of the Regional Quiz was a face-to-face confrontation with Inverness, held at Dalwhinnie on 24 September; Dundee won by 35 points to 21. We meet a team from Falkirk or Stirling in the next round.

G. K. Duncan

## EDINBURGH CENTRE

Our 1976–77 session opened on 9 August with an excellent visit to the Forth railway bridge, attended by 23 members. We were able to appreciate the enormous amount of work that went into the design and building of the structure. The weather was in our favour and allowed us to examine the bridge from top to bottom.

This year, for the first time for many years, we are including in our syllabus a film show. The main theme of the proposed film night will be safety, but a variety of other technical films will also be shown.

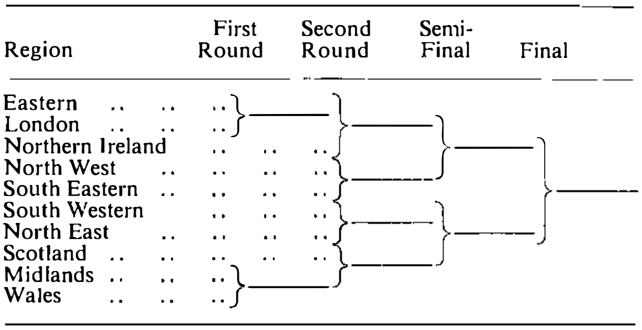
Talks for this year include one on police communications, to be held at Blackford Hill police radio station, Edinburgh. We also have a visit to the Scottish Telecommunications regional museum project in Edinburgh, in the hope of catching some interested volunteers for the work necessary to maintain our allocated programme.

J. L. M. Alexander

# The Associate Section National Committee Report

## NATIONAL TECHNICAL QUIZ COMPETITION

At the National Committee's last meeting, at the Post Office Technical Training College, Stone, on 2 October 1976, the draw for this year's National Technical Quiz Competition was made, and the result is shown in the table. The final will be played at the Institution of Electrical Engineers, Savoy Place, London WC2, on 25 March 1977.



## REGIONAL AND CENTRE MUSEUMS

The Projects Organizer, Eric Philcox (0234 61561), would very much appreciate a list of the museum items held by each Region and Centre, so that he can compile a complete catalogue. It is expected that this will assist people involved with museums in borrowing and lending equipment held by or needed by other museums in the UK.

## PROJECT COMPETITION

This year's project competition is an illustrated essay competition, to be presented using 8 mm film or 35 mm slides. The subject must be chosen from the field of communications, and the technical content must be accurate. The commentry should be recorded either on tape or on a sound stripe on the film.

## FUTURE ACTIVITIES

The National Committee is in the process of formulating future policies and planning future activities. The next committee meeting will be in May, and any comments on these items should reach the Secretary by the end of March.

## CHANGE OF ADDRESS

All correspondence to the Secretary should now be addressed care of Holsworthy Telephone Exchange, North Road, Holsworthy, Devon.

C. J. WEBB
*Secretary*

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# Institution of Post Office Electrical Engineers

## LOCAL-CENTRE SECRETARIES

The following is a list of local-centre secretaries, to whom inquiries about the Institution may be addressed. It would be particularly useful if members would notify any change in their own address to the appropriate secretary.

| *Centre* | *Local Secretary* | *Address* |
|---|---|---|
| Birmingham | Mr. D. F. Ashmore | General Manager's Office, ED3/7,<br>84 Newhall Street, Birmingham B3 1EA. |
| Eastern (Bletchley) | Mr. D. R. Norman | Telephone House, ED9/3,<br>25–27 St. John's Street, Bedford MK42 0BA. |
| Eastern (Colchester) | Mr. P. M. Cholerton | Eastern Telecommunications Region, Planning Division,<br>St. Peter's House, St. Peter's Street, Colchester CO1 1ET. |
| East Midland | Mr. D. W. Sharman | General Manager's Office, Room 1301,<br>200 Charles Street, Leicester LE1 1BB. |
| London | Mr. M. S. Armitage | City Telephone Area, ESS1, Telephone House,<br>8–18 London Bridge Street, London SE1 9SH. |
| North Eastern | Mr. D. Spencer | North East Telecommunications Region, Service Division,<br>Darley House, 79 St. Paul's Street, Leeds LS1 4LW. |
| Northern | Mr. L. G. Farmer | Telephone Area Office, Swann House,<br>157 Pilgrim Street, Newcastle-upon-Tyne NE1 1BA. |
| Northern Ireland | Mr. W. H. Tolerton | Belfast Telephone Area, GM/1M2,<br>55–61 Donegall House, Donegall Square, Belfast BT1 5DR. |
| North Western (Manchester and Liverpool) | Mr. W. Edwards | North West Telecommunications Board, Planning Division,<br>Bridgewater House, 60 Whitworth Street, Manchester M60 1DP. |
| North Western (Preston) | Mr. J. Allison | Post Office Telephones, Clifton Road Depot,<br>Marton, Blackpool FY4 4QD. |
| Scotland East | Mr. W. L. Smith | Scottish Telecommunications Board, Planning Division,<br>Canning House, 19 Canning Street, Edinburgh EH3 8TH. |
| Scotland West | Mr. G. A. Dobbie | Telephone House, 65–95 Pitt Street,<br>Glasgow G2 6AH. |
| South Eastern | Mr. J. M. Smith | South Eastern Telecommunications Region, Planning Division,<br>Grenville House, 52 Churchill Square, Brighton BN1 2ER. |
| South Western | Mr. R. C. Willis | South Western Telecommunications Region, Planning Division,<br>Mercury House, Bond Street, Bristol BS1 3TD. |
| Stone/Stoke | Mr. K. A. Priddey | Post Office Technical Training College,<br>Stone ST15 0NQ. |
| Wales and the Marches | Mr. R. E. Jones | Wales and the Marches Telecommunications Board,<br>Planning and Works Division,<br>25 Pendwyallt Road, Coryton, Cardiff CF4 7YR. |

A. B. WHERRY
*Secretary*

## COLCHESTER CENTRE'S EXHIBITION AND PRESTIGE LECTURE

An exhibition and prestige lecture on the theme of Alexander Graham Bell, held on 29 September under the auspices of Colchester IPOEE Centre, was attended by an invited audience of some 650 people, including civic dignitaries and representatives of educational establishments and the business community. We were honoured to have Professor J. H. H. Merriman, C.B., O.B.E., Post Office Board Member for Technology, present the lecture, and many tributes were paid to the interest it held and the quality of the supporting demonstrations.

Mr. S. H. Sheppard, Chairman of Colchester Centre, in his introductory remarks, referred to the role of the Institution of Post Office Electrical Engineers in the advancement of the science of telecommunications, and described how the 69 volumes of the *Journal* enshrine a significant record of the history of telecommunications in Britain. The theme of the lecture was then exemplified by a live call to the curator of the Bell Homestead Museum in Brantford, Ontario, Canada.

The Chairman then introduced Professor Merriman and invited him to address the meeting.

Professor Merriman, in his lecture, dealt with the historical record of the invention of the telephone, and went on to trace the subsequent development of the world-wide telephone system. Finally, he gave an indication of the new services and techniques for the future that were under development.

As the lecture progressed, it was illustrated by slides and films, and live interviews were given on stage and by land-line with operators and engineers who demonstrated the variety of skills and range of services involved in the telecommunication business. Waveguides and optical fibres, used in working demonstrations, were a novel feature for most of the audience.

After a short question period, Dr. Ena Knight, Director of the Eastern Telecommunications Region, closed the proceedings by explaining the part played by the Region in the British Post Office's overall job of providing telecommunications services. She expressed the meeting's thanks to Professor Merriman and all the supporting staff involved in the presentation of the lecture and associated exhibition.

R. A. SPANNER

## BIRMINGHAM, COVENTRY AND WEST MIDLAND CENTRE PROGRAMME, 1977

Meetings will be held in the Alston Suite, Thorpe Street Sports and Social Centre, and will commence at 14.00 hours.

10 February: *Customer Data Networks* by C. Bullock, D. M. Copeland and A. K. Ainsworth.

10 March: *The National Exhibition Centre* by J. Clougher.

14 April: *Forecasting in Practice* by M. Turner.

## SOUTH EASTERN CENTRE PROGRAMME, 1977

Meetings will be held at: the conference room, 46 Holland Road, Hove; St. Saviours Church Hall, Leas Road, Guildford; or the Social Centre, Culverden Park Road, Tunbridge Wells. All meetings start at 14.00 hours.

26 January (Guildford): *The Provision of Communications for Oil/Gas Production Platforms in the North Sea* by L. C. Nash and S. Hill.

9 February (Tunbridge Wells): *Electronics in the Local Network* by I. G. Morgan.

16 February (Hove): *Energy—The Need to Conserve* by E. P. Jenner and A. J. Clarke.

16 March (Guildford): *Electronics in the Local Network* by I. G. Morgan.

23 March (Tunbridge Wells): *Viewdata* by S. Fedida.

27 April (Tunbridge Wells): *Energy—The Need to Conserve* by E. P. Jenner and A. J. Clarke.

4 May (Hove): *Standardization of Exchange Switching Equipment—The Enigma* by D. Kelson.

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# Notes and Comments

## BALANCE OF ARTICLES

The view is often expressed that too many articles are published in the *Journal* on tomorrow's systems and equipment, and that there are not enough contributions on day-to-day topics of direct interest to the man in the field.

This is not deliberate policy, but reflects the difficulty in commissioning articles of this nature. Indeed, more articles on day-to-day subjects, particularly by authors in Areas and Regions, would be warmly welcomed by the Board of Editors. There must be many potential subjects of technical interest—investigations, innovations and unusual projects—and there must be many potential authors to write about them, in all grades.

It is a possibility that Area authors do not feel confident that their contributions on day-to-day topics have a place among the more technically-based articles often published in the *Journal*. This seems to be borne out by the fact that 2 very interesting Area contributions (*Installation of the UK-France No. 1 Cable: Brighton Telephone Area's Involvement*, published in the October 1976 issue, and *Underwater Duct-Laying in Bristol's Floating Harbour*, in this issue) were originally submitted as Regional Notes, when they were long enough and sufficiently meritorious to be considered for publication as short articles. The prospect of publication in the main section of the *Journal* should not be daunting; day-to-day topics are as much a part of telephone engineering as high-speed digital line systems—more immediately important, perhaps, to many engineers in the field—and they make a perfect contrast to the more specialized topics, giving balance to the range of articles.

Nor should it be thought that only major grades are capable of writing suitable articles. A recent article by a precision testing officer (*A Review of Cable Pressurization in the British Post Office Network*, published in the October 1976 issue) gave an excellent survey of the subject from an Area point of view. If it is the case that an author feels he has a contribution to make but is not competent to cover all aspects, the editors will be glad to try to arrange help by Telecommunications Headquarters (THQ) in the production of the article. Such co-operation took place over the cable-pressurization article mentioned above, with excellent results.

The editors will therefore be happy to advise authors on the suitability for publication of any contribution, and will also be pleased to see the continued trend of brief reports of items of technical interest being submitted for publication under Regional Notes.

### 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* 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 Regional Notes and 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; Regional Notes are generally up to about 500 words in length. Articles and Regional Notes 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*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

### 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. Correspondents should note that, as it is necessary to send copy to the printer well before publication date, it will be possible to consider letters for publication in the April issue only if they are received by 14 February 1977.

Letters intended for publication should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

### SPECIAL ISSUES AND BACK NUMBERS

Copies of the April 1974 issue covering sector switching centres, and the October 1973 special issue on the 60 MHz transmission system, are still available.

Back numbers can be purchased, price 70p each (including postage and packaging), for all issues from January 1972 to date, with the exceptions of July 1972 and January 1973.

Copies of the July and October 1970 issues are also still available.

A reprint, containing all the most important articles published over the years on Trunk Transit Switching is also available, price 22p.

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. A self-addressed label, accompanying the order, is helpful.

### CORRECTION

In the article *A Review of Cable Pressurization in the British Post Office Network*, published in the October 1976 issue, the figure given for the rate of air flow into each cable is incorrect. The correct value is $10 \cdot 167 \times 10^{-6}$ kg/s.

### INCREASE IN THE PRICE OF THE POEEJ

As announced recently in the *Post Office Gazette*, the price of the *Journal* to British Post Office staff has been increased to 36p per copy with effect from this (the January 1977) issue. The Board of Editors regrets that this increase must be made, but it has been necessitated by continued increases in costs, particularly for paper; this is almost entirely due to the fall in the international value of sterling. All possible economies have been made (for example, the use of still lighter-weight paper for the Supplement and Volume Index), but further cost savings are not possible without a reduction in either the quality or the quantity of the pages printed.

Members of the Institution of Post Office Electrical Engineers will not, for the present, have their subscriptions increased.

# Post Office Press Notices

### AN ERA ENDS IN PORTREE VILLAGE

On 14 October, the telephone service reached a historical milestone when Britain's sole surviving manual exchange bowed to progress and made way for a new automatic system.

It happened at 11.30 hours at Portree village on the Isle of Skye. Inside a wooden hut, the operator-connected circuits that have carried the hum of island chatter since 1948 closed down for good. Seconds later, villagers were able to dial their own calls to most parts of the British Isles.

The first manual exchange at Portree opened in 1926—half a century after Alexander Graham Bell invented the first workable telephone. The first operator at the exchange was Helen Nicolson, now Mrs. Ramage, a housewife in Bearsden, Glasgow.

"The switchboard was in my father's house in Wentworth Street", she recalls, "and I remember there was a bell by my bedside to wake me when someone called during the night". A lass of 15 at the time, Helen was paid the sum of 17/9d for attending the switchboard around the clock, every day of the week.

Fifty years later, the march of progress has brought automation across the sea to Skye. Said Miss Winifred McLeod, supervisor in charge at Portree for the last 17 years, "We have always known this day would come, but now that it has, it is difficult to realize that we have reached the end of an era. Even the Misty Isle, it seems, cannot escape the wind of change".

Now, the calling lamps at Portree have darkened for the last time, and the switchboards are silent. The new exchange, just 200 m further down the road, has taken over.

### PROVINCIAL INTERNATIONAL CONTROL CENTRES

Some changes, aimed at speeding up operator-connected telephone calls to Cyprus, Israel and a number of African countries, have been introduced by the British Post Office (BPO).

The move will help ease congestion at one of the main international exchanges in London, where these calls are handled at present. In future, they will be handled at a different exchange in London, or at one of 3 provincial international control centres: at Brighton, Leicester and Glasgow.

Countries directly affected are Cyprus, Israel, Kenya, Tanzania, Uganda and the Republic of South Africa. Customers will be given different codes to dial from those used at present. Places in Britain where a change in code is needed are London, Birmingham, Edinburgh, Glasgow, Manchester, and parts of the Midlands, North of England and Scotland.

The new procedure should help to improve the telephone service to all 6 countries, with most calls being connected straight away. Previously, customers had to give the operator the wanted number and wait to be called back.

## NORTH WEST INTRODUCES JULIE

Contractors about to dig, tunnel or blast in the Central and East Lancashire area of the North West Telecommunications Board are being invited first to pick up a telephone and contact JULIE. The call costs nothing, and it could prevent expensive damage claims and costly delays.

JULIE stands for joint utilities location information for excavators, and is the name given to a trial campaign that started in the Central and East Lancashire area in September. Julie is also the name adopted by 22-year-old Karen Palmer, a professional model from Bolton, Lancashire, to help publicize the scheme to prevent damage to plant.

The problem JULIE is designed to alleviate is the accidental damage to underground plant caused by mechanical diggers. These can easily shift large quantities of earth and rubble but, all too frequently, gas, telephone and water services are damaged in the process.

North West Gas, the North West Telecommunications Board and the North West Water Authority have joined forces in an effort to prevent such damage. JULIE is a new approach to the problem and, if successful, will save a lot of time, effort and money and, most important of all, prevent loss of service to customers.

Every year, vast quantities of water and gas are wasted by damage. Breakdowns in the emergency telephone (999) services, and in circuits provided for ambulances, hospitals and doctors, are also caused. The North West Telecommunications Board alone makes damage claims amounting to £100 000 a year. But, quite apart from the financial liability contractors may face if they damage plant, they are also hampered by costly delays.

In the past, anyone wishing to excavate had to contact each public undertaking separately to discover the location of underground plant. All they need do now, about 2 d before they start work, is contact a special JULIE centre by simply dialling 100 and asking the operator for Freefone 111. They are then connected to the centre where staff take details of the site and relay the information, over facsimile links, to control rooms set up within each of the 3 utilities. Each will then check on the location of their underground services and make direct contact with the caller. If necessary, arrangements will be made for a representative to visit the site and help locate and mark the plant. He will also advise on methods of excavating near the plant and on suitable back-filling.

The JULIE service is being launched for a trial period of 1 year. Each utility will monitor the effects of the scheme within its own organization and evaluate its overall efficiency.

Julie

Free publicity material has been produced to promote the JULIE trial. It takes the form of colourful posters, leaflets and vehicle stickers, and features attractive photographs of Julie seated in the grab of a mechanical digger. Special presentation packs have been distributed to many contractors operating in the Central and East Lancashire area, and it is hoped that these will ensure contractors' interest in the scheme.

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### Copyright

### Subscriptions and Back Numbers

The *Journal* is published quarterly in April, July, October and January, at 45p per copy, 70p per copy including postage and packaging (annual subscription: £2·80; Canada and the USA: $6·00).

The price to British Post Office staff is 36p per copy.

Back numbers will be supplied if available, price 45p (70p including postage and packaging). At present, copies are available of all issues from July 1970 to date, with the exceptions of January, April, July and October 1971, July 1972, and January 1973.

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 £3·00, including return postage, by sending the complete set of parts, with a remittance, to Press Binders Ltd., 4 Iliffe Yard, London SE17.

### Remittances

Remittances for all items (except binding) should be made payable to "*The POEE Journal*" and should be crossed "& Co."

### Advertisements

All correspondence relating to advertisement space reservations, copy, proofs etc., should be addressed to the Advertisement Manager, *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.

### Distribution and Sales

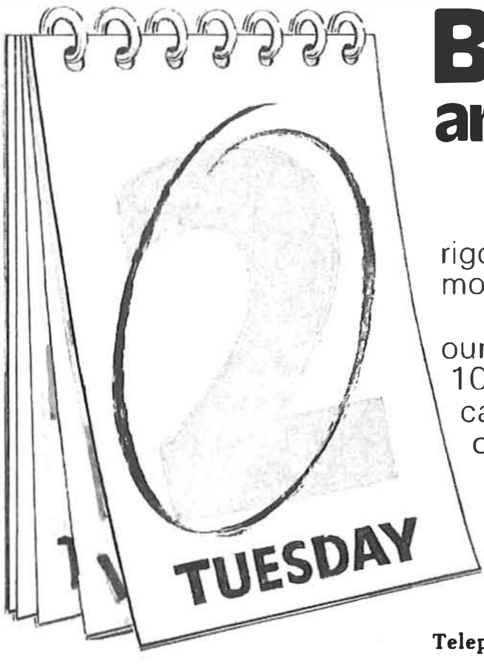
Correspondence relating to the distribution and sale of the *Journal* should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG.

### Communications

With the exceptions indicated above, all communications should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

### 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. Details of the books available are given at the end of the Supplement to the *Journal*. 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.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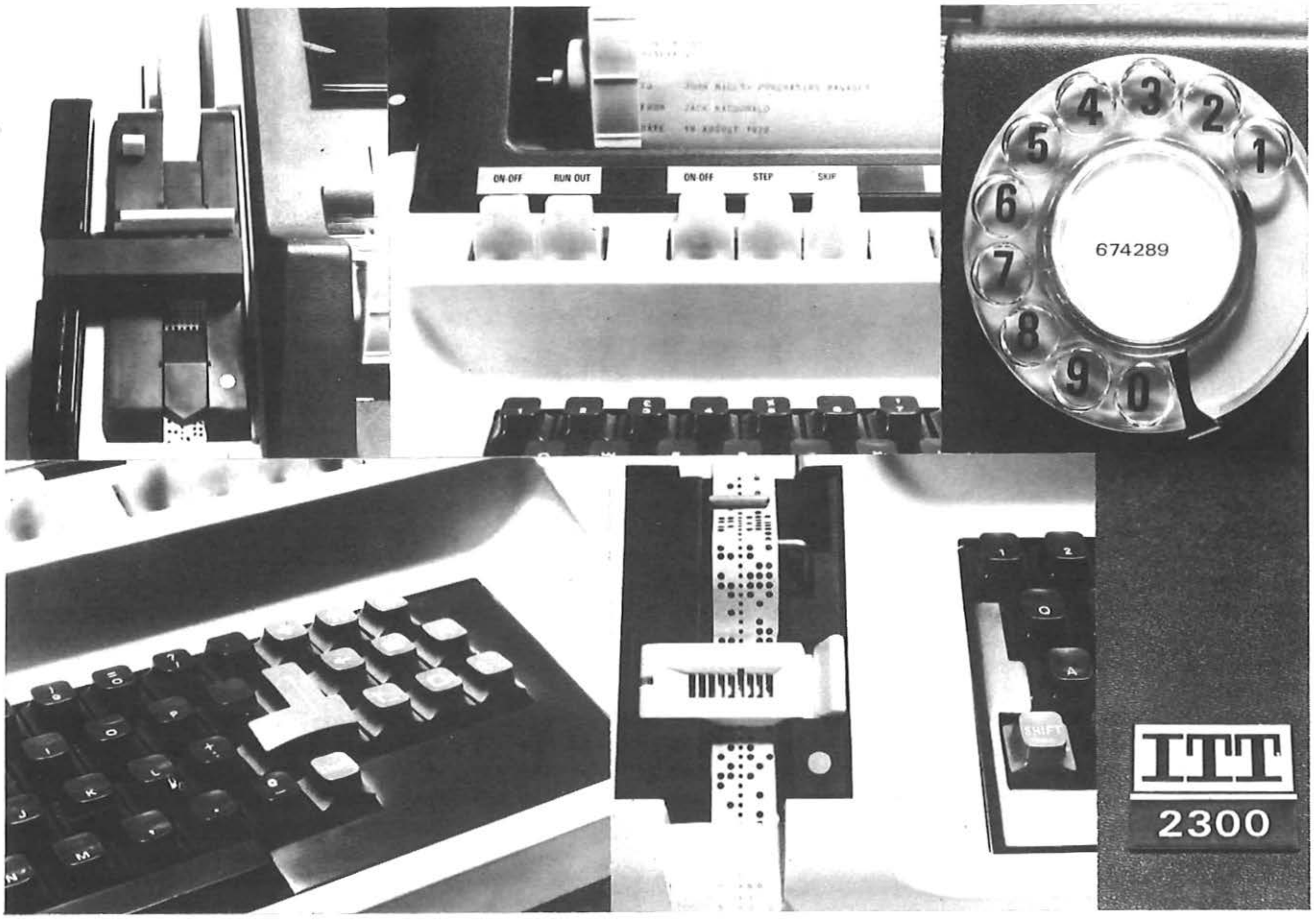
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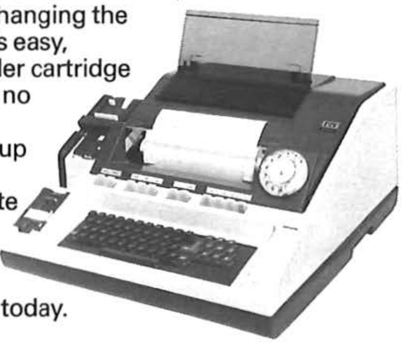

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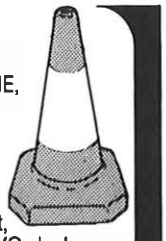

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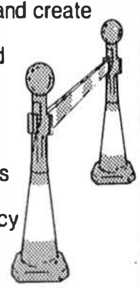

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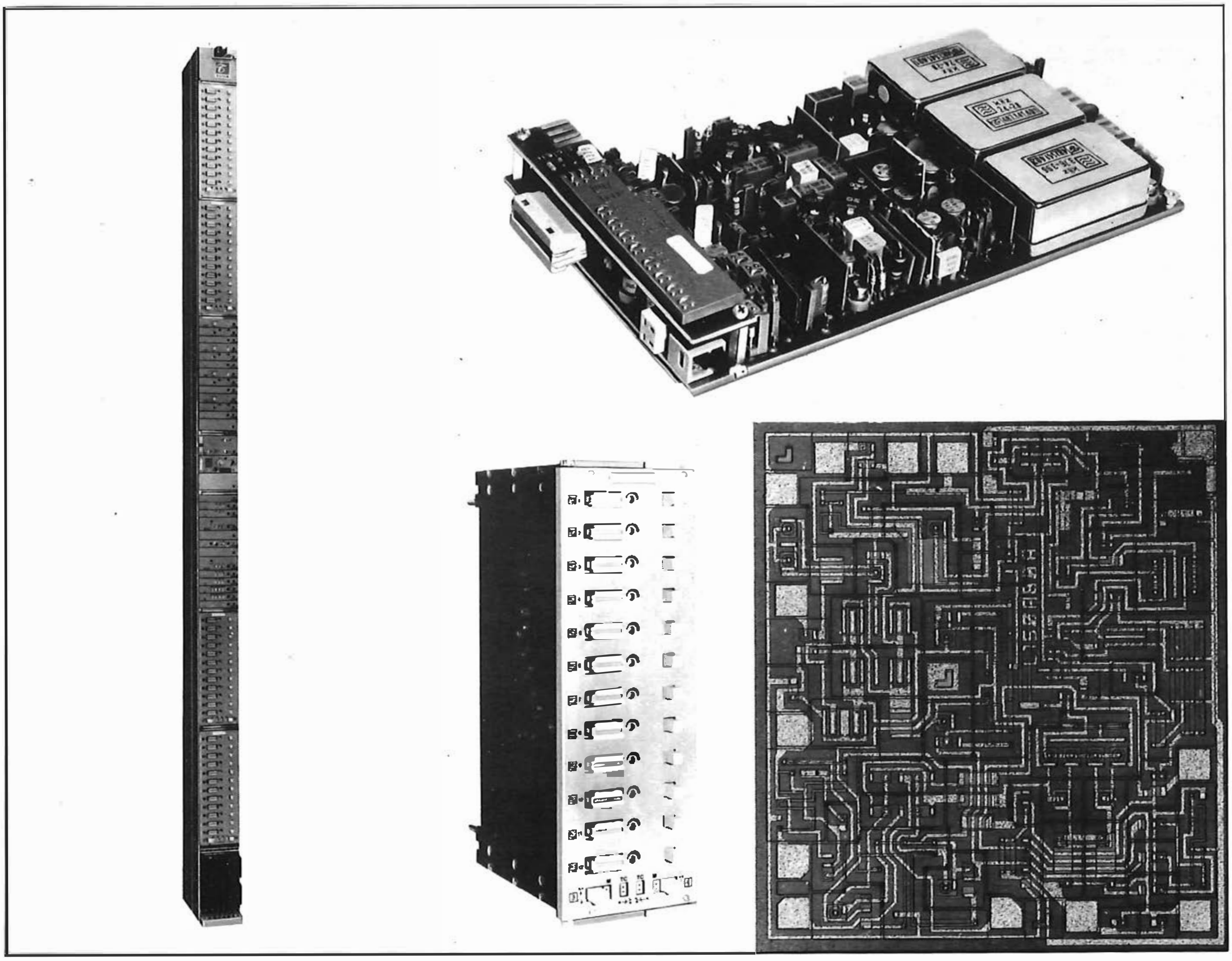

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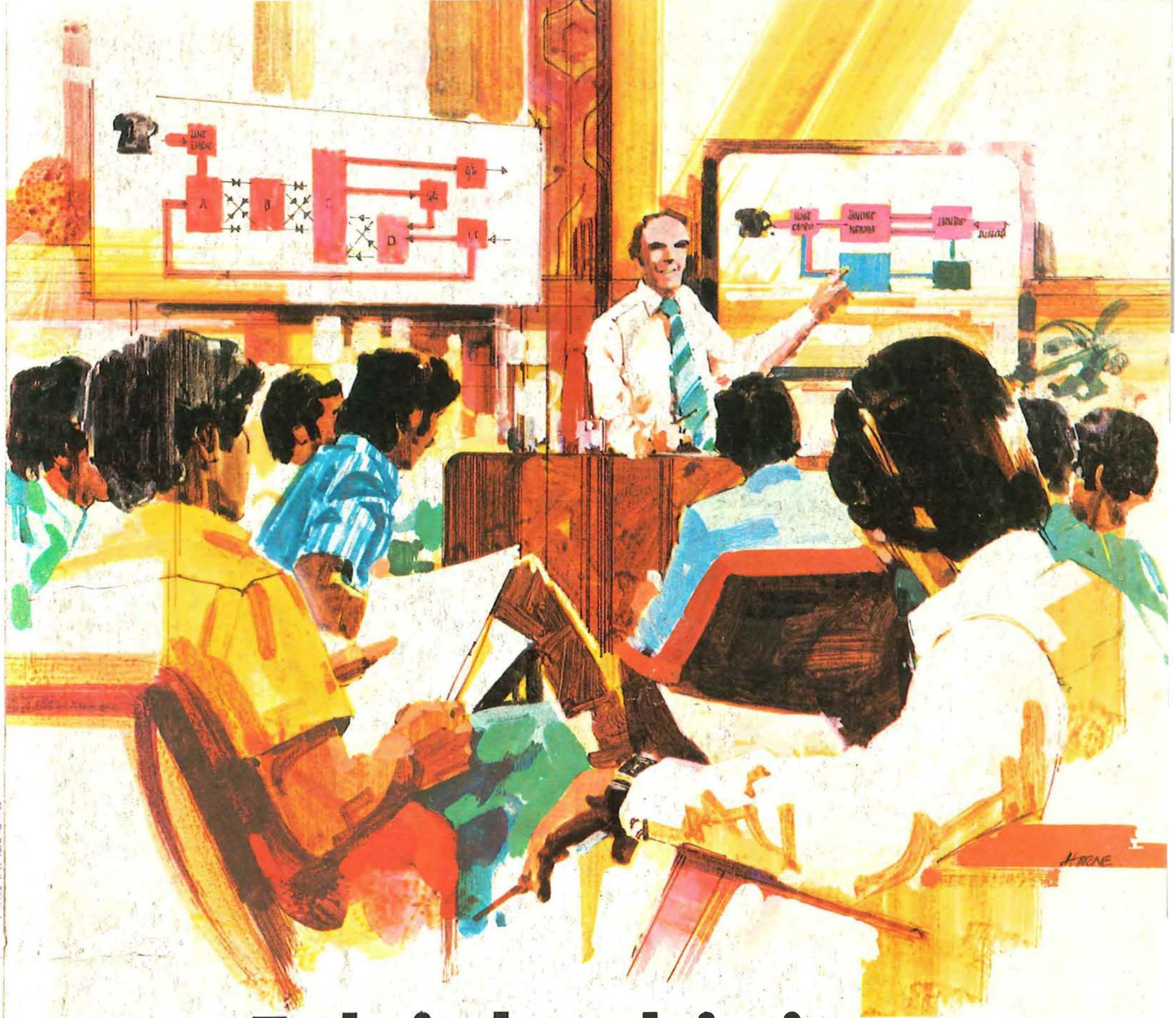

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