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Contents

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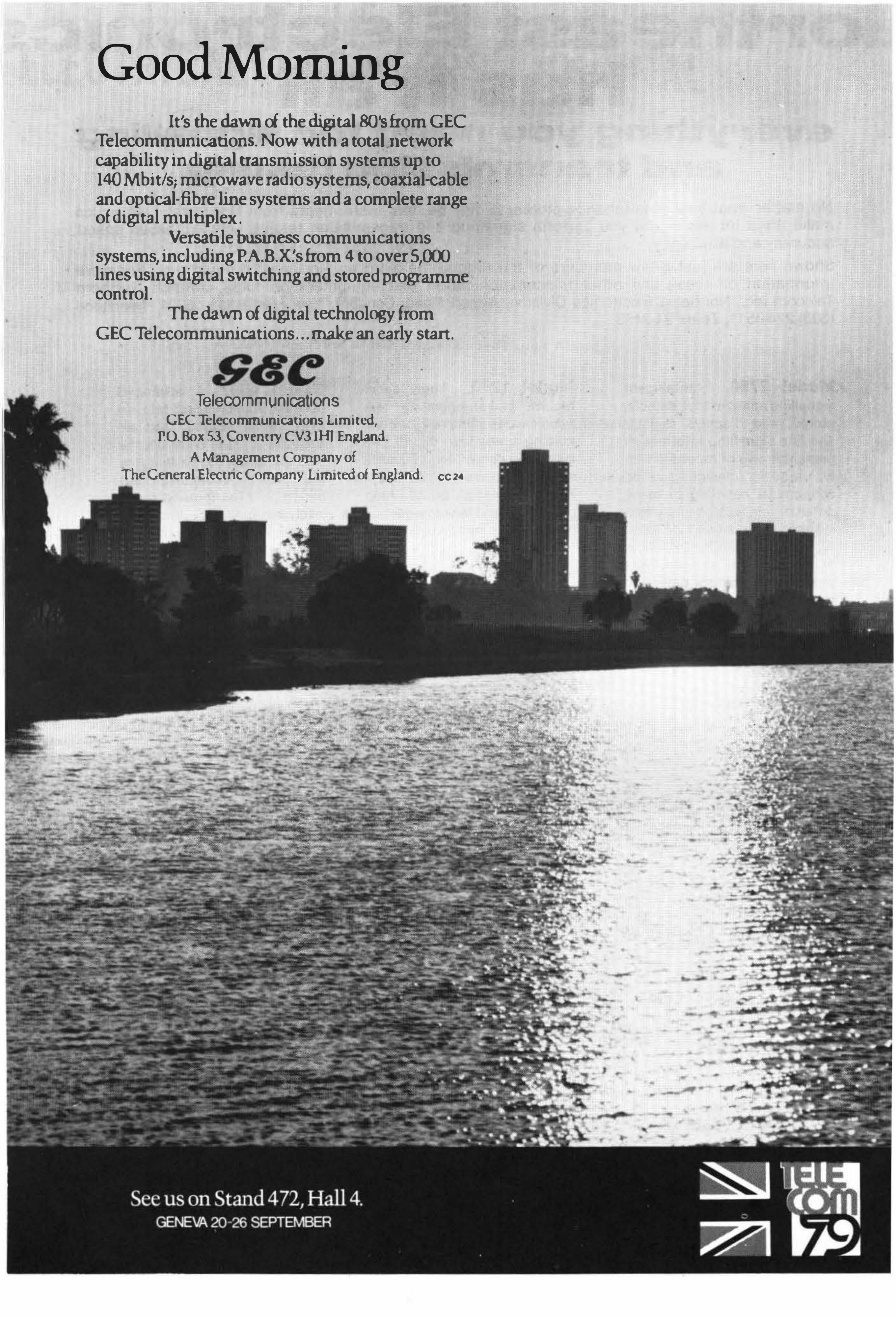
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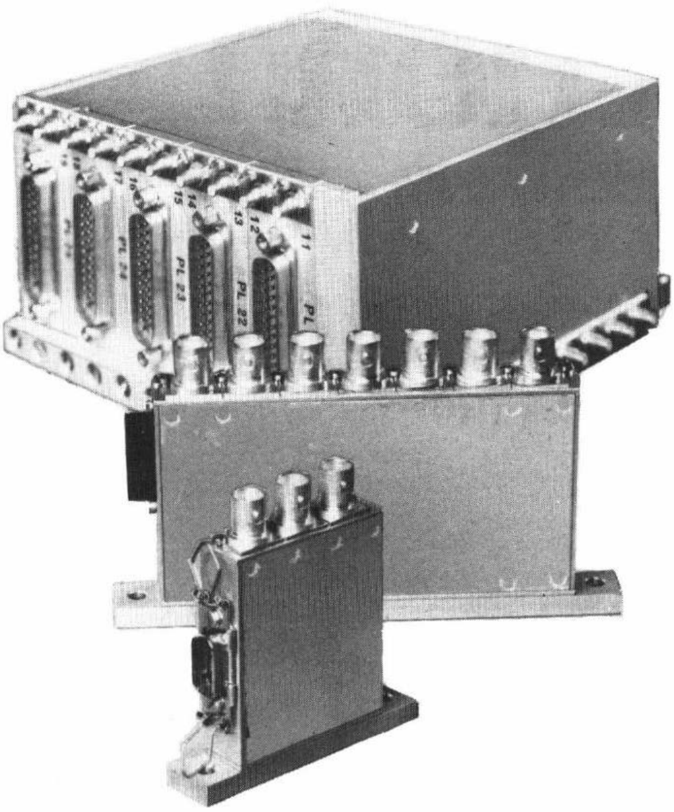

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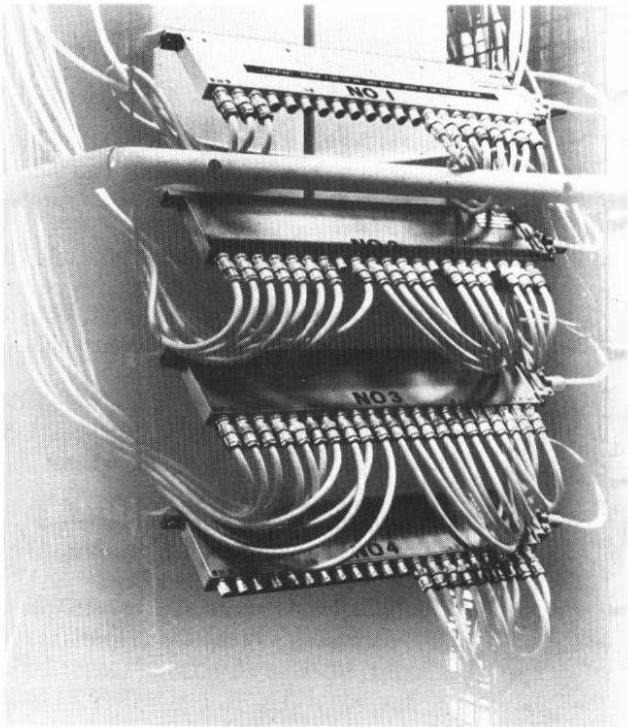

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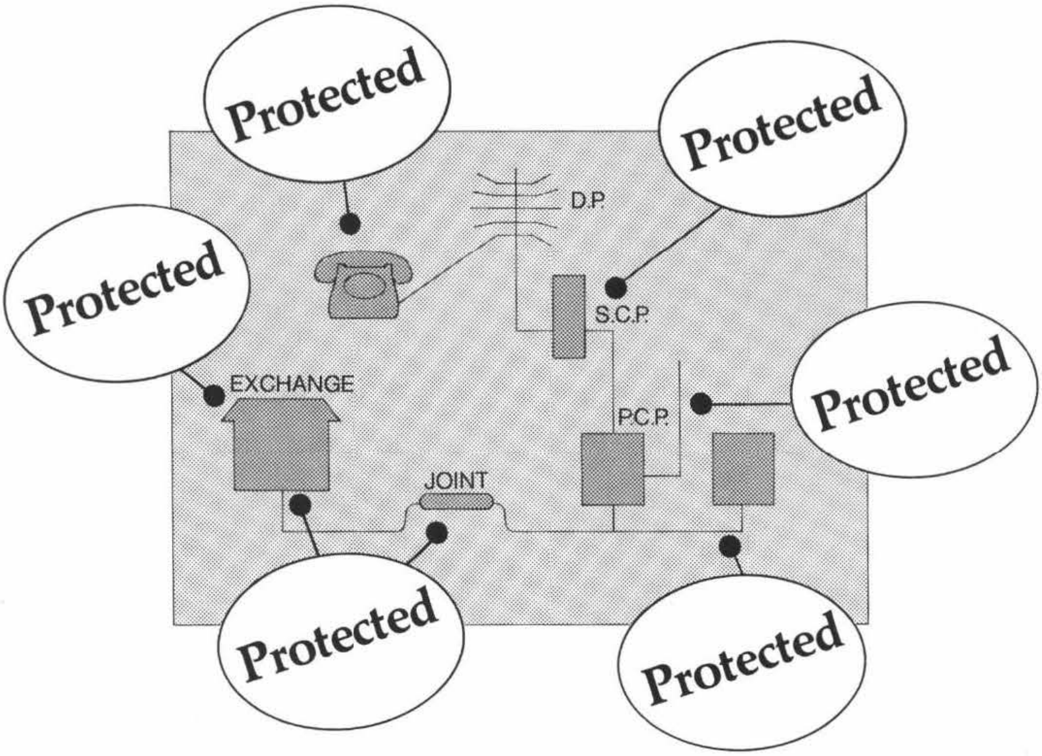

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Mr. J. S. Whyte, C.B.E., M.SC. (ENG.), C.ENG., F.I.E.E.

President of the Institution of Post Office Electrical Engineers

The Post Office Electrical Engineers' Journal

Institution of Post Office Electrical Engineers

A MESSAGE FROM THE CHAIRMAN OF COUNCIL

I am sure all members of the Institution of Post Office Electrical Engineers will join me in expressing our congratulations and pleasure in learning that our President, Mr. J. S. Whyte, C.B.E., has been appointed a Deputy Managing Director (Telecommunications) of the British Post Office.

Those of us who attended the first Annual General Meeting of the Institution over which Mr. Whyte presided will recall that he gladly accepted his role as President as being not merely an honorary figurehead but as a position in which he could energetically further the activities and influence of the Institution. Furthermore, during his inaugural address he made very clear his personal view that service to society was the justification for recognition by society of the status of the engineer. He subsequently demonstrated his desire for active participation by presenting, to a packed audience, a lecture which spanned the whole sweep of the Post Office's modernization programme culminating in the introduction of System X, which is intended not only for the UK but as the major instrument of expanded export success by the British telecommunications industry. Council will know, too, that behind the scenes he has taken a lively interest in all aspects of the Institution's work.

With the enhancement of the influence of our President, all members can look forward to an era in which the profession of engineering will play an increasingly important part in the policies and achievements of the British Post Office.

J. F. P. THOMAS

A MESSAGE FROM THE PRESIDENT

Engineering in the British Post Office—A Look Ahead

The British Post Office has a proud history of public service extending to over 300 years, and for a significant fraction of that period engineering has been a major factor in its affairs. Today, the telecommunications business is absolutely dependent on the skill, inventiveness and dedication of its engineering staff, supported increasingly by their scientific colleagues working near the frontiers of current knowledge. Everbody working in the Post Office today has lived with changing technology throughout his career, but there has never been a time in our history when the pace of change has been greater, when the nature of the changes has been more fundamental, and when the opportunities that this situation offers to us have been more dramatic and exciting than those we see before us today.

It is against this background—of change, of expansion, of opportunity—that a significant reorganization of Telecommunication Headquarters (THQ) is taking place and many of you may have wondered about its implications for the role and status of engineers in the Post Office, both at THQ and in the field.

The present organization has been in being for about 11 years and has, I believe, served the Post Office very well. During this period we have seen our system grow from 13 million stations to over 24 million, international calls have grown from 26 million to 180 million p.a. and our annual revenue has increased from £600M to over £3000M. We have seen too the beginnings of the digitalization of our transmission facilities, the introduction of many new services and items of customer apparatus, and an accelerating programme of exchange modernization. In this same period, postal mechanization, despite some setbacks, has made significant progress and now employs a variety of sophisticated technologies. None of this could have taken place without the skill and dedication of our engineers in all areas of our wide range of activities.

The years ahead of us all will see even greater developments. We face an era of continuing expansion of our current services and a proliferation of new facilities and customer apparatus. We are all aware of the often-stated—indeed over-stated—threat to employment which new technologies may bring in their wake. We are fortunate to be in an industry and a Business which is not only expanding to meet an unfaltering growth in customer demand but also has the opportunity of providing totally new services which will generate demands of their own if we are able to grasp the opportunities as they arise. Prestel is only one example of such new services. There will, I am certain, be many more.

But the key to expansion, if I may repeat the phrase, is to grasp the opportunities as they arise. And these opportunities will arise particularly in the area of customer services. I am not referring merely to the repackaging of telephones into new shapes and colours—although of course customer appeal will be increasingly important. I am thinking, in particular, of the whole range of terminal apparatus which will become possible with the advent of small cheap microprocessors. Here we already have a head start with our new digital PABX, the CDSS1, now called the *Monarch 120*. In this whole new world of customer apparatus we must be prepared to face comparison with the best that anyone, anywhere, can offer.

This theme of rapid change in the technological scene, and in the scale and nature of the market we serve, finds its echo in our own organization. Organizations themselves must evolve to suit the changing environment.

One essential element of the new THQ organization is therefore a sector of the Business dedicated to "Products and Services". This will include not only the present marketing functions but also its own engineering development force who will have the task of both designing the apparatus, and giving the engineering support to the introduction of proprietary apparatus which will be seen by the public in their homes and offices. It will be a fast-moving enterprise in which imagination and market awareness will be on an equal footing with sound engineering.

Engineering will also play major roles in other Business sectors—New Technology, Network, and International. Each of these will have its own developers, planners and service engineers, as appropriate, striving to generate ideas and create products and services second to none in the world.

There is always the danger, of course, that restructuring an organization, although forging valuable new links, may diminish fruitful existing associations. It would be a lamentable waste of scarce resources if techniques and practices devised in one sector of the Business were not picked up and utilized in other sectors where they might find application. There must be, therefore, appropriate visibility of the plans of all sectors to ensure that new technology and concepts are available for all sectors to exploit and that special traffic requirements generated by new products and services are catered for in the network programme.

For these reasons it will be an important part of my new role to survey the work of engineers in all THQ Business sectors and the Regions and Areas, both to ensure that they are following a coherent pattern and to encourage the cross-fertilization of ideas. Equally important as my oversight of engineering programmes and techniques, is that I will maintain and strengthen my personal interest in engineers themselves—their status in the organization, their avenues for advancement, their training, morale and their well-being generally. The future well-being and prosperity of our country will depend heavily on the skill and commitment of those involved in engineering and technology. In my view it is vital to maintain, and indeed enhance, our professional standards. In that, we all have a role and a duty.

Although, in my new post, science, engineering and technology will form an important part of my concern it represents by no means the total. Jointly with my fellow Deputy Managing Director, John Harper, I will be closely concerned in the running of the Business as a business and the formulation of the Business policies and strategies. There is in this statement an important message for all engineers. Our commitment to good engineering and technological excellence must not obscure our broader responsibilities. Our dedication should be to the customer not the technology; technology is a means to an end, not an end in itself. We are in business to provide effective, profitable service to customers, and the achievement of that is the only justification for our jobs. In the situations each one of us face every day we need to bring a businessman's attitude of mind to our engineering judgements, relating technical factors to customer needs and market-oriented thinking, with its service, revenue and profit connotations.

It is clear that the Institution of Post Office Electrical Engineers will continue to have as important a part to play in the future as it has in the past. For our Institution is at the same time an informal educational force, a forum where the research scientists can rub shoulders with experienced practical engineers, a channel of uninhibited comment and—not the least important—the justification for friendly sociable occasions. It will be an invaluable part of the mortar that binds together the elements of our enterprise.

I wish all of you all possible success in the exciting and challenging years that lie ahead.

J. S. Whyte

Principles of System X

W. G. T. JONES, B.SC., C.ENG., M.I.E.E., J. P. KIRTLAND, B.SC.(ENG.) and B. W. MOORE, B.SC., C.ENG., M.I.E.E.†

UDC 621.395.34

The foundation of System X lies in 3 basic principles: digital switching, processor control and common-channel signalling. This article explains these principles in relatively simple terms and discusses the reasons for choosing them.

INTRODUCTION

Two previous articles [1, 2] in this *Journal* have described firstly the basis of System X and the subsystems of which it is made up, and secondly the way in which System X will be used in the UK telecommunications network. Before giving detailed technical descriptions of the individual subsystems, which will be the subject of future articles, it is appropriate to consider the basic principles of System X and the reasons why they were chosen. These principles did not arise overnight, but evolved gradually with advancing technology. Over a period of some years it became clear that technology offered the prospect of new switching systems which overcame many of the disadvantages of previous systems and which could evolve for the future. This led to development in 3 areas: digital switching, processor control and common-channel signalling, which form the subject of this article.

DIGITAL SWITCHING

Early work by the British Post Office (BPO) on digital switching began in the 1960s and led to 2 field trial installations of pulse-code modulation (PCM) tandem exchanges: Empress in 1968[3] and Moorgate[4] in 1970. At that time, PCM transmission systems were beginning to be introduced where they showed economic advantage over earlier analogue transmission plant.

Where a number of PCM line systems terminate at a switching node, the signals are converted back to audio baseband and switched by electromechanical equipment, such as Strowger or crossbar exchange equipment. However, this switching process involves demultiplexing and decoding the incoming signals, with encoding and multiplexing on the outgoing side of an exchange. The purpose of the Empress and Moorgate experiments was to demonstrate the technical feasibility and economic viability of switching the speech while still in a digitally-coded form, which would result in the provision of less equipment and reduce transmission loss, noise and distortion.

Both exchanges successfully met their objective, the main difference between them being that Moorgate was processor controlled while Empress was not. This success, combined with subsequent advances in technology, led to consideration of digital switching for local exchanges, as well as for junction and main-network switching centres. The result is that all System X exchanges will incorporate digital switching. For junction and main-network switching centres the switching will be entirely digital, while in local exchanges the switching will be digital in the route switching area (that is, after the traffic from customers' lines has been concentrated). Although development is most advanced on an analogue switch for the concentration stage, referred to as the *subscribers' switching subsystem*, work is well in hand on a digital switch for that area too.

The calls arriving at a digital switch can be identified both in space, by the PCM system on which they are carried, and in time, by the channel time-slot within the time-division multiplex of the PCM system. The function of the digital switch is therefore to interconnect appropriate incoming and outgoing channels in both time and space. It must be remembered, however, that PCM systems operate on a 4-wire basis, with the two speech directions carried separately; thus, for each call, the digital switch has to complete 2 half-connexions, though the control is designed to ensure this happens automatically after a single set-up instruction.

Trunking

When considering the trunking of a digital switch, the designer has a large variety of time and space switch arrangements from which to choose. At the time of Empress and Moorgate, the storage devices needed for time switches were slow and expensive. The designers usually chose to minimize the quantity of time switches by using a trunking scheme of the form space–time–space. Since then, however, the scale of integration and speed of storage devices has increased enormously, while their cost has fallen dramatically. There has not been a comparable improvement in space-switch devices since they are more limited in capacity by the number of leads which a single device can contain. The net effect has been a change in the balance of costs in favour of time switching, hence the digital switch in System X uses a time–space–time (TST) trunking scheme.

The basis of a TST digital switch is shown in Fig. 1. Each PCM line system is connected to a digital line termination (DLT) unit, which serves to detect faults on the line system

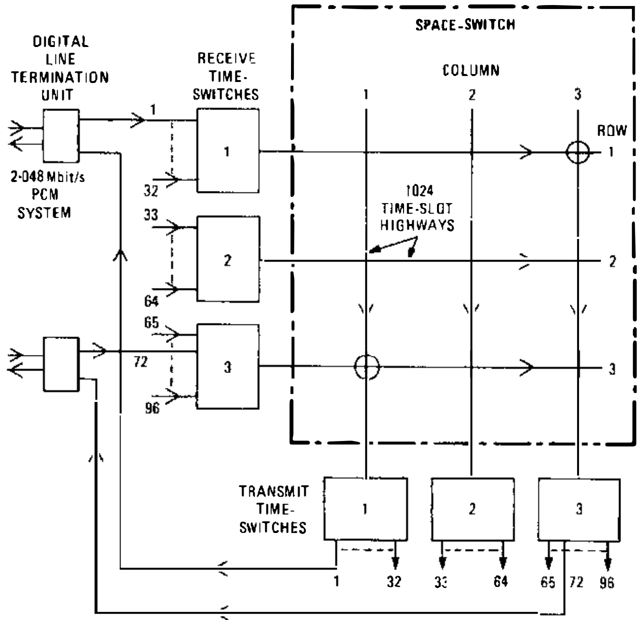


FIG. 1—Basic structure of a time-space-time digital switch

† Mr. Jones and Mr. Kirtland are in the Integrated Systems Development Department and Mr. Moore is in the Telecommunications Systems Strategy Department, Telecommunications Headquarters

and to align the timing of the receive side of the system to that of the exchange timing unit. From the DLT, the PCM system is split, with the receive and transmit directions of transmission connected to receive and transmit time-switches respectively. Up to 32 receive PCM systems terminate on one time-switch, that is, a total of 1024 channels. To prevent blocking within a time switch, the highway into the space switch has 1024 time-slots. This is achieved without operating at very high speed by converting from serial to parallel operation and by dividing a space-switch row into 2 segments, each carrying 512 time-slots. The space-switch columns and transmit time-switches are organized on a similar basis.

Consider how a connexion is made between, say, channel 5 on PCM system 1, connected to time-switch 1, and channel 7 on PCM system 72, connected to time-switch 3. A received word from channel 5 on system 1 is written into a fixed storage location in receive time-switch 1. At some chosen time-slot out of the 1024, the word is read out of receive time-switch 1 and passed via space-switch row 1, the ringed crosspoint at column 3, and is written into a fixed location in transmit time switch 3. The word can then be read out of the transmit time-switch onto PCM system 72 during the next channel-7 time. A similar and complementary process is used to transfer a word from the receive side of system 72 to the transmit side of system 1, via the other ringed crosspoint in Fig. 1.

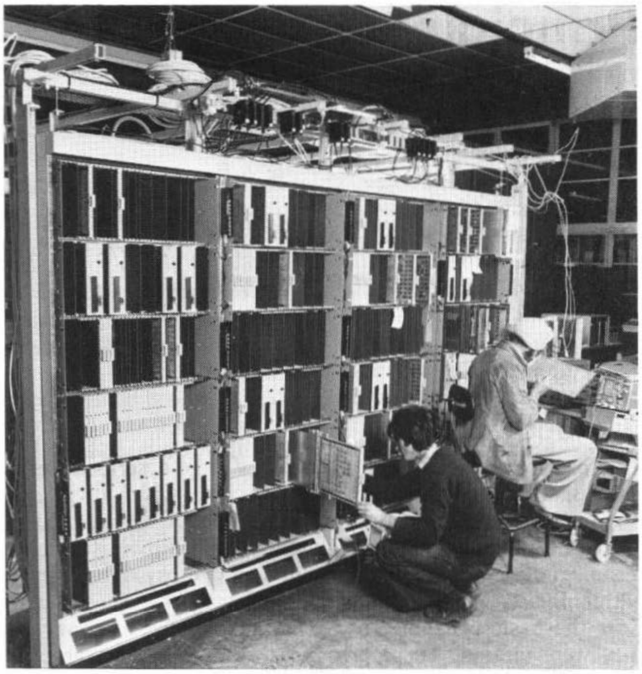
The main reasons for choosing such a large number of time-slots on the space-switch highways are to minimize the probability of blocking within the space switch and to reduce its physical size. To avoid the risk of losing a large proportion of the traffic capacity if a time switch or part of the space switch fails, the whole of the time and space switching area is duplicated. Thus, each DLT has 2 pairs of connexions on the switch side, one to each of the duplicated switches. A parity bit is added to each word on the parallel paths so that the DLT can select a valid word to transmit if there is a fault in one switch.

Growth

Growth of the digital switch is provided by first adding PCM systems to time switches, and then additional time switches with associated space-switch rows and columns. As the switch grows, so the length of each row and column increases. In a practical design, it is therefore necessary to divide the crosspoints into modules; a module size of 32 × 8 is used in System X. Since the space switch must have an equal number of rows and columns, the minimum provision is sufficient for an 8 × 8 space switch, or 8192 channel terminations. However, not all 8 receive and transmit time-switches need be provided at initial installation. The space switch grows in stages, by adding modules, up to a maximum size of 96 × 96, sufficient for nearly 100 000 channel terminations.

Even the minimum size space-switch is larger than necessary for a small/medium local exchange. No physical space-switch crosspoints are provided at all, but each receive time-switch can be wired directly to up to 4 transmit time-switches. This gives an effective maximum space switch of 4 × 4.

Fig. 2 shows a partially equipped System X digital switch for a digital main-network switching centre (DMNSC) undergoing testing at a manufacturer's site. The units are mounted on System X equipment practice, which has a significantly lower overall height compared to earlier switching equipment. The adoption of digital switching also results in significant savings in floor area. Typically, a complete System X main-network switching centre requires only about a third of the floor space of an equivalent Strowger exchange. This requirement will fall even further as more of the network becomes digital and there is a reduced need for equipment to interwork with existing signalling and transmission systems. Compared to Strowger, the daily energy consumption of the System X exchange is slightly higher. However, the power dissipation is constant throughout the day, so there is a smaller peak load on the power plant. The digital switch is responsible for only about a quarter of the total power, the remainder being for the processor, common-channel signalling and interworking equipment. Once again, therefore, the overall requirement will fall with increasing penetration of digital working.



Note: The switch is mounted on System X equipment practice; the height of the equipment rack is 2·2 m.

FIG. 2—Testing a partially-equipped System X digital switch for a main-network switching centre

(Photograph by courtesy of Plessey Telecommunications Ltd.)

This description has centred on hardware aspects. The digital switching subsystem, like various other System X subsystems, also includes software, which acts as a handler for the hardware. To achieve minimum cost and optimum efficiency, a careful balance has been struck between the functions performed in hardware and in software. A description of the software will be given in a later, and more detailed, article to to be published in this *Journal*.

PROCESSOR CONTROL

The control functions of a telephone exchange (that is, how the exchange responds to customer action) follow a unique and clearly defined sequence. For every customer action there is a closely defined response. In some cases, this response is conditional upon information supplied by the administration. For instance, when an ordinary customer picks up his receiver he expects to be connected to a digit receiver and to hear dial tone. However, before even this step has been achieved the exchange has implicitly decided the answer to a number of simple questions such as

(*a*) is he allowed to make outgoing calls?

(*b*) has he paid his bill?

(*c*) what sort of digit sender does this customer use—dial or multi-frequency tones?

(*d*) has the exchange a digit receiver of the appropriate type free and available for use?

(*e*) can the exchange set up a connexion between the customer and this digit receiver?

Depending on the answer to these sort of questions the customer will receive either dial-tone or some other tone as appropriate. Subsequent progression of the call may be broken down to a similar sequence decision and, although there may be many steps in the process, each step is relatively simple.

In the past, these logical operations have been performed by a combination of relay-sets, selective grouping of types of line using strapping on the exchange main or intermediate distribution frames or by the use of hard-wired straps on translation fields, segregated groups of junctions, etc. These techniques suffer from the disadvantage that any changes in the operation of the exchange (for example, the general introduction of a new service or a change to the service offered to a particular customer) require on-site hardware changes ranging from the inconvenient to the near impossible.

Modern digital computers have the capability of handling many tens of thousands of instructions every second and the trend world-wide is to reduce the exchange control functions to a series of program steps. These steps are stored in the memory of one or more processors, which can then control the operation of the switching network. In addition to the control program, the processor memories hold all exchange-dependent data such as customer data, translation tables, routing and charging information, and call records.

The most immediate effect of holding both the control program and the exchange data in electrically alterable stores is that the administration can become much more responsive to customer requirements, both in terms of introducing new or modified general services, or in responding to the demands of individual customers. To take a simple example, to restore service on payment of an overdue bill or to permit a change from a dial instrument to a multi-frequency sender, requires only that the appropriate entries in the customer's data file are amended. This can be done by typing in simple instructions from a teletype or visual display unit. The ability of the administration to respond rapidly and effectively to customer requirements is likely to become increasingly important in the future.

In some limited cases, customers can be given the ability to modify their own data entries for supplementary services such as on-demand call transfer and short-code dialling facilities.

A secondary advantage of having a processor in each exchange is that information on the performance of the network, traffic flow, fault situations and billing information is readily available in machine-readable form. This allows better control to be exercised on the overall performance of the network. The computer functions are also available to assist in the diagnosis of faults in a working system.

The allocation of functions between dedicated hardware and software in the control processor calls for careful judgement, as mentioned above in relation to the digital switch. In the past, designers have sometimes tended to load too much onto software, on the basis that dedicated hardware is costly and inflexible in its operation. This has resulted in the processors being overloaded with routine functions, with consequent limitations on the traffic handling capability of the system. In System X, a deliberate decision has been made to bias the design towards retaining in the central control only those functions which are intimately concerned with call handling and the manipulation of the exchange data base. In addition, however, there are minimal software handlers to interface to those subsystems which consist mainly of hardware. This policy has facilitated the use within the hardware of dedicated microprocessors, so that relatively complex logic functions can be performed cheaply and effectively by standard microelectronic devices which are in volume production.

Two types of processor have been designed for System X, one primarily for small to medium size exchanges and the other for large exchanges. The units differ from commercial computers in that they must

(*a*) provide continuous service even in the presence of faults,
(*b*) operate in a normal exchange environment without special requirements for close control of ambient temperature, humidity, dust and electrical noise,

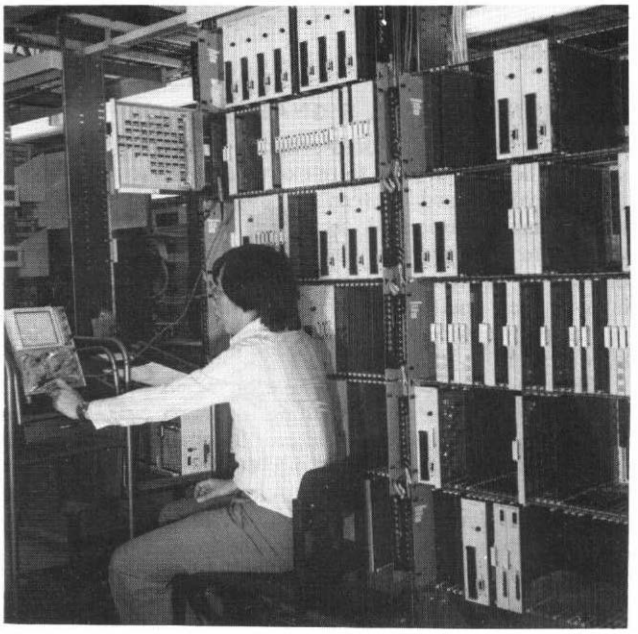


FIG. 3—A small processor utility being commissioned

(Photograph by courtesy of GEC Telecommunications Ltd.)

(*c*) be capable of extension without interruption to normal service,
(*d*) operate from the standard exchange battery,
(*e*) use an equipment practice compatible with the rest of the electronic exchange, and
(*f*) be maintainable by exchange maintenance staff.

The small processor utility (SPU) uses worker-standby techniques to achieve continuity of service; the large processor utility (LPU) uses a multiprocessor arrangement. However, both units share common hardware and software techniques and present similar interfaces to users. Both are provided with complex operating systems which deal with the scheduling of the work load, and they are also used to deal with faults in either the hardware or the software of the processor. Fig. 3 shows a small processor utility being commissioned. The units are mounted in System X equipment practice.

In concept, the software is divided into 3 parts, namely the *operating system*, the *applications code* and the *applications data*. The operating system software performs a general utility function within the processor and deals with such functions as storage allocation, job scheduling and overhead control. It is also responsible for the fault detection and recovery mechanisms which enable the processor utility (PU) to recover from either hardware or software faults which may occur in service. The applications code, as its name suggests, determines the telephony function and facilities to be provided by the exchange, whereas the applications data area contains all the exchange-dependent data such as routing tables and directory number translations.

The design and structuring of the software will be the subject of a subsequent article, but it can be said that the software is modular, is written in an easily understood high-level programming language and is capable of being readily changed in the future if new facilities are required. In service, changes to the generic software (that is, the operating system and the applications codes) are expected to be relatively infrequent and need to be closely controlled, vetted and tested by the central software authority. To assist in the management of compatible hardware and software updates, a comprehensive change control procedure has been established for System X. On the other hand, changes to the exchange data (for example, starting and ceasing lines, changing translations and charging rates) can be implemented in a controlled manner from a simple keyboard.

COMMON-CHANNEL SIGNALLING

With the advent of stored-program control of switching systems there was a need to re-examine the form of signalling that should be used between exchanges. In the existing network, channel-associated signalling[5] is used in which the signals are conveyed over the same circuits as the speech (in the case of AC and DC line signalling and multi-frequency inter-register signalling) or over a dedicated signalling channel permanently associated with the speech circuit (in the case of PCM systems[6].)

When centralized control of an exchange is used, there are advantages in conveying signalling for many circuits over a common path because the structure of signalling information received is more compatible with the functions within the processor, and the need for per-circuit signalling terminal equipment is avoided.

Other advantages which led to the choice of common-channel signalling in System X are that

(*a*) it greatly increases the repertoire of signals that can be carried,

(*b*) the speed of operation of common-channel signalling increases the potential of the network to reduce post-sending delays experienced by customers, and allows the sending of an increased number of signals required for customer supplementary services,

(*c*) it is more efficient than existing signalling systems from the viewpoint of processor power needed per call,

(*d*) flexibility can be incorporated in the design to allow changes to the information carried and to meet new service requirements,

(*e*) it enables all signalling to be transmitted completely inaudibly between exchanges and provides a clear delineation between the customer signalling and control of the network, and

(*f*) it provides greater independence between signalling and transmission, enabling each to be developed separately to take full advantage of changing technology.

Signalling Principles

Requirements

One of the main requirements for a common-channel signalling system is that it should be optimized for use over digital bearers operating at 64 kbit/s, though it should also be capable of use over slower speed analogue bearers; for example, 4800 bit/s. The system should permit as much commonality as possible between different services (for example, telephony and circuit switched data), and should be suitable for conveying administrative information as well as call-control information. The information should be conveyed in the form of messages, and arrangements must be made to ensure reliable transfer of this information in the presence of transmission disturbances. The system should permit operation in a non-associated signalling mode so that the signalling may follow a different path from the speech. Finally, adequate security must be provided so that the stringent availability requirements can be met.

Functional Description

The main functions of any call-control signalling system are, firstly, the transfer of signalling information between exchanges and, secondly, the handling of this information as part of the call-control processes in the exchanges. The structure of the new signalling system is governed by the fundamental principle that the two functions are clearly separated. The function of transferring signalling information constitutes the message transmission subsystem (MTS), while the functions related to call-control procedures form a user subsystem that is defined separately for each user. The term *user* in this context refers to any other subsystem using the message transfer capability of the signalling system.

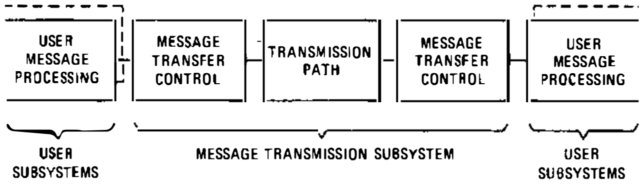


FIG. 4—Basic structure of the common-channel signalling system

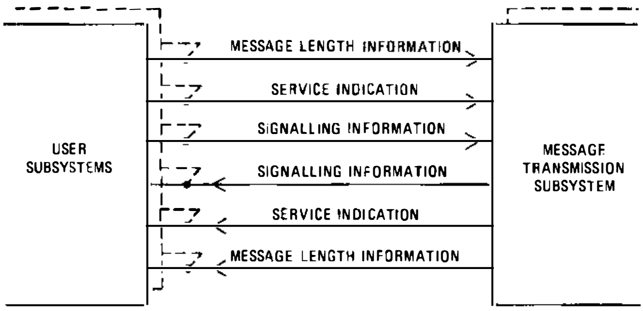


FIG. 5—Functional interface between user subsystems and message transmission subsystem

The separation of the functions means that the signalling system can be used for communication needs other than call control. For example, the message transfer function can be used to convey administrative data such as network management and maintenance information.

The resulting basic structure of the signalling system is shown in Fig. 4. In System X, the MTS and a part of the call-processing subsystem form the telephony application of BPO Signalling System Common-Channel No. 1 (SSCC No. 1).

The functional interface between the MTS and the user subsystems is shown in Fig. 5, which illustrates the separation of the functions of the signalling system. The information in each user message is carried through the MTS in the signalling information field of a signal unit, the length of which depends on the length of the message. Data on the message length is passed into the MTS from the user subsystem which forms the source, and is then conveyed through the signalling system by means of a length-indicator in each signal unit. Each signal unit also contains a service indicator to identify the source user subsystem. This ensures that messages are delivered to the correct user subsystem at the distant end. The MTS is transparent to signalling information; that is, formats and codes applying to the signalling information field can be defined independently of the functions of the MTS.

Error Detection and Correction

The detection of errors in signal units carried over the MTS—due, for example, to transmission disturbances—is performed by means of a polynomial check of each signal unit[7]. A unit carries 16 check bits which contain the remainder after dividing the bits of the unit by a generating polynomial. At the receiving end, the signalling terminal operates on the signal unit with the generating polynomial and the check bits. In the absence of errors, a pre-determined remainder will result. Any other remainder indicates the presence of one or more errors and causes the signal unit to be discarded.

Many error-correction techniques are possible and may be classified as either *compelled* or *non-compelled*. In compelled systems, each message is sent repeatedly and must be successfully acknowledged before the next message can be transmitted. In non-compelled systems, messages may be transmitted continuously so the flow of information will be interrupted only when a retransmission is required. The advantage of non-compelled systems is their greater traffic throughput.

Retransmission techniques are classified with regard to the type of acknowledgement used. In a positive-acknowledgement system, a message is not assumed to have been received correctly until a successful acknowledgement is received at the transmitting end. Failure to receive an acknowledgement within a given period initiates a retransmission. In a negative-acknowledgement system, a message is assumed to have been received correctly unless a negative acknowledgement is received. Receipt of a negative acknowledgement initiates a retransmission. After a specified period, messages are removed from the retransmission store.

In a combined positive- and negative-acknowledgement system, each message is acknowledged as having been received correctly or incorrectly. This technique provides a more explicit control of retransmission and, under high error rate and link change-over conditions, is considered to be more secure.

The error-correction method selected for the MTS is termed *non-compelled, positive/negative-acknowledgement cyclic retransmission.* At the transmitting end, signal units that are sent are also stored in a retransmission buffer until a positive acknowledgement is received. At the receiving end, when a signal unit has been received in error a negative acknowledgement is sent to the transmitting end. All signal units received after the one that was in error are discarded until the originally incorrect one is received correctly. When the negative acknowledgement is received at the transmitting end, all signal units in the retransmission buffer are retransmitted cyclically. The precise method of operating this arrangement will be described in a later article. This retransmission procedure is designed to minimize out-of-order messages, duplication of messages, lost messages and unrequested retransmissions. The first 3 factors simplify the procedures of the user subsystems, while the last factor avoids unnecessary loading of the signalling system.

Signal Unit Delimitation

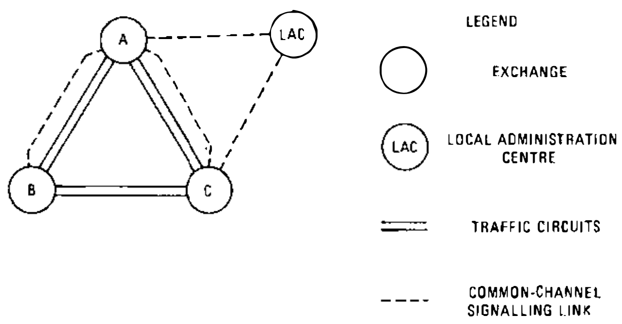
As the signal unit may vary in length, depending on the amount of information in a message, the signalling system includes a means for delimiting the signal units; that is, marking their ends. This is achieved by placing a *flag* pattern at the start and end of each signal unit, although the flag at the beginning of one signal unit may be considered as the end flag of the previous signal unit. The flag is 8 bit long and is coded 01111110.

Before the flags are attached, the transmitting terminal inserts a *zero* after every sequence of 5 consecutive *ones* to ensure that the flag is not imitated by any other part of the signal unit. At the receiving terminal, after flag detection and removal, each *zero* which follows 5 consecutive *ones* is removed. The signal unit is then checked for errors as described above.

Security

Common-channel signalling may carry signalling information for many hundreds of traffic circuits, so it is essential that the signalling facility operates with high availability. This is achieved in SSCC No. 1 by sharing the signalling traffic load over a number of signalling links. In general, 2 signalling links are provided between any 2 exchanges, though up to 4 may be used where operation is at 4800 bit/s over analogue circuits. The signalling load is shared between the signalling links on a traffic circuit basis; hence, under normal conditions, signalling for each traffic circuit is carried over a predetermined signalling link.

Should one signalling link fail (for example, its message error-rate becomes unacceptable) new signalling traffic for the circuits concerned is diverted to a working signalling link. In addition, signalling messages which were in the course of being sent over the failed link are retreived and transferred to the assigned back-up signalling link. Upon recovery of the failed link the signalling traffic distribution is normalized.



Note: The signalling links operate in the following modes:
AB—associated for AB traffic, quasi-associated for BC traffic.
AC—associated for AC traffic, quasi-associated for BC traffic.
The LAC operates associated to A and C, and quasi-associated to B.
Exchange A serves as signal transfer point for signalling from B to C and B to LAC.

FIG. 6—Modes of operating common-channel signalling

Modes of Operation

Due to the nature of common-channel signalling it is possible to send signalling for a traffic circuit either directly between the 2 exchanges at which the traffic circuit terminates or via intermediate exchanges. The former is termed *associated signalling* and the latter *non-associated signalling.* Various degrees of non-association are possible. The method adopted for part of the UK network is termed *quasi-associated signalling*, in which the path taken by each signalling message is predetermined and depends on the identity of the traffic circuit. The modes of operation are illustrated in Fig. 6. Each message includes a "label" which, in the case of call-related messages, identifies the traffic circuit to which the signals refer. The label contains a band number and a circuit number. The former is used to determine the path the message is to take and is translated at a signal transfer point to a value which identifies the traffic route concerned at the terminating exchange. The signal transfer point does not process the signalling information, but merely transfers the message to the appropriate outgoing signalling link.

Applications of Common-Channel Signalling

Besides the technical advantages of common-channel signalling, there are very considerable benefits in space and power. MTS equipment is provided at a rate of about one rack per 1000 traffic circuits, which is less than one tenth of the equipment required for interfacing circuits with channel-associated signalling. The power dissipation is reduced to approximately one fifth. Thus, there is a clear incentive to use common-channel signalling on a widespread basis.

SSCC No. 1 will be used between System X exchanges in the main and junction networks, operating at 64 kbit/s wherever possible. In the main network, the associated mode of operation will generally be used. In the junction network, each System X local exchange will be provided with common-channel signalling to its parent DMNSC. Signalling for small direct routes between local exchanges, and for direct routes where digital plant is not available, will be carried via the DMNSC in the quasi-associated mode. SSCC No. 1 will also be used to connect System X exchanges to the local administration centres (LACs) and, for this purpose, an administration user subsystem is being developed, as part of the man-machine interface subsystem.

International Aspects

Work is in progress in the CCITT† to specify a new common-channel signalling system for use between digital processor-controlled exchanges. The system is called *CCITT Signalling System No. 7* and is being specified with the aim of making it suitable for national as well as international applications. The CCITT SS No. 7 specification will be ready by the end of the current plenary period (1980) and the BPO have been active in the studies and specification writing.

The objective in designing SSCC No. 1 has been to make it as similar as possible to the emerging CCITT SS No. 7. As development of SSCC No. 1 has been undertaken in advance of the international studies there are inevitably some detailed differences. In general, however, the nature of the differences is such that when the CCITT SS No. 7 specification is ratified in 1980, then SSCC No. 1 may be brought into line with the international standard.

† CCITT—International Telegraph and Telephone Consultative Committee

CONCLUSION

A brief description has been given of 3 of the underlying principles of System X: digital switching, processor control, and common-channel signalling. Besides outlining the reasons for adopting these principles, the aim has been to serve as an introduction to the reader who is less familiar with these concepts. From this basis, future articles in this *Journal* will deal with these and other aspects of System X in considerably more detail.

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Book Review

Electronics in Communication. S. Lapatine. John Wiley & Sons Ltd. x + 341 pp. 192 ills. £10·00.

This book was written as an introduction to radio and microwave systems. The chapters cover the following main topics: introduction to communications; radio-frequency (RF) coupling, filters, amplifiers and oscillators; amplitude modulation (AM) and frequency modulation (FM); AM & FM receivers; transmission lines; waveguides and devices; active microwave tubes; VHF & microwave antennas; and miscellaneous communicationssystems. Two appendices are included: one defining 'constant-k' and 'm-derived' filters, the other explaining the construction and use of the *Smith Chart*.

The author commenced each chapter with a list of the principal items to be covered and poses a number of self evaluation questions. At the end of each chapter the principal items are summarised, together with more self evaluation questions and, where relevant, some numerical problems.

The book was very easy to read and understand, but there were occasions when confusion arose due to either poorly labelled or drawn diagrams, as was the case in the sections concerning waveguides and pulse position and pulse duration modulation. There are also some irritating instances of the author withholding useful pieces of information, such as the reference to constant-k filters being 'improved' by using m-derived sections. It would not have taken much text to have indicated just what improvements were possible.

There is a wide range of topics in both the RF and microwave sections, some of which have not been given attention in the past. For instance, stereo transmission and telemetry are included, but there is one noticeable shortfall; the double heterodyne receiver warranted only one sentence and a block diagram.

The author did not intend to give an in-depth study of the subject, but a very broad introduction, and on balance this has been achieved very well. The book should make a useful aid to students of the City and Guilds of London Institute subjects of Radio Communications and Microwave Communication C, those studying Radio and Line Transmission B and to those wishing to get a broad appraisal of radio and microwave topics.

D. J. BRACE

Reliability of Electronic Components: Results of the Field Trial of the Regenerator 5A

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UDC 621.38.004.6—181.4: 621.395.34

The reliability of the Regenerator 5A and its components, which include a metal-oxide-semiconductor integrated circuit, have been monitored during a three-year field trial of over 6000 units. Analysis of the results reveals that the reliability of the electronic regenerator is vastly superior to that of its electromechanical predecessor, the Regenerator 1A. Failures of the integrated circuit occurred however due to corrosion of the aluminium interconnexion tracks arising from a period of defective component manufacture. The need for procurement to assure adequate component standards reliability is thus emphasized.

INTRODUCTION

The crucial and essential role of integrated circuits (ICs) in new generation telecommunications equipment, be it for switching, transmission, or apparatus on subscribers' premises, is now widely recognized, but before that era truly dawns, these remarkable components will have done much to improve the UK network as it is structured today. Among ICs of low or medium complexity for example, some 2-million diode-transistor logic parts are presently operating in 24-channel pulse-code modulation systems (the oldest for 8 years), there are now about 3-million low-power transistor-transistor logic circuits and half a million operational amplifiers in miniaturized type AC9 signalling equipments, and approximately a quarter million transistor-transistor logic parts are deployed in modems. Within the large-scale-integration (LSI) category —albeit small LSI by today's standards—nearly half a million p-channel metal-oxide-semiconductor (MOS) parts are used in keyphones, and another 200 000 perform the logic functions of the electronic Regenerator 5A, distinguished as the first equipment in the world to introduce LSI parts into a Strowger system.

The Regenerator 5A, which was recently described in this *Journal*[1], is a plug-in replacement for the long-serving electromechanical impulse Regenerator 1A[2], an ingenious magnet-driven mechanism which, nevertheless, requires very careful repair or adjustment about every 6 months, or even more frequently under heavy load; as an auto unit in a busy exchange, a regenerator may handle up to 100 000 calls/annum, and over three times as many when performing the discriminator function. The Regenerator 5A, containing no moving parts (except for one reed relay) was, by contrast, expected to be insensitive to loading and attain a target mean-time-between-failures (MTBF) of 30 years at, moreover, a lower initial cost.

Being an innovation, a field trial, spread over 24 widely-distributed exchanges, was started in August 1972 to determine the reliability of the regenerator and its components. The sample comprised 6628 units of a Mark II version, which contained only one MOS IC instead of the two used in the original Mark I design[1]. The outcome of this exercise in respect of the active components of the regenerator has been reported elsewhere[3], featuring data-analysis methods, failure-rate predictions and describing a significant failure mode of the IC caused by corrosion of its aluminium interconnexions. These results are now reproduced in abridged form, together with further observations, which include the effect of the regenerator operating circumstances and a summary of the behaviour of the remaining regenerator components.

† Research Department, Telecommunications Headquarters

REGENERATOR COMPONENTS

The heart of the electronic regenerator is a single p-channel metal-gate MOS IC, purpose-designed in 4-phase dynamic logic[4] using rules based on 10 μm line widths and separations, and driven by 28 V clock pulses. The circuit die, comprising over 1000 transistors, is some 10 mm^2 in area, dissipates about 2 mW, and is enclosed by an hermetic, welded-nickel, 14-lead, TO5-type encapsulation. The ICs were processed, from common photolithographic mask designs, by two sources of different ownership, one greatly preponderating, the dates of manufacture ranging from early-1972 to late-1973. Although the process may now be considered obsolescent, it was at that time widely reproduced throughout the world-wide semiconductor industry and is still committed to new applications in the UK network. Some minimal procurement requirements were applied to the MOS circuits, supplemented by a 24 h burn-in at 85°C (with the clock pulses applied) prior to assembly.

The regenerator also contains 13 silicon transistors of 4 different types, 10 being acquired to early BPO specifications, with the remainder having *CV*-type codes. The passive components comprised 26 silicon diodes, 36 metal-oxide resistors, 9 capacitors (7 metallized polyester, one polystyrene foil and one solid-aluminium electrolytic), 2 inductors, and a mercury-wetted reed-relay, regarded as one component with its coil. Most of the components were mounted on a printed-wiring board, with the entire assembly housed in a steel box and plugged into the relay-set at precisely the location of its electromechanical predecessor.

LIFETIME DATA COLLECTION

The history of each regenerator was recorded on a punched card, raised when the unit was initially examined for correct operation on an exchange tester. If accepted, the regenerator was checked again, in its relay-set, and if still satisfactory, card entries were made identifying, the exchange, the physical location of the regenerator in the equipment rack, whether it functioned as an auto or a discriminator unit, the day of installation, and the date and reason for any subsequent removal of the unit from its relay-set. If a unit failed, it was returned to the equipment manufacturer who identified the component primarily responsible (wherever possible) and completed the record with the essential particulars of the failure mechanism, although a full explanation, or even a partial diagnosis, was not always possible.

Some failed regenerators were actually repaired and returned to service, but the information subsequently gained

TABLE 1

Pre-Service and In-Service Regenerator and Component Failure

Item Failing \ Failure Observation	Number of Failures: At Initial Test	Number of Failures: After Insertion into Relay-Set	In-Service
Regenerator	53	23	360
MOS integrated circuit	5	0	164
Transistors	7	21	75
Diodes	5	0	12
Resistors	1	0	17
Inductors	7	0	11
Capacitors	1	0	0
Reed relay	6	0	3
Assembly (wiring)	18	2	29
Fault not found	3	0	49

is excluded from the present account. The analysis is also restricted to the first 1003 d of the trial, measured from the first installation day†.

Before analysing the records, the cards were inspected for omissions and inconsistencies, but the data on only four regenerators had, in consequence, to be discounted. Of the remainder, the 76 that failed the pre-service tests are not properly relevant to the reliability of the regenerator but before dismissing them a breakdown of the responsible components is given in Table 1. The initial test failures were not evidently due to any one component. No component was, moreover, dominated by any distinctive fault, except perhaps the reed-relays which mostly failed from open-circuit windings. All the transistor failures occurring after insertion were satisfactorily ascribed to a preliminary accidental misalignment of the regenerator plug with the relay-set socket, causing 50 V to be momentarily applied to the emitters of two of the transistors. These failures were distributed over just half the exchanges, with none significantly more affected than the remainder. After making the above exclusions, the data on 6548 regenerators remained available for analysis.

DATA ANALYSIS

The popular *bath-tub*[5,6] characteristic, depicting the supposed trend of the failure rate of a system or component, is a frequent starting point for reliability studies. Burn-in procedures (as used for the MOS circuit in the regenerator) assume, for example, an early region of high failure rate, whilst the use of failure-rate formulae, or failure rates given in component handbooks[7,8], presupposes the existence of a flat-bottomed curve. Failure mechanisms that induce a wear-out behaviour are also known in semiconductor components (notably in a plastic encapsulation). In the present exercise, the stipulation of the regenerator MTBF was clearly based on an expected constant failure rate, the relation being[9]

$$\text{MTBF} = \frac{10^9}{\text{failure rate}}\ \text{h},$$

where the factor 10^9 is introduced to express the failure rate in *fits**.

The implication of a failure-rate curve is the existence of a system or component population having a *lifetime distribution* describable by a *frequency density function*[10,11] which enables the fraction of the lifetimes in any given incremental range t be expressed. When only a few lifetimes are known from a te or field sample, it is not possible to identify the populatic distribution so it is customary to assume, without justi cation, that the operative frequency density function is oı giving a constant failure rate, corresponding to the fla bottom region of the bath-tub curve. In the present exercis however, the lifetime yield for the regenerator and some of i components is comparatively large, permitting the populati lifetime distribution to be properly identified. Among tl more useful products of the resulting model, are predictio of the percentage cumulative failures and rate of failure th would be observed at any time on another sample from t same population, assuming the items are pressed into servi simultaneously.

Considering first the lifetime distribution for the regenerat itself, each record revealed either, its *lifetime*, or its operati time without failure known as its *censoring time*. Due to t distributed dates of entering service, the lifetimes and cens ing times intermingle when ordered from smallest to large Sample data in this form is said to be *multiply-censored*.

If the distribution for one particular component is sougl its lifetimes are known at once from the registered cause regenerator failure, but the failures due to other componer become additional censoring times. Similarly, if the lifetir distribution for the failure of a component by one or mc specified causes is desired, the lifetimes due to the otl causes also have to be censored. Whatever data selection made, the sample data is thus multiply-censored, to which standardized method of analysis can be applied, outlin briefly as follows††.

First, the form of the lifetime distribution is postulated, t from past experience of electronic equipment and componen only the *lognormal* and *Weibull* distributions need be cc sidered. Both are characterised by parameters, which are th estimated by the *maximum-likelihood method*, involving iterative procedure easily implemented with the aid of computer. Finally, a statistical test –the χ^2 *test*[12]—is appli to check the validity of the model††.

If neither distribution is validated by the above procedu it may be that the lifetimes are *bimodally* distributed, opposed to being single-moded; in other words, each pop lation member may belong to one of two distinct dist butions. Estimating all four parameters, as well as t fraction of the population members belonging to each dis bution, is then more difficult, but is still achievable by t maximum-likelihood method.

When the number of lifetimes in the multiply-censored d is small, say less than 20 (and certainly less than 10), the fo going procedure is not justifiable and recourse must be ma to the constant-failure-rate assumption which is equivalent postulating an *exponential* population lifetime distributic with the failure rate determinable at an upper confidence li from the number of failures and total operating hours[13].

Reliability Performance

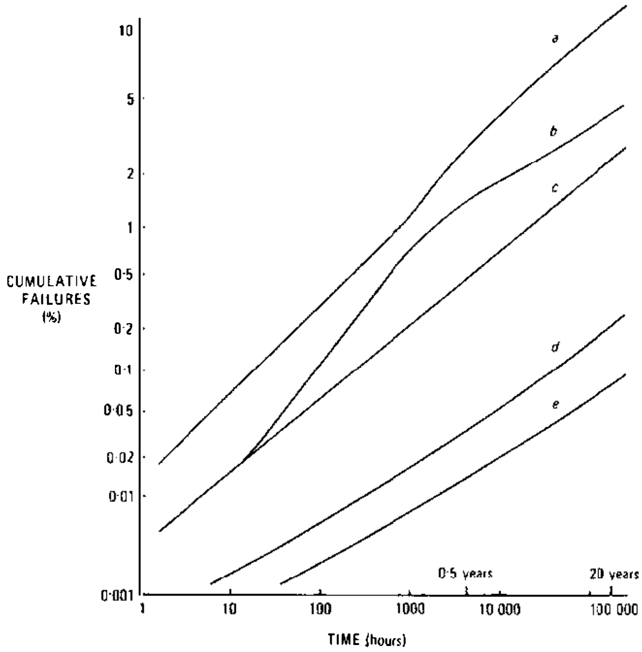
Almost 120-million regenerator-hours were accumulat during the trial period surveyed. The in-service summ statistics in Table 1 show that a total of 360 regenerat failed during that period, 282 being definitely due to co ponents, with 164 attributed to the MOS IC and 75 transistors. Relatively few passive components failed, c sidering the large number deployed.

Unless indicated to the contrary, it can be assumed that lifetime distributions that follow were adequately validated the χ^2 test.

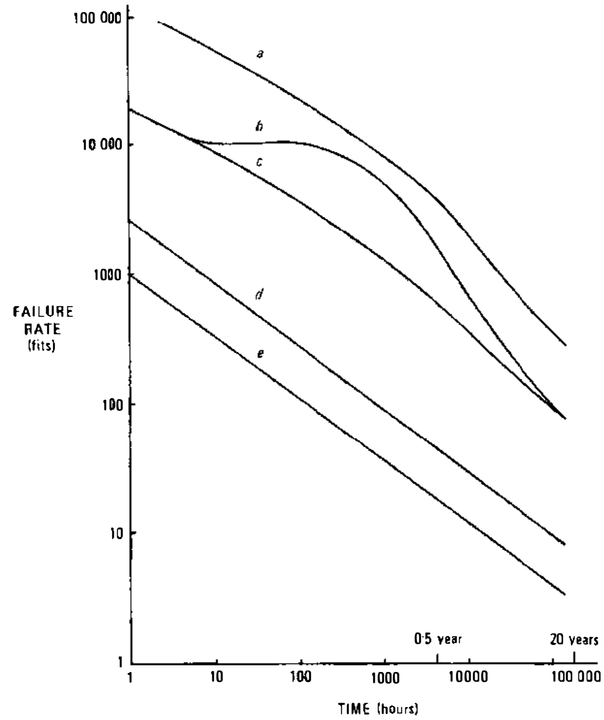
† The trial actually continued for 1248 d, but with less comprehensive records

* A *fit* (*f*ailure un*it*) is a failure rate of one component per 10^9 component-hours, and is preferred to the more familiar, but clumsy, unit of %/1000 h. Thus 100 fits = 0·01 %/1000 h

†† References 10 and 11 review most of the theory and methc employed, and reference 11 includes nearly 50 further references



(*a*) Cumulative failure fraction



(*b*) Failure rates

(*a*) Regenerator (bimodal)
(*b*) MOS IC (bimodal)
(*c*) MOS IC excluding metallization corrosion
(*d*) Transistors
(*e*) Transistors, excluding chemical attack

FIG. 1—Observed failure characteristics of regenerator and its components

Regenerator

For the regenerator lifetime distribution, a bimodal-lognormal model was accepted, yielding the cumulative failure plot shown as curve (*a*) on Fig. 1(*a*). The curve shows, for example, that if the regenerators of a batch were installed together, the time for 5% failures—called the 5% *reliable life*—would be about 2 years, whilst approximately 12% would fail in 20 years.

From the model, the failure rate can be calculated as a function of time; the result, given by curve (*a*) of Fig. 1(*b*), implies very high early values, falling to about 4000 fits at 6 months and reaching 300 fits after 20 years. For a varying failure rate, the MTBF has little meaning, so the regenerator performance is not easily measured against its 30-year target; one can only speak of an "instantaneous MTBF", using the formula given earlier. On this interpretation, the regenerator MTBF lengthened continuously, requiring about 6 months to reach the target and rising to about 400 years after 20 years. As an alternative approach, average failure rates can be found using the model, choosing, say, from installation up to 6 months, and from 6 months to 20 years and regarding the outcome as simple expressions of short- and long-term reliability. The resulting average failure rates are shown in the first entry of Table 2, indicating that the settled MTBF of the regenerator is about 200 years.

TABLE 2

Mean Failure Rates for Active Components

Item	Average Failure Rate (fits)	
	up to 6 months	6 months to 20 years
Regenerator	6600	570
MOS integrated circuit	3500	150
Corrosion-free MOS circuit	1100	130
Transistor	85	12
Attack-free transistor	35	5

Integrated Circuits

Of the 164 MOS IC failures in service, summarized in Table 3, 139 were the product of the major supplier and, of those, corrosion of the aluminium metallization accounted for 90. A similar defect was identified on 9 of the 25 failures amongst the parts processed by the other manufacturer.

On an unfortunately large number of failed circuits, the fault could not be found, either electrically or physically, but the cause was probably not corrosion, which was rather easily detected as seen later. Of the remaining, positively-identified causes of failure, the most prevalent is shown on Table 3 as *parameter shift*, which is, however, a supposition based on the observation that the malfunction was sensitive to a clock-zero level. The *oxide defect* refers to pin holes in thin gate oxide and, of the metallization faults (excluding corrosion), one appeared to be an example of electromigration[14].

For the MOS circuit, a lognormal-bimodal model was again validated; the cumulative failure plot, curve (*b*) in Fig. 1(*a*), indicating that the 2% reliable life† is just over 1 year. The failure rate, curve (*b*) of Fig. 1(*b*), remains at about 10 000 fits for the first month, but thereafter falls

TABLE 3

Causes of MOS IC Failure in Service

Cause of MOS IC Failure in Service	Number of Failures
Metallization corrosion	99
Parameter shift	9
Oxide defect	7
Metallization defect	4
Threshold voltage shift	1
Missing bond	1
Fault not found	43
TOTAL	164

† The 2% reliable life is often quoted for telecommunications components

TABLE 4
Causes of Transistor Failure in Service

Cause of Transistor Failure in Service	Number of Failures
Chemical attack	26
Surge damage	25
High leakage	6
Bond defect	1
Metal whisker	1
Fault not found	16
TOTAL	75

TABLE 5
Failure Rates for Passive Components Assuming an Exponential Model

Component	Average Failure Rate (fits)	
	up to 6 months	beyond 6 months
Diodes	920	4
Resistors	840	4
Inductors	15 000	34
Capacitors	2	
Reed relay	56	

Values are to upper 90% confidence level

steadily, going below 1500 fits at 6 months and taking 20 years to fall to the 100 fit level.

In the course of the bimodal analysis of the lifetimes of the MOS circuit, the two constituent distributions were identified as one, comprising 1·6% of the population, which would ultimately fail due to metallization corrosion, the other being the remaining fraction failing for all other causes. The (single-mode) cumulative failure plot for all other causes is also given on Fig. 1(*a*), as curve (*c*), showing that, if the corrosion phenomenon had not existed, the 2% reliable life of the MOS circuit would have been increased to about 10 years. The corresponding failure-rate plot of Fig. 1(*b*), curve (*c*), compared with curve (*b*), shows clearly how this failure mode increases the failure rate by 3–4 times over the first 6 months, and then persists for several years. The curve indicates that the median lifetime of the corrosion failures (the 50% reliable life) must be quite short, and is indeed approximately 3 months (compared with a million years for failures due to the remaining causes).

Calculations of the average failure rates, below 6 months and from 6 months up to 20 years, as shown in Table 2, also emphasize the early impact of the corrosion phenomenon.

Published results, with which the foregoing failure rates can be compared, are hard to find and, if derived from laboratory tests (which is inevitable unless the sample size is comparable with that of the present study), the calculations are always open to question. Values from 50 fits up to 3 orders of magnitude greater were being quoted[15] for contemporary MOS circuits, whilst a calculation using the current MIL-HDBK-217B formula[7] yields about 43 000 fits. It is possible to conclude only that the reliability of the regenerator IC is at least as good as that of others of its generation.

Transistors

Of the transistors, for which the failure causes are given in Table 4, a total of 25 appeared to be damaged in a manner resembling that caused by faulty insertion as mentioned earlier, with the same two transistors in each unit affected. There was again no evidence of any one exchange exhibiting an exceptionally large failure total.

Not being genuine failures, the lifetimes arising from damage were censored, but in doing so, it was noted that they were quite widely distributed and if not excluded, would have added some 20 fits to the transistor failure rate at all times. On the evidence, therefore, these transistors suffered from a damage-inflicted loss of long-term reliability.

The remaining transistor lifetimes satisfied a Weibull distribution showing, by the cumulative plot of curve (*d*), Fig. 1(*a*), that the 2% reliable life is well beyond any normal equipment lifetime. The transistor failure rate, shown as curve (*d*) on Fig. 1(*b*), again falls steadily, dipping below 40 fits in 6 months and reaching down to 7 fits in 20 years. There was no clear evidence that any one transistor was less reliable than the others, although the *CV* transistors, as a group, suffered significantly more failures than those bought to BPO specifications. The reason for this disparity is not known.

The failure mode termed *chemical attack* in Table 3, refers to a gross defect due to the ingress of plating solution into the transistor encapsulation during manufacture, which manifested itself in high leakage currents and bond wires corroded through their full section. Analysis showed that about 0·4% of the transistor population would ultimately fail for this cause with a median lifetime of about 11 weeks. If the lifetimes due to attack are also censored, there remain scarcely enough failures for a proper analysis, and the outcome—from the χ^2 test—has only a 3% chance of being valid. The cumulative failure and failure-rate plots have, nevertheless, been added to Figs. 1(*a*) and 1(*b*) as curves (*e*).

These results, and the mean values of failure rate shown in Table 2, emphasize that silicon transistors can be very reliable indeed, a conclusion well supported by other field experiences[16, 17] where values in the range 5–50 fits appear for low- or medium-power components.

Passive Components

The failure-rate totals for the passive components, recorded in Table 1, permit only an assumption that the exponential model is valid. An inspection of the lifetimes for the diodes, resistor and inductors (for which the failures were sufficiently numerous) suggested, however, that their failure rate also tended to fall with service time. To provide a simple expression of this trend, lifetimes shorter and longer than 6 months were separately counted and taken with the corresponding component-hour totals to give the estimated average failure rates shown in Table 5. For the relays and capacitors, only a single estimated value could be determined with the outcome also given in Table 5. There were no especially notable causes of failure, although most of the defective resistors appeared to have suffered electrical or mechanical damage and the inductors were generally open circuit. Both high-leakage and short-circuit failures were observed amongst the diodes.

The observed failure rates are somewhat high (the inductors especially) relative to values quoted in the literature. The failure rate of metal oxide resistors is often better than 1 fit and diodes can be in the 1–2 fit range. The capacitors, including the electrolytic (actually 7 fits) are quite typical.

Reliability Sensitivities

The foregoing estimations were based on the entire regenerator sample. Similar analyses could be carried out for, say, each exchange (wherever there were sufficient failures), but the results would be of minimal interest. Instead, it would be useful to know if the reliability of the regenerator and its components is influenced by the exchange identity, shelf position or regenerator function (auto or discriminator) but these questions are answerable statistically only if every regenerator deployed had an equal chance of being assigned to the location or function under scrutiny. In respect of the allocation of regenerators to exchanges, this condition is not satisfied, as will be appreciated after reading the next section. It is, however, possible to examine the hypotheses of Table 6,

TABLE 6

Influences of Shelf Position and Regenerator Function on Regenerator and Active Component Failures

Hypothesis	Conclusion
Does the regenerator shelf position influence the failure of the:	
regenerator?	No
MOS IC?	No
transistors?	Yes (16%)
Does the regenerator function influence the failure of the:	
regenerator?	Yes (5%)
MOS IC?	No
transistors?	Yes (<1%)

Figure in parenthesis are significance levels, indicating the chance of a false positive judgement

using the χ^2 test, to compare observed failure totals with corresponding expected figures calculated from the lifetime models already established. Other propositions could also be formulated (for the remaining components), but there are insufficient failures for valid tests.

Of the components examined, Table 6 shows that the reliability of the MOS circuit is influenced neither by its shelf position, nor by the regenerator function. As the local ambient temperature at the top of the equipment rack can be as high as 65°C, an enhanced failure rate for MOS ICs on the upper shelves was possible but, as noted in the next section, the corrosion phenomenon should be decelerated by increases in ambient temperature. The transistors are possibly sensitive to position but, almost certainly, to the regenerator function with (as the data showed) an inferior reliability in discriminator units. The regenerators themselves are also less reliable when operating as discriminators, partially reflecting the transistor influence. No reason for this functional sensitivity can be advanced.

METALLIZATION CORROSION

Being the dominant cause of regenerator failure, the MOS circuit corrosion phenomenon was selected for further study. This attack was always highly selective, favouring metal at a negative potential relative to the substrate die, as shown by the typical image of Fig. 2. Quite often, only regions overlain with protective glass were affected, as is apparent from an inspection of the bottom-left bonding pad, where the glass has been removed to allow the wire bond to be made.

From the literature[18, 19], it appeared that an analysis of the encapsulation atmosphere would help to explain the phenomenon, but most of the specimens had been dismantled in the summary investigations to identify the primary cause of failure. Nevertheless, a total of 32 failures, processed by the major supplier, were located, some from service or burn-in, with others of unknown history, but they all bore manufacturing date codes within the period under review.

Semiconductor component manufacturers often check the hermeticity of encapsulations by pressurizing them in helium, followed by their transfer to a vacuum chamber equipped with means for detecting the emergence of any injected gas, but this method is not highly sensitive. By refining the procedure, notably by puncturing the encapsulation when located in the vacuum chamber, it was possible to detect leaks as small as 5×10^{-11} millibar-litres/s† and, at the same time, determine the amounts of the various gases in the encapsulation. For water vapour, the lower detection limit was 0·01%.

The examination revealed that all the specimens were hermetic and that the most prevalent impurity of their predominantly nitrogen content (the original encapsulating gas) was water vapour, which correlated with corrosion and the date of manufacture as in Fig. 3. Whilst the non-random nature of the sample examined must not be overlooked, the evidence suggests that the primary cause of the metallization problem was a deficient manufacturing period when the water-vapour content of the encapsulations from the principal supplier was disposed to exceed a critical level, seemingly of about 0·5%. At other times, however, the moisture content could clearly be very close to this level.

Because the relative humidity inside an hermetic encapsulation rises with falling temperature, there is a good reason to expect that, unlike most semiconductor component failure mechanisms, metallization corrosion is accelerated by low ambient temperatures. This correlation is believed to explain the increase in reported corrosion failures over the recent years, when IC dissipations have steadily fallen.

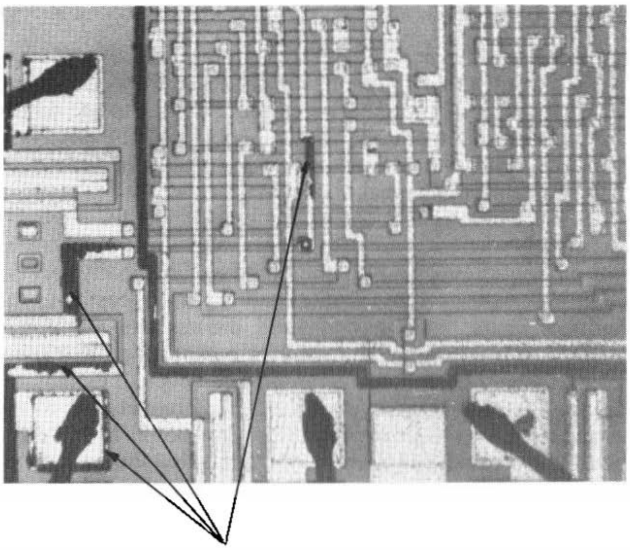


FIG. 2—Corner of MOS IC die showing corrosion of aluminium metallization

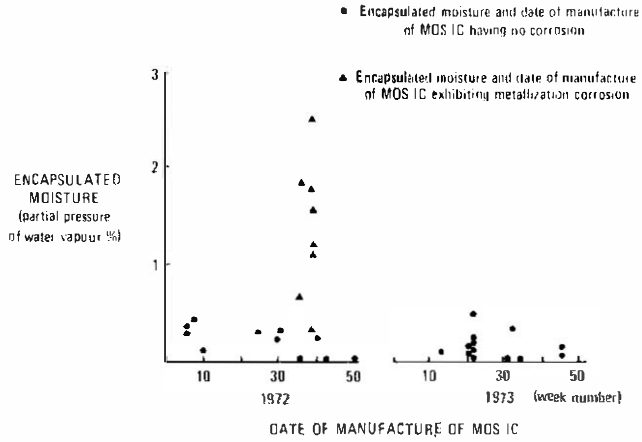


FIG. 3—Relation of encapsulated moisture to date of manufacture of MOS IC and the occurrence of metallization corrosion

† A typical manufacturing specification, just within the range of commercial leak-testing equipment, is 5×10^{-7} millibar-litres/s maximum

CONCLUSION

As a comparative study of the electromechanical and electronic solutions to a problem, the results need no emphasis; the trial was an indisputable success and has led to the supply contracts already reported[1]. The superiority of the electronic item was moreover realized using components of little more than ordinary commercial quality.

For electronic equipment in many new systems, however, particularly where ICs are used extensively to realize functions not otherwise practicable, the observed reliability of the MOS IC would have been quite inadequate, at least over the first few years. It is tempting to dismiss the aluminium corrosion phenomenon as a mere manufacturing aberration, but parts from both manufacturers were affected. Corrosion, for one of several possible reasons, is moreover one of the principal failure modes of present-day low-power ICs. Viewed broadly, no reason is seen why the results should not be regarded as characteristic of the standards of procurement and manufacture adopted. Raising those standards, especially by adequate component procurement specifications, as have been described[20], is seen as the primary route to improved reliability.

Three other broad conclusions may be drawn. Firstly, in terms of the bath-tub curve, the failure-rate trends were downwards and are predicted to continue in this way for a period within which the electronic regenerator is likely to become obsolete, so the term *infant-mortality*, as applied to that region of the curve, hardly seems appropriate, and the flat bottom region does not appear. Recalling the wear-out segment of the bath-tub curve, serves as a reminder that a field study of less than three years' duration cannot be expected to expose long-term risks, which is one reason why a good procurement specification will include an element of accelerated testing.

Secondly, the excellent reliability attainable from semiconductor components has been demonstrated, but on a package-by-package comparison, the passive components are better still. Put another way, the intuitive feeling that there should be a general tendency for reliability to decrease with increasing component complexity is confirmed.

Finally, the raw data used for the exercise, even with a substantial content of faults-not-found, is much more comprehensive and authentic than is usually available from telecommunications systems. If, as believed, useful information for manufacturers, designers and maintenance personnel has in consequence emerged, it may be concluded that a consistent policy of accumulating field returns could have enduring benefits, provided that the data is gathered with similar care and in comparable detail.

ACKNOWLEDGEMENT

The carefully-collected and well-documented data generated by the field trial is the outcome of excellent co-operation between telephone exchange personnel throughout the UK, BPO Service Department and the equipment manufacturer, Pye TMC Ltd.

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Book Review

Electrical Safety Engineering, W. Fordham Cooper, B.SC., C.ENG., F.I.E.E., F.I.MECH.E. Butterworth. 366 pp. 125 ills. £15·00.

Much of this book considers advanced electrical theory involving higher mathematics and is, therefore, more suited to the specialist electrical safety expert, or designer, than the run-of-the-mill safety officer who covers electrical safety as part of his responsibilities. Nevertheless, it contains a good deal of useful safety information, which would be of considerable use to safety officers and, as the author was formerly HM Electrical Inspector of Factories, it can be considered as an authoritative work.

The author's use of "condenser" instead of "capacitor" is irritating, and there are a considerable number of printing errors, particularly in the early chapters. It is surprising that the chapters covering fire and explosion hazards contain no mention of halons for fire fighting or rendering hazardous atmospheres inert. The physiological limits quoted for the effects of electric shock on the human body are somewhat higher than those currently being considered by the International Electrotechnical Commission.

The book is a useful addition to the safety armoury, particularly for engineers designing or controlling power equipment, and is recommended as an addition to any technical library.

W. F. SEARLE

Submarine Cable Systems: A Review of their Evolution and Future

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UDC 621.315.28

This article reviews the progress that has been made in submarine cable technology in the last 25 years or so.

INTRODUCTION

That submarine cable systems have achieved a remarkable standard for equipment reliability is renowned: nothing in this modern technological world has attempted, or needed, to meet the high probability of survival for effective service for over a quarter of a century as has been built into the manufacture of the undersea cable and its associated amplifiers. The only detraction from excellence of performance has been interference by fishermen.

Much is made of the statistics relating to equipment survival in all aspects of present-day electronics and, even in the submarine cable field, the requirements for components in terms of mean time between failures (MTBF) and failure rates (in fit)* are sometimes used. However useful and necessary these statistics may be in some fields of telecommunications, they have little meaning for the submerged repeater. Except perhaps for active devices like transistors, which can be subjected to controlled overstress and the failure rate predicted by extrapolation, no demonstration can be given that a component has met a probability of survival target. The innovators of the submerged repeater, some 25–30 years ago, both in the British Post Office (BPO) Research Department[1] and the Bell Telephone Laboratories (BTL) of the USA[2], were certainly not basing their work on failure rate predictions. And the situation has not changed today because recently, in 1978, R. L. Easton of BTL published[3] succinctly what is the real situation when he wrote 'there is no way to prove ahead of time that this level of reliability has in fact been reached, but the indications are that we have achieved it in previous systems and . . . in the year 2000 it will be clear that the new system is as reliable as we tried to make it'.

We now know that the decisions made 25 years or so ago were correct, for both the first transatlantic cable system (TAT 1) and the Aberdeen–Bergen cables (laid in 1954) have now exceeded their planned operational life of 20 years, showing that both the American and British technologies arrived at correct decisions on component reliability.

TAT 1 was withdrawn from operational service in November 1978, not through any malfunction of its repeaters but because design evolution has rendered its low circuit capacity uneconomic to maintain. This, then, offers an appropriate time to review the significant progress that has been made in submerged cable technology since TAT 1 came into operation in 1956, to consider those influences which have detracted from complete success, and to conject wherein lies the future for this form of transmission media—indeed, has it a future?

† Network Planning Department, Telecommunications Headquarters

* A fit (failure unit) is a failure rate of one component per 10^9 component-hours, and is now preferred to the more familiar unit of %/1000 h; thus 100 fit = 0·01 %/1000 h

A REVIEW OF BRITISH SUBMARINE CABLE SYSTEM EVOLUTION

The evolution in circuit capacity in the 2 decades since TAT 1 has been remarkable, but most apparent in the last decade. From 1956 to 1965, the UK designs had only doubled their capacity from 1 to 2 supergroups, whereas from 1966 to 1976 the systems available for use had increased in capacity from 2 69 to supergroups (see Fig. 1). The relatively slow early development was due to 2 prime factors:

(*a*) The growth demand was not pressing. Even within Europe the need to communicate overseas remained latent until the early-1960s when the need to lay 2 concurrent cables between the UK and Germany indicated the need for greater sea-cable capacity, at least on the primary routes into continental Europe. Elsewhere in the world, the one and two supergroup cables were adequate and were being installed in considerable numbers to meet the first requirements of telecommunications administrations for a more reliable form of communication than high-frequency radio. Typically, the concept of a Commonwealth Cable[4] was commenced by cables of this bandwidth laid first across the Atlantic (CANTAT 1 system), and later across the Pacific to link Canada with Australia, New Zealand and South-east Asia up to Hong Kong (the COMPAC and SEACOM systems).

(*b*) The thermionic tube was imposing limits on the exploitation of higher-frequency systems. To meet the reliability demanded of submerged repeaters, thermionic tubes required a rugged cathode-grid structure not commensurate with high mutual-conductance, and little progress was possible until the evolution of the long-life silicon-planar transistor, which did not become perfected and commercially viable for this class of use in sufficient quantities until the mid 1960s. From that time, the thermionic tube was entirely superseded, except for its use on a system designed by Standard Telephones and Cables Ltd. (STC), operating at up to 3 MHz, which was laid between Portugal and South Africa (SAT 1) in 1969[5].

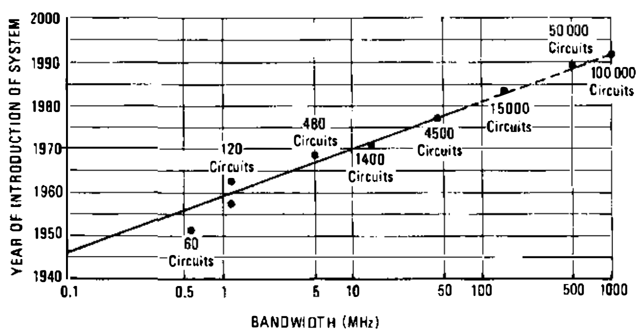


FIG. 1—The increase of submarine cable system bandwidth

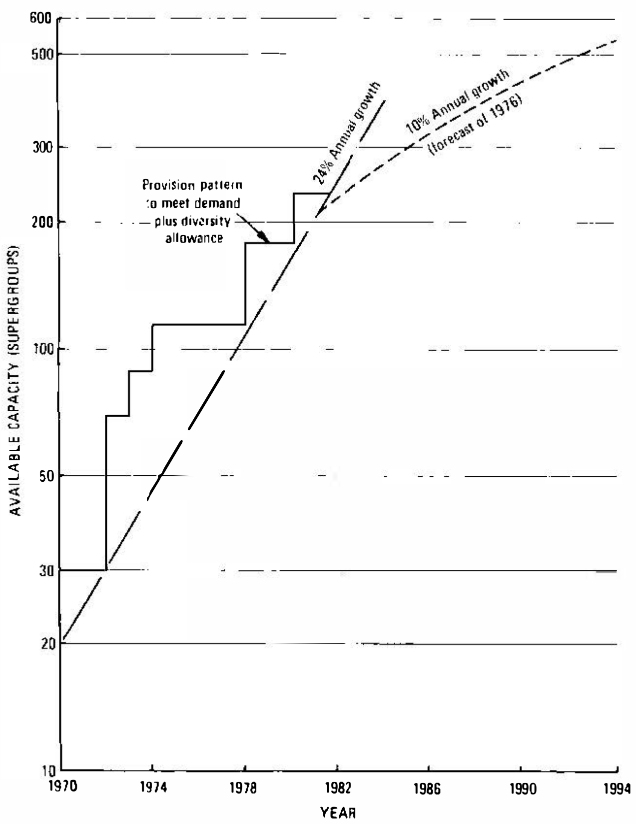


FIG. 2—The North Sea cable system demand growth

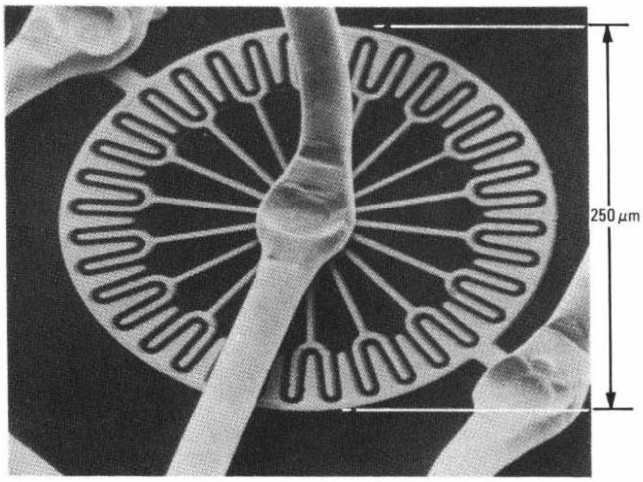


FIG. 3—Micrograph of the Type 40-C transistor

This cable system, which is still operating successfully, identified the ultimate problem of thermionic tube operation in that the anode potential could not be reduced below, say, 50 V, implying a power-feeding voltage of up to 24 kV to series-feed the repeaters, which are spaced 10 nautical miles apart in the cable. The voltage is applied at 12 kV from both ends of the cable in the series-aiding mode. The design of the power-separating capacitors, stressed to this voltage and used in every repeater, is onerous. Hence, it was to the transistor, with its low operating power, that designers looked for a large reduction in system cable operating power.

Growth in the second decade of the submarine cable system era has followed a pattern which has resulted in an increase of circuit availability of about 3-fold every 5–6 years; for example, 8 supergroups in 1965[8], 23 supergroups in 1971[9] and 69 supergroups in 1977[10]. Extrapolating this to 1982/3 would suggest that about 200-supergroup systems would be available, but this now seems unlikely: not because it cannot be done—it has already been demonstrated experimentally to be feasible—but more because the circuit demand pattern has changed significantly. Since 1975, there has been a reduction in the demand for high-capacity systems, suggesting a slow trend towards saturation superimposed on a general recession of trade (which may eventually restore), but which, at present, shows no sign of complete recovery (see Fig. 2). However, there is evidence that the end of the road may have been reached for frequency-division multiplex (FDM) transmission by submarine cable. The practical difficulties attached to the development of a coaxial cable system working beyond 100 MHz are considerable: the subsequent step to 300 MHz presents grave doubts as to its feasibility. This is because the ultra-reliable silicon planar transistor is reaching its practical limit, in the same way as the thermionic tube did some 12–15 years ago, in that to work at even higher frequencies it must sacrifice its already-tenuous robustness. The emitter-base spacing is only 5 μm on the 40-C type transistor (see Fig. 3) used for the STC 45 MHz system; the transistor has a frequency cut-off of 4000 MHz. For use at higher frequencies, the dimensions would be even smaller.

Quite apart from the transistor problems, there are other limiting factors, most of which relate to the lower repeater gains which follow inevitably from higher-frequency working. Higher-frequency working results in closer spacing of repeaters (more repeaters per given cable length, with the implication of increased reliability requirement and higher line voltages) or larger diameter cables, which are already an expensive proportion of system costs and could well, at one stroke, make all existing cable ships in the world redundant if they were unable to stow and lay the larger cable.

FOREIGN SUBMARINE SYSTEM POTENTIAL

Any review of submarine cable system progress would be incomplete without reference to the potential of overseas manufacturers. Apart from the Communist bloc, about which little is known, there are only 5 manufacturers of complete system competence in the world, of which one is British (the Submarine System Division of STC Ltd.). The others are

(*a*) Weston Electric (WE. Co.) of USA, a subsidiary of the American Telephone and Telegraph Corporation (ATT),

(*b*) *Compagnie Industrielle des Telecommunications* (CIT) of France with its associate, *Les Cables de Lyons*; both are subsidiaries of the large French consortium, *Compagnie Generale d'Electricite*,

(*c*) Fujitsu Ltd. of Japan, and

(*d*) Nippon Electric Company (NEC) of Japan.

Development in the USA

Because they met the same constraints, the ATT development pattern over 20 years has been remarkably similar to that in the UK. It is well known that TAT 1 used separate GO and RETURN cables of the conventional European 15·8 mm (0·62 inch) light-armoured type (much of it made in the UK). Amplification was provided in flexible repeaters whose design included long-life thermionic tubes made by BTL. These repeaters were unique, and were designed to be as contiguous with the cable as was practical so that, being multi-articulated, about 7 m long by 75 mm in diameter, they could be paid out from the cable ship using the normal drum-machinery. However, 2-cable systems did not survive the TAT 1 (and TAT 2) era for a variety of reasons, principally cost; neither was the flexible repeater really necessary nor further exploitable. Thus, ATT reverted to the single rigid-housing with bi-directional amplifiers, broadly in the manner pioneered by the BPO Research Department[1] and supplied for the 60-circuit TAT 1 and TAT 2 extension systems across the St. Lawrence seaway in Canada, following the successful trial of the Aberdeen-Bergen system laid in 1954. There, any similarity between the BTL and British designs ended because the BTL philosophy, particularly of mechanical design, was divergent from that of the BPO Research Department. That both designs have passed the test of practical service suggests that both approaches were equally good.

The more significant differences resulted from the BTL fundamental belief in the use of only compatible metals to avoid any complication created by the need to combat corrosion in a salt water environment. This approach can be expensive: BTL used wholly copper conductors for their cables and beryllium copper for their repeater housings, equalizers and cable-repeater connexion components. BTL use a much shorter housing (900 mm) than the BPO but with a larger diameter (330 mm) to accommodate the volume of internal components. To permit laying the repeater round a 3 m sheave, BTL also designed a gimbal-mounted flexible termination to the cable, which was also made from beryllium copper.

The ATT systems using this mechanical design are coded

(*a*) the SD-system[12], first used on the Florida-Jamaica and TAT 3 systems in 1963 to provide about 130 circuits of 3 kHz bandwidth,

(*b*) the SF-system[13], first used on TAT 5 in 1970 to provide about 800 3 kHz circuits, and

(*c*) the SG-system[14], first used on TAT 6 in 1976 to provide 4000 3 kHz circuits.

The SD-system (about 1 MHz upper frequency) was the last ATT system to use thermionic tubes.

ATT have always used the system baseband to maximum efficiency by using 3 kHz-spaced channels. They use the high-efficiency double-modulation technique evolved by the BPO Research Department around 1960[15] and, in fact, the first racks of British-made equipment were installed and commissioned for ATT at their terminal in Florida by BPO personnel.

Development in France

CIT of France is the only other submerged system manufacturer in Europe. CIT have been operating for many years and have tended to concentrate their development to meet the French market in the Mediterranean for medium length systems of around 3000 km in length. The rise of circuit demand was slower in the Mediterranean zone than across the North Sea, and the CIT thermionic-tube-operated 1 MHz system met the traffic needs through the 1960s. Since then, CIT have developed and supplied transistor operated systems of both 5 MHz and 25 MHz capacity, using cables of either 25 mm (1 inch) or 38 mm (1·5 inch) diameter. Their cable construction follows the American practice more than that of the UK, but in the last few years, aluminium outer conductors have tended to replace copper, presumably for reasons of economy. CIT have also always used a gimbal to provide a flexible joint between the cable and repeater but they are now thought to be considering a more direct means of coupling the cable to the repeater.

The CIT repeater construction is different from both the British and American patterns, although its dimensions more closely resemble the latter. It uses a pressure housing of stainless steel, and CIT solve the corrosion problem by encapsulating the housing with a thick coating of glass reinforced plastics.

Development in Japan

For the purpose of this brief review of the world manufacturing potential, it is appropriate to consider Fujitsu and NEC of Japan together, because, as far as is known in the UK, the 2 products are basically similar in order to meet the Japanese telecommunications administration (NTT) requirements and specifications. Certainly the repeaters from Fujitsu and NEC are identical at their interfaces, both in appearance and electrical performance, although the inner capsule designs may well be different. As both firms sub-contract their cable to the Japanese Ocean Cable Company Ltd. (OCC) the end result is complete compatibility, but both firms will claim to be in active competition with each other. The Japanese repeater is very small, being enclosed in a pressure housing of beryllium copper, only 1·060 m in length and 230 mm in diameter. Like the Americans, the Japanese firms restrict themselves to compatible metals and use only cables with copper conductors: they also employ a gimbal-coupling of beryllium copper for the cable termination. As far as the author knows, the Japanese have never competed for the long-haul market. At the present time, systems are made in Japan to provide either 1200 or 2900 high-grade 4 kHz circuits, and both types have been laid within the last few years in European waters. Whether they intend to develop a larger system in advance of the (assumed) transition to fibre-optic cables is not known.

SUBMARINE CABLE 1950–1980

Submarine cables have changed remarkably little in 30 years, other than in size. To fulfil the theoretical requirements for minimum loss, the ratio of diameters of the inner and outer conductors has remained fairly constant at between 3·6 : 1 and 4·0 : 1, depending upon the outer conductor metal. The impedance of the cables has therefore been constrained to about 50–55 Ω (although there have been exceptions). What has changed of course, is the diameter of the coaxial pair to meet the requirement for lower loss at higher frequencies. It is well known that the loss of a cable varies as the square root of frequency in respect of the conductor loss, and directly with frequency in respect of the dielectric loss, that is

$$\text{loss} \simeq A\sqrt{f} + Bf,$$

where A and B are coefficients relating to the conductors and dielectric respectively.

By 1950, the size of sea cable that had become a world standard was a copper/copper cable 15·8 mm in diameter, and it was used on the systems then evolving having an upper frequency of about 0·7 MHz. To attain flexibility, the outer conductor consisted of 6 copper tapes which were spirally applied over the dielectric and supported by a thin short-lay binder tape of copper. No attempt was made to exclude sea-water. Even using the low-grade polyethylene then available, the contribution of the dielectric loss term to total loss at 1 MHz was little more than 1%, so loss was then a function only of the resistivity of the copper conductors (and hence their size). The 15·8 mm 'wet' cable remained the standard through the 1950s, being used on TAT 1 and other cable systems of that era, although a larger variant 24 mm (0·935 inches) in diameter had been introduced to permit longer cable sections between repeaters where this was necessary.

By 1960, the so-called *lightweight cable* had been developed by Research Department for the CANTAT 1 project[16]. It is, as its name implies, a deep-water cable with no external armour. It has a nominal diameter of 25 mm and, in its Mark II form, an overlapped horizontal aluminium tape as its outer conductor; the loss-angle of the polyethylene dielectric had by then been reduced from about 300 μrad to 200 μrad, chiefly as a result of the development of low melt-flow polyethylene. At about the same time, BTL introduced a 25 mm armourless cable for their SD system[12], but they retained copper for the outer conductor. Both armourless designs used an over-sheath of polyethylene to provide the necessary hoop-stress to maintain the homogeneity of the longitudinal outer conductor under bending stresses but, in the British case, it is also necessary to keep the aluminium conductor away from contact with the sea. Because the malleability of aluminium is much better than copper, the British armourless cable uses a low-density polyethylene as its sheathing jacket, whereas the BTL design uses a high density polymer. The American pattern cable has also been adopted by Japan and, to a lesser extent, by France.

The development of the 5 MHz systems in 1965 and, to a much greater extent the 14 MHz systems of 1968–70, dictated the need for a lower loss cable. The cable size was increased by 50% to a nominal 38 mm, both in the UK and in the USA, followed closely by Japan and France. These cables were armoured when used in shallow water. The improvement in polymer technology had, by then, allowed the loss angle of the polyethylene to be specified to about 100 μrad. To achieve accurate prediction of sea bed performance and attenuation frequency equalization, a tighter control on polymer variation tolerance became essential. These cables remain standard today and are the normal choice for short and medium length systems working in the 10–50 MHz range of up to 2000 nautical miles. For trans-oceanic systems, in which the need to predict performance is paramount, a very low-loss polyethylene was developed about 1974/5 having a loss-angle of less than 50 μrad. Low-loss polyethylene is difficult to produce in bulk quantities and is therefore expensive. Its use so far has been confined to the 43 mm copper cable developed jointly by France, the UK and BTL for the TAT 6 cable[14], which uses the BTL Type-SG repeaters working up to 30 MHz for a system of up to 4000 nautical miles. This is an expensive cable and unlikely to be economic on the shorter routes.

CABLE POWER REQUIREMENTS

The expectation that the advent of the transistor would drastically reduce the cable power circuit requirement has not been achieved on systems of British design, except for the 5 MHz generation.

The phenomenon of cross-band power transfer under noise-overload conditions, colloquially referred to as *non-linear singing*[17], has dictated that very careful control of the circuit parameters is necessary to provide an acceptable cross-band transfer matrix at the amplifier overload points; alternatively, to avoid the problem, individual amplifiers are used for each transmission band. The former course had to be adopted for the 5 MHz British-type repeater because the development was complete but, for subsequent systems, the 2-amplifier solution has been used. To date, BTL and Japan have retained the single amplifier design, but the design problems are considerable and BTL, at least, are unlikely to continue with a single amplifier design in any future systems. However, individual band amplifiers inevitably increase the repeater power consumption.

Repeater design dictates that

(*a*) the amplifier output stage transistor overload point be set as high as possible, and

(*b*) that the amplifier DC power circuit voltage be kept as low as possible. This is necessary to minimize the serious design problems of the power-separating filter capacitors installed in each repeater. A very high DC cable voltage results from the series connexion of 500–1000 repeaters, each having, say, an applied potential of 15–20 V.

The only way to avoid high DC rail voltages consistent with providing a reasonably high transistor output power, is to increase the output stage transistor collector current, and this is the solution adopted. The resultant line current is 0·5 A which, in turn, implies cable powers of up to 9 kVA.

FAULT LOCALIZATION

The various repeater types developed during the last 2 decades have included many different forms of supervisory circuit (many of them being of the pulse-return type using time-identification) to provide gain, intermodulation and noise level information. With the increase of experience of transistor performance parameters, it has been independently decided by most manufacturers during the last 5 years or so that noise and intermodulation changes, unrelated to amplifier gain change, are unlikely. The practice today is to provide only a discrete supervisory oscillator in each repeater (or for each transmission band) to indicate the performance state of each repeater to the terminal stations.

The universal use of Zener diodes, either to protect the repeater power rail from surges, or to stabilize the power-rail voltage, or both, has created a non-linear repeater DC characteristic of relatively high resistance at low currents which tends to be variable, and this had made fault localization prediction on an unpowered cable by low-current DC test methods unreliable. For this reason, most European telecommunications administrations specify a reasonably-stable DC resistance plateau over a few milliamperes, which usually implies some dilution of the Zener characteristic with shunt resistance (although this unhappily results in an increase of line current), see Fig. 4.

The low-current resistance of the repeater is much greater than that of the associated cable and, hence, the system resistance is characterized with little error by equating it to nR_r, where R_r is the single-repeater low-current resistance and n is the number of repeaters. To attempt to localize a fault to better than one repeater position in these circumstances is therefore unrealistic but, as the deep-water repair technique (referred to later in this article) only attempts a centre-section cut, the actual position of a fault in a section is of no particular significance. Even to achieve this measure of positional accuracy is difficult due to the high test-voltage required to drive, say, 10 mA DC through a de-powered cable system resistance of up to 100 000 Ω. Published information on fault localization theory is sparse, but interested readers are referred to an *JIEE* article by A. L. Storey[18].

The localization of faults on the shallow-water sections, generally no more than 200 nautical miles from the cable terminal, is done to a higher accuracy because, in these depths, ships would normally expect to be able to raise a cable bight

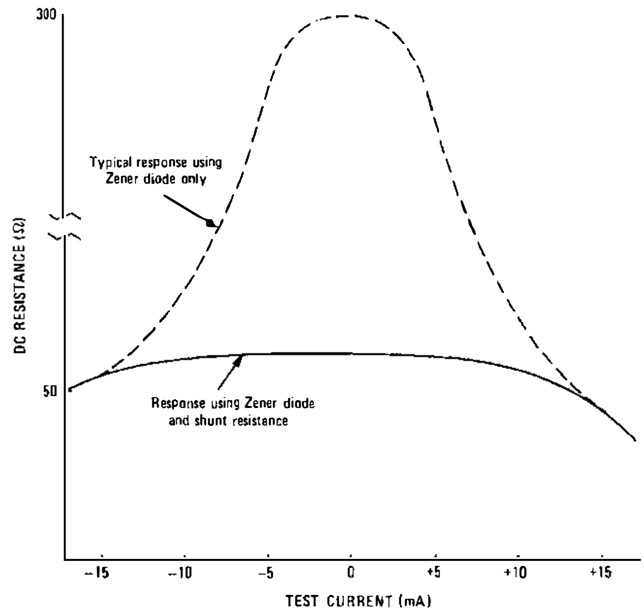


FIG. 4—The effect of the Zener diode on the repeater DC characteristic

to the surface to effect a repair and, hence, errors in location are time consuming. A variety of classical DC tests are possible in this situation. Impedance/frequency localizations are often used for faults that are near to a cable station and increasing use is being made of low-frequency pulse-echo test equipment. For all low-frequency testing, a low impedance path through the repeater at audio frequencies is necessary, and this is made a requirement for systems specified by the BPO and many other administrations. Finally, a ship will usually wish to confirm the localization by the very old technique of electroding; that is, detecting a current at a very-low-frequency (17 or 25 Hz) applied from the terminal and picked-up to the point of the fault as an EMF between 2 electrodes trailed in the sea behind the ship.

THE MENACE OF TRAWLER FISHING TO SUBMARINE SYSTEMS

No review of the submarine cable scene would be complete without a consideration of the problem of cable interruptions caused by trawler fishing; nor should the menace be minimized although, in theory, fishing over cables is forbidden.

With very few exceptions, cables survive indefinitely in deep water (the oceanic abyssal plains are under between 2 and 3 miles of water) due to lack of external interference. But, it is on the shallow continental shelves that most cable interruptions occur. In the last 20 years, the world has grown greedy for fish and trawlers have become larger to meet the demand. But cables have got bigger too, and the degree to which they are armoured has also increased, so the situation could be mistaken for a war between the fishermen and the cable operators. In Europe, the worst culprits by far are the large beam trawlers which work out from Dutch and Belgian ports. Their *tickler chains* virtually rattle the sea bed to make the flat fish rise into their nets, see Fig. 5. Two beams are used, each 10 m in width, one being towed on each side of the trawler at speeds of up to 7 knots, which requires the trawlers to be powered by engines of many thousand horse power.

Another form of fishing of great potential menace is the clam dredger, used considerably off the eastern seaboard of the USA. This resembles a large heavy multi-pronged fork which is used such that the prongs dig into the sea bed to a considerable depth in order to catch the clams.

There is no perfect solution to the problem, but the task is being tackled on 3 fronts. Firstly, the cable can be buried in the sea bed to a depth to which fishing devices are unlikely to penetrate; secondly, the cable can be armoured to such a degree that it is virtually immune to fishing devices; and thirdly, the fishing devices can be constructed in such a way that they ride over cables without mauling (clearly, this cannot be done for the clam dredge).

FIG. 5—The beam trawl

Cable Burial

At present, the burial of cables in the sea bed can be achieved by either of 2 methods:

Use of a Plough Device

A plough may be used to bury a cable in the sea bed during cable-laying operations. It requires a powerful ship to tow the plough, and the ship must have very precise positional control, and the sea bed conditions have to be suitable for moleploughing operations. Given these conditions, burial is more quickly carried out in this manner than by any other. ATT pioneered and perfected burial by this method using a sophisticated plough, which was designed and made by BTL and which is now in its Mark IV stage of evolution. Using these devices, all the transatlantic cables over the North American continental shelf, which includes the famous Newfoundland Banks, have been buried to a nominal 610 mm, as have many cables over the European continental shelf.

The Japanese have also developed, and use, a bury-while-laying device, but BPO staff have not had the opportunity to witness its operation. The main disadvantage to a plough is its inability to bury an existing laid cable.

Use of a Water-Jet Device

A water-jet device is used to bury existing cables. The device liquifies the sea bed under the cable to create a trench into which the cable falls under its own weight. These devices vary considerably in complexity and size and, at present, are adaptations of devices developed to bury oil pipelines in the North Sea. Burial progress is much slower than in the case of the sea-bed moleplough, and more than one attempt is generally necessary to ensure the depth of burial; this method is much more flexible in its utilization than the towed plough and the BPO is very interested in its potential for development to meet specific cable needs, although the development costs are high: the technique is not yet perfected.

Improved Cable Armour

Armour designs have changed very little in more than 100 years. However, recently, trials of variants have been made under pseudo-dynamic conditions at the BPO Research Department in an effort to determine a more trawler-resistant pattern. The work has been funded by a consortium of North Sea cable-owning administrations and has shown that, in general, little improvement is to be gained. Nevertheless, a double layer of armour wire proved very superior to a single layer, and a variant of double armour using a very short lay outer wire shows promise of being very effective against trawler mauls. However, an analysis of North Sea failures indicates that, because large modern cables do not break easily, a number of trawlers are lifting the cable they have fouled to the surface and cutting it with a flame. Up to 25% of failures in recent months appear to have been caused in this way and it is obvious that there is no protection against this quite unlawful activity. Hence, the possibility of re-designing the trawls was attempted.

Re-Design of Fishing Trawls

The re-design of fishing trawls to minimize damage to cable has recently been pioneered by the Netherlands PTT. The BPO Research Department also attempted this many years ago when otter-boards were damaging the North Sea cables, but the time was not then opportune for co-operation and the proposed changes were not adopted. Last year, however, the BPO's Dutch partners to the cable-armour trials decided to re-open discussions with the fishing industry and considerable interest has been shown in their proposals. The beam-trawls have proved comparatively easy to modify to ensure that they ride-over cables without snagging the armour; this work is still proceeding. As long as trawlermen are persuaded to keep their gear in good condition, then development along these lines may be very rewarding.

CABLE HANDLING AT SEA

This is a specialist facet of cable engineering that is the preserve of marine staff, but at the fringe of their experience has to exist an engineering interface, and the subject is introduced here in that context only.

In the broadest terms, the way in which cables are loaded on ships, laid on the sea bed and recovered for repair, have changed little since the early transatlantic telegraph cables of the 1869 era. The vision displayed by those early pioneers is remarkable and it is appropriate to recall the basic concepts they set out as the requirement of their art, and to review in outline the way in which marine and cable engineers today are meeting these same requirements which are:

(*a*) That the only practical way to stow many thousands of kilometres of cable on a ship is to coil it in repeater section lengths in the ship's hold, or *tanks* as they are called. Loading a cable ship therefore implies neither pre-loaded drums nor spools, but that the cable be hauled across from the factory storage tanks and literally coiled in the ship's tanks until the ship is fully stowed: obviously this is a lengthy labour-intensive exercise and must be carried out with extreme care to ensure that no coil in any way ensnares its neighbour.

(*b*) That, at sea, it must be possible to pay out the cable over the stern or the bow of the cable-laying ship, as planned beforehand, in an unrestricted manner and that the ship's structural design ensures that no stanchions or standing ironwork impedes the free-running of the cable in the reverse manner to that in which it was loaded. (The advent of repeaters stowed away from the cable tanks requires the cable to be 'bighted-out' at these points, which has imposed stringent attention to this detail.) This has created the centre-castle requirement for an open space at the tank head, with open access fore and aft which, on the later and larger vessels, gives the impression of a vast arcade.

(*c*) That a cable ship be designed such that cable can be paid out either over the bow sheaves (large rotable drums or wheels), or over the stern sheaves (frequently, no more than a chute). At all times the ship must have complete control over the cable being paid out, whether at the bow or the stern. Not all readers may be aware that cable is driven out of the ship only at the commencement of lay or in very shallow water: at all other times the outboard weight of the cable rapidly increases to many tonnes and pulls itself out of the tanks. This must be restrained or runaway will take place, so the major requirement of a cable engine is its ability to apply sufficient back tension to stop the pay-out of cable, and, if necessary, to revert to the pick-up mode. The bow engine is the most powerful machine on a cable ship; the reason for this is that a ship has the greater potential for manoeuvre if the cable is secured at its bow than at its stern. Hence, 2 powerful drum engines (horizontally-mounted capstans of very large diameter with about 40–50 t lift) are fitted on the foredeck for the variety of manoeuvres which are conducted over the bows, and a third engine is fitted aft for stern pay-out. A century ago, and indeed until the advent of the submerged repeater in the 1950s, the stern engine was also of the drum-type, as this type has the greatest hold-back potential against slip. But it cannot easily be used to pay-out a repeater. For these operations, a linear engine is required; a linear engine can apply a driving force to the cable in either direction, or stop it, in a straight line. Thus, the passage of a long rigid body such as a repeater is not inhibited (as it is by the circular drum engine).

The first stern pay-out engine—albeit not linear—was the 5 V-sheave gear developed by the BPO Research Department[20] in the late 1950s and fitted on CS *Monarch* to lay th CANTAT I and COMPAC, and similar systems. The V-sheave gear worked adequately but repeater launching ha to be carried out at slow speed (1 knot) and with considerabl manual assistance; it would be quite impracticable for use o modern systems with repeaters spaced at 3–5 nautical mil intervals.

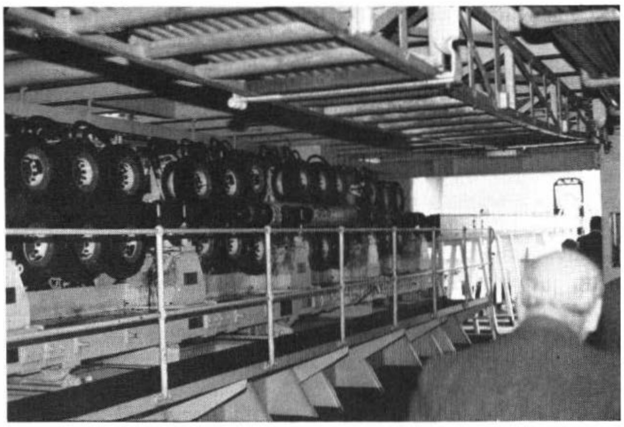


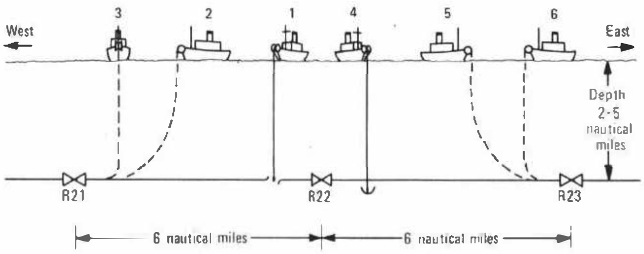
FIG. 6—The BPO linear cable engine

The linear engine avoids these problems because, theoreti cally, it has been designed for pay-out at normal cable speed say 5–7 knots. In practice, it is never used to lay repeaters a that speed—2 to 4 knots is the more common. The reductio in speed is not because of concern by the ship's commande that the engine may snarl up, but for a real concern for th safety of his crew when the leading bight rises out of the cabl tank ahead of the repeater, and then instantaneously snatche at the half-tonne housing to propel it suddenly down th trolleyway along the centre of the ship at pay-out speed.

The first linear engine was developed by BTL[12] for thei SD-type systems and installed on CS *Long Lines*. The engin resembles 2 vertically-opposed caterpillar-type metal articu lated bands some 14 m in length and 900 mm wide, wit compression applied between the 2 moving adjacent faces b hydraulics, such that the gap aperture will adjust itself t accept whatever diameter of cable or repeater is presente to it. It is a monster of a machine, but it has continued t work immaculately for over 15 years. The British approac was quite different: the BPO Research Department develope a machine which they installed on CS *Alert* to lay the UK Spain No. 1 cable in 1970. This comprised a series of car-typ wheels, including rubber tyres, which were installed as 1 vertically-opposed pairs under hydraulic compression (se Fig. 6). Each wheel is powered by an hydraulic motor, whic can drive in either direction. This machine is also still i service and developed variants of it have been fitted on man other cable ships since 1970.

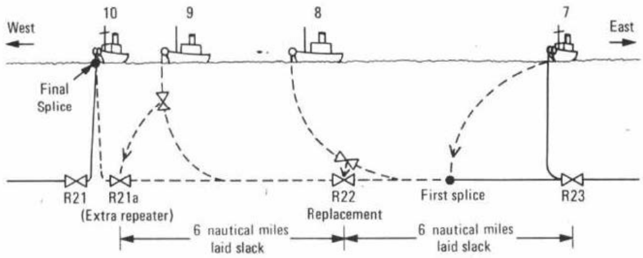
REPAIR TECHNIQUES

The need to repair a cable is, regrettably, inevitable. A shi must therefore carry sufficient types of sea-bed grapnels t enable it to trawl the sea-bed, trap the cable, and bring it t the surface for repair. This facile sentence embraces a host c problems not appropriate to this article but, in the sense c a review of techniques, some significant changes have take place which justify mention. The change of technique reflec to a large extent the fact that repeater spacing is very muc less than it used to be and, as it is impolitic to deliberatel drag or roll the repeaters on the sea-bed if it can be avoide ships set out to effect repairs without disturbing operation repeaters. If this is unavoidable, then disturbed repeaters a generally withdrawn from service for overhaul and replace



1—Ship cuts cable west of repeater R22 and holds cable to the west of repeater R22
2—Ship picks up cable and travels west
3—Ship buoys off at position of repeater R21 and cuts away surplus cable
4—Ship lifts cable to the east of repeater R22 and raises cable and repeater R22
5—Ship picks up cable and travels to the east of repeater R22
6—Ship cuts off surplus cable and repeater R22

(*a*) The recovery process



7—Ship connects 3 nautical miles of cable plus replacement repeater R22, plus a new section of cable, plus repeater R21A and 3 nautical miles of cable
8—Ship sails west, paying out cable with repeater R22 overboard
9—Ship continues towards buoyed cable end and pays-out repeater R21A
10—Ship recovers buoy and cable to repeater R21, joints to cable from repeater R21A and drops bight

(*b*) The replacement (pay-out) process

FIG. 7—Repair sequence in 2500 fathoms to replace faulty repeater R22

with new repeaters.

Some 20 years ago, when the deep-water laying strategy for repeatered systems was being evolved, it was decided to lay 6% slack cable, that is, 6% more cable than that demanded by the distance between 2 geographical points. This was chiefly to permit a cable section length of 27 nautical miles to be brought to the surface for repair by a cable ship, but it also reflected imprecise navigation (before modern radio navigational aids became available[19]), which dictated a measure of positional tolerance. In the last decade, ships' positional accuracy has become much more precise and, at the same time, the spacing between repeaters has become much smaller so that, the percentage slack which would be necessary to lift a bight to the surface from oceanic depths without considerable disturbance to the submerged repeaters has become too large. Hence, with the advent of the CANTAT 2 cable[19], laid in 1973, it was decided to lay only sufficient slack to fill the sea-bed contours and, with repeaters spaced at 6 nautical miles in up to 3 nautical miles depth of water, to plan to cut the cable on the sea-bed in the event of a failure.

To make a repair, a planned sequence was organized whereby, say, 1 repeater would be recovered and 2 reinserted, with an appropriate addition of 6 nautical miles of spare cable to maintain the correct system transmission levels. A description of the detail of this operation would be inappropriate here, although Fig. 7 outlines the principle, but it has been included to identify the need, recognized at that time, for a new grapnel that would cut and hold one of the cut sides without dragging the cable to any extent across the sea-bed. The earlier cutting grapnels cut the cable over a

FIG. 8—The cut-and-hold grapnel

sharp edge at forces near the breaking strain of the cable, which inevitably disturbed the cable for considerable distances.

The basics of such a repair policy were agreed also with ATT for the TAT 6 project and some common ground was established for the design of the new grapnels.

The BPO Research Department produced a cutting grapnel and a cut-and-hold grapnel[21]; the grapnels are powered by hydraulic action, locally-triggered, to sever unarmoured cables up to 43 mm diameter and, in the case of the cut-and-hold grapnel, to coil one cut side round a mandrel to secure it to the grapnel. These grapnels are inevitably large precision tools (see Fig. 8), and are expensive, but they have been successful on trials: fortunately there have been no deep-water faults to prove them operationally. These grapnels would not normally be part of a ship's permanent equipment. For the more usual class of faults, which are more likely in shallow water, where a bight can usually be brought to the surface without cutting the cable, ships still carry the traditional grapnels; for example, those known as the *Rennie*, the *Gifford*, the *flatfish*, the *spearpoint* and the *multi-pronged sand* grapnels. These grapnels have evolved over a century's experience and, apart from modifications which reflect the larger cable sizes now in normal use, they have remained remarkably similar to those used in the telegraph-cable era.

THE WAY AHEAD

The introduction to this article posed the question as to whether or not the submarine cable had a future. It would be hard to foresee, in 1979, a future without the submarine cable. As any manufacturer of submarine systems is only too well aware, the growth market is not steady: it never has been. Nevertheless, the BPO and its continental European partners have already placed contracts for 3 further very-high-capacity cables to Europe; the cables are scheduled to be completed before 1981.

The prospect of a further transatlantic cable of at least 4000 circuits now appears to be probable for 1983. Further development in the Mediterranean is both projected and mooted, as is an increase of cable potential from Europe to South America, and there is considerable scope for further expansion in the far East, from India to the Pacific basin, even down to the Antipodes. The only serious competitor to the submarine cable is the satellite: however, both media have their relative advantages and disadvantages, and most of the world's telecommunications administrations now concede that they are complementary media and neither one nor the other is likely to form the total basis of most countries' external communications services.

Between now and, say 1985–1990, the submarine cable industry has to reorient its designs to digital working to meet the increasing demand for coded traffic and digital switching. It is probable that each of the worlds' manufacturers have by now decided that digital transmission on optical fibres offers the greatest degree of development potential for cheaper circuits and planning flexibility, and are actively researching designs which can be viable over transoceanic distances by about 1990—certainly this is so in the UK. One of the big problems which has yet to be solved is the development of a laser-detector combination that will work reliably for many years at a wavelength of between 1·2–1·5 μm. The problem will be solved somewhere in the world—hopefully in the UK.

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Installation of an Auto-Manual Centre in Non-Standard Premises

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Early in 1976, a decision was taken to clear floor space in the existing exchange building at Chester to overcome problems likely to arise as a result of exceptional difficulties and delay with the Chester Central building extension. By re-siting the auto-manual centre (AMC) this objective could be achieved, and by using Cordless Switchboard System No. 1 (CSS1), with its less demanding needs for floor strength, it was hoped that suitable existing accommodation could be acquired to enable early completion of the changeover from the existing switchboard to the CSS1 installation.

Several properties in Chester city centre were examined, and the most suitable to meet all the constraints imposed by the project, and which was available for purchase, was the Ursuline Convent situated opposite the existing automatic exchange. At the time the project was conceived, the Convent was still in operation as a school, and indeed continued to function as such during the initial stages of modifying the building. Purchase of the property was put in hand and it was decided to call the new establishment Chester Dee House.

The design and installation of a CSS1 AMC of the size required had, in all previous cases, been carried out by contractors with a programme usually anticipating an overall period of 3 years for planning and installation. At the outset, a target completion date of October 1977 was established, and it was decided that all the planning and installation would be done by the British Post Office (BPO), making this the first CSS1 installation in the country to be carried out in this fashion.

Equipment designs were commenced and enquiries made of Regional Headquarters and Telecommunications Headquarters to establish the availability of equipment. As there was a marked decline in operator-controlled calls nationally at that time, it was thought that surplus equipment would be readily available, but, while this was the case for the bulk requirements, it was not so when it came to items of detail.

† Chester Telephone Area

Eventually, equipment was located and released from Leeds, Maidenhead, Portsmouth and Hereford. Once the equipment had been located, transportation was arranged and the equipment was brought into the Area and stored at Buckley Exchange, where the racks were erected and renovation carried out, while the Convent accommodation was being refurbished. An inventory of the equipment was made and checked against the design details and a list of the shortages was drawn up. The only way of making good the missing items of equipment was by means of a contract, and this was let for 554 relay-sets and 3 racks against promised delivery dates of June 1977.

During the time in which the equipment was being located, negotiations for the purchase of the Convent were being conducted and the building was finally acquired in October 1976. As the original part of the building dates back to 1743, with a final extension added to the school in 1960, extensive alterations were required to bring the property up to BPO standards. Full plans of the building were non-existent, and the local drawing office produced outline drawings from which layout drawings for the new accommodation were agreed. In general terms, the more recent additions to the building were used for the AMC and associated equipment, with canteen and welfare accommodation situated in the older parts of the building.

On 1 November 1976, a planning team moved into Dee House among the dust and rubble of the alterations. As this was the first CSS1 installation in the Area and as the building was non-standard, everything dealt with by the team presented novel and probably unique problems. Two members of the team attended a CSS1 training course, and familiarization visits were made to Crewe (Queen Street) which was the nearest working CSSl to Chester.

The apparatus room was to be established on the ground floor in the old gymnasium, with the switchroom on the first floor directly above in an old classroom area. The art room was to become the directory enquiry room with direct access to the switchroom via a short staircase. Batteries, power equipment and standby engine were to be housed in the converted cloakrooms alongside the old gymnasium on the ground floor. Floor layouts already worked out had to be checked constantly on site as the building contractor carried out the alterations. The power Planning & Works team was called upon to work on a day-to-day basis in order to keep one step ahead of the builders.

The building work was planned for execution in two stages. Stage 1 comprised the apparatus room, power room, switchroom, directory enquiry room and construction workshop and was scheduled for completion by the end of December 1976; stage 2 comprised the canteen and welfare accommodation, which was to follow at a convenient time. On 4 January 1977, the construction staff moved in. Staff had been drawn from all parts of the area to supplement staff normally headquartered in Chester. The task presented was to spend an estimated 22 000 manhours in Dee House with a further 6000 manhours at Chester Central telephone exchange in a period of 40 weeks. In total, the installation comprised 48 equipment racks, 1500 relay-sets, 34 CSSl positions, 14 directory enquiry positions, 1 Chief Supervisor's desk, 1 Supervisor's desk and 4 Assistant Supervisors' desks, plus the associated power plant.

A new 20-vertical intermediate distribution frame (IDF) was fitted in the apparatus room and all cross connexions were carried out on this frame. One 160-pair and four 320-pair distribution cables were run between the IDF and the external cables, which had been brought into the old laundry room. The external cables and their routing had also caused problems. The number of circuits required and the technical requirements to keep the transmission losses between the telephone exchange and Dee House to a minimum (not more than 0·5 dB attenuation was to be added to any call extended via the new AMC) indicated that two 748-pair (748/0·63) cables would be needed. Each of these cables was to occupy one duct, and a third duct was to be used for cables serving the internal telephones in the building, while a spare duct was provided to allow for any unforeseen developments in the future. The most direct route for the ducts from the telephone exchange into Dee House was under the front drive of the property from a manhole existing in the roadway immediately outside. Wayleaves for duct on the public highway were applied for, and the Department of the Environment was informed, as the proposed route was very close to a Roman amphitheatre. A subsequent survey of the site carried out by the Inspectorate of Ancient Monuments showed that, unfortunately, the proposed route would cross the perimeter of the still buried section of the amphitheatre. The BPO was asked to seek an alternative route to avoid disturbing the archaeological layers of the ancient monument, which would eventually be excavated for display to the public. The only alternative route available was via a lane at the side of the property. This route presented other problems: the lane would have to be closed to vehicular traffic throughout the period required for duct laying and cabling operations; and the old laundry room, which was to become the new cable chamber, was situated about 6 m above the lane, which would necessitate a vertical lead-in. The first problem was overcome by co-operation with the Local Authority, which requested that the work be done before the Easter holiday, as the lane provides the main access to the banks of the River Dee—a favourite attraction for the many visitors to Chester. The duct contract was let and executed between January and the end of March 1977. The second problem was overcome by cutting a chase in the brickwork of the boundary wall and fixing four Ducts No. 57 into the chase. A hole was made into the old laundry room and a weather shield and hardwood seal were fitted to the riser. Cabling operations began on the night of 21 May 1977 and were completed by the following day. Jointing work and proving of cables was completed by July 1977.

Internal construction work was progressing simultaneously with the external operations and in the first three weeks the racks and all the ironwork were erected. After many trials and tribulations, the CSSl positions were assembled (without the use of a jig) by the end of the fifth week. Cabling and modification started in Week 4 and continued until Week 18. The total length of cable used exceeded 21 000 m.

The power staff provided, in addition to all the accommodation wiring, battery, engine and power plant to enable temporary power to become available which permitted acceptance testing to start in the nineteenth week.

Early in May 1977, it was learned that the equipment being obtained by contract, and other crucial items being made by BPO Factories Department, would not be available by promised dates. As this delay would have seriously affected the testing programme, further enquiries were made and equipment was located at Irvine (Scotland West Telephone Area). With the help and close co-operation of our Scottish colleagues, the necessary missing pieces of equipment were loaned to the Chester Area. Testing continued and, in addition to faults, some design problems were found and overcome. Due to problems beyond our control, the original target opening date of October 1977 was not met but operator training started in January 1978 and the AMC was scheduled to open in February 1978. Alas, this date was not achieved because of industrial action and the centre opened in February 1979.

The project was both interesting and challenging. It produced many challenges which had to be overcome. That they were overcome was due to the enthusiasm shown by all concerned and the unstinting help and co-operation obtained from many people outside the Telephone Area, to whom our thanks are extended.

Jitter Specification in a Digital Network

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Jitter is an inherent impairment in digital systems which was first observed as telegraph distortion in long-distance telegraph circuits. The subject has been studied extensively in the last 20 years as pulse-code-modulation systems have evolved, but it is only recently that a consistent approach to the specification and measurements of jitter has emerged through agreements within CEPT and CCITT††. This article briefly reviews the causes and effects of jitter in a digital network and explains the approach to its specification.*

INTRODUCTION

The formal definition of jitter[1] is: "short-term variations of the significant instants of a digital signal from their ideal positions in time". What exactly constitutes a significant instant depends on the operation of the circuitry involved, but it can be any convenient identifiable point on a digital signal; for example, the time at which the leading edge of a pulse reaches a defined amplitude. It is often convenient to consider jitter as a form of phase modulation of a digital signal, particularly when the signal concerned is a clock or a timing signal within an item of equipment. In this way, the jitter can be considered in isolation from the digital signal, and its waveform, spectrum and statistical properties calculated.

The units in which jitter is specified are largely a matter of convenience, and its amplitude is frequently expressed in units of time, phase or digit periods. A digit period, commonly referred to as a *unit interval* (UI), is the nominal time allowed for the transmission of one symbol and, hence, is numerically equal to the reciprocal of the symbol rate. For example, an instantaneous jitter amplitude of 0·01 ms on a 1 kHz timing signal is equivalent to a jitter amplitude of 3·6° or 0·01 UI.

SOURCES OF JITTER

Noise Induced Jitter

All types of oscillator have a certain amount of phase noise inherently present on their output signal which is caused by noise sources within the circuit. Since the amplitude of most of the noise in these circuits is proportional to the reciprocal of frequency, f, (that is, it has a $1/f$ characteristic), the jitter produced also has a spectrum of increasing amplitude at low frequencies. In addition, noise in logic circuits can generate jitter on signal transitions because of the finite rise-times of practical pulses (see Fig. 1). Jitter from both these sources is therefore present at the output of a digital equipment; although such jitter may be measurable, it is generally of minor importance because of its low amplitude and low frequency in comparison with other sources.

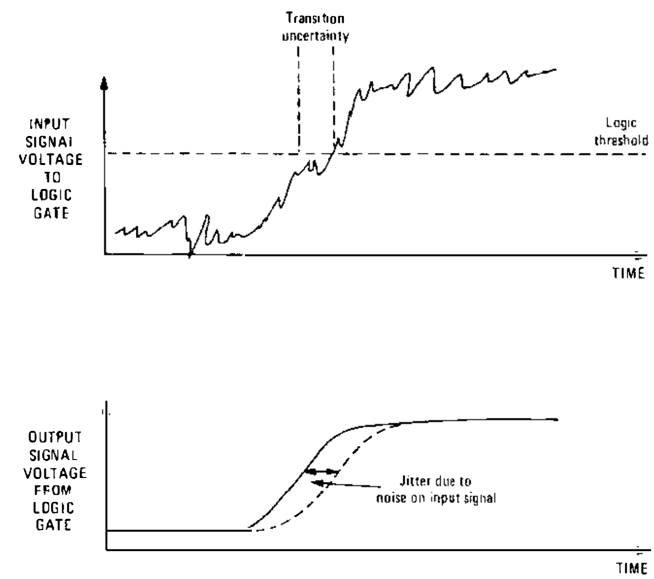

FIG. 1—Jitter due to noise on logic signal

Jitter Produced by Digital Regenerators

Most digital repeaters currently in use are fully regenerative and self-timed; that is, the output signal is retimed under the control of a timing signal derived from the incoming signal. Although such regenerators do produce jitter having random noise type characteristics, as described above, the most significant form of jitter arises from imperfections in the circuitry, which cause jitter that is dependent on the sequence of pulses in the digital signal being transmitted, termed *pattern-dependent jitter*. The mechanisms that generate jitter within a regenerator have been extensively studied[2, 3, 4, 5, 6], and are principally related to imperfections in the timing-recovery circuit.

Mistuning of the timing-recovery tuned-circuit (for example, due to ageing or incorrect initial adjustment), and use of a tuned circuit having a lower design value for its Q-factor can both lead to an increase in the jitter generated. This is illustrated in Fig. 2, which demonstrates that, although a tuned circuit with a high Q-factor generates less jitter under ideal conditions, a tighter tolerance on the mistuning is required.

Since pattern-dependent jitter from regenerated sections is the dominant type of jitter in a network, the manner in which it accumulates must be considered. For jitter purposes, a regenerative repeater acts as a low-pass filter to the jitter present on the input signal (see Appendix), but it also generates jitter, which can be represented by an additional jitter source at the input. If this added jitter were truly random, as distinct from pattern dependent, then the total RMS jitter, J_N,

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* CEPT—European Conference of Posts and Telecommunications

†† CCITT—International Telegraph and Telephone Consultative Committee

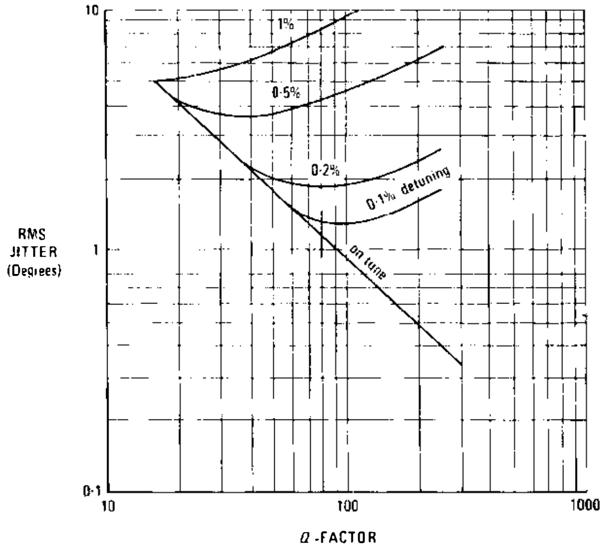

FIG. 2—Effect on jitter of Q-factor and tuning accuracy of timing-recovery tuned circuit

present on the digital signal after N regenerators[2] would be given by the approximate relationship:

$$J_N \approx J_1 \times \sqrt[4]{N}, \qquad \ldots\ldots(1)$$

where J_1 is the RMS jitter from a single regenerator.

However, most of the jitter added is pattern dependent and, since the pattern is the same at each regenerator, it can be assumed that the same jitter is added at each regenerator in a chain of similar regenerators. In this case, it can be shown that the low-frequency components of the jitter add linearly, whereas the higher-frequency components are increasingly attenuated by the low-pass filtering effect of successive regenerators. If a random signal is being transmitted, the spectrum of the resultant jitter is as shown in Fig. 3, and the change in mean-squared amplitude with the number of regenerators is as shown in Fig. 4. The latter curve is approximately described by the equation:

$$J_N = J_1 \times \sqrt{2N}, \text{ for large values of } N. \ \ldots\ldots(2)$$

Equations (1) and (2) demonstrate 2 important results:

(*a*) pattern-dependent jitter accumulates more rapidly than non-pattern-dependent jitter, as the number of regenerators is increased, and

(*b*) the amplitude of jitter produced by a chain of regenerators increases without limit, as the number of regenerators is increased.

The jitter produced by a random pattern is itself random in nature, having a gaussian amplitude distribution. Hence, for a given RMS amplitude (standard deviation), the probability of exceeding any chosen peak-to-peak amplitude can be calculated. A peak-to-peak to RMS ratio of 15 is often assumed for specification purposes, which has a probability of being exceeded of less than 10^{-13}.

In contrast, when the signal being transmitted is composed of 2 repetitive patterns, alternating at low frequency, the jitter appears as a low-frequency repetitive wave, having an amplitude proportional to the number of regenerators[2,7]; this could lead to very large amplitudes of jitter. This situation is very unlikely to arise in normal operation because the signal transmitted is generally made up of traffic from a number of different sources, together with a frame-alignment signal and justification control digits. Furthermore, the probability of fixed patterns occurring can be reduced still further by the use of digital scramblers, which tend to randomize the signal; if necessary, devices that are capable of reducing jitter can also be used.

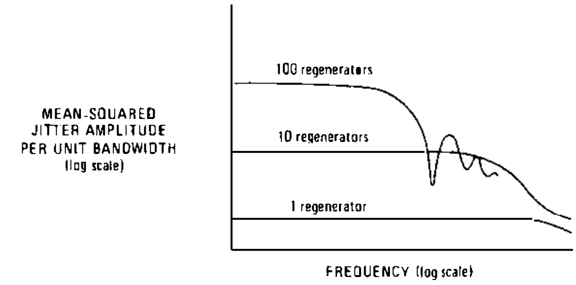

FIG. 3—Spectrum of jitter produced by digital line sections transmitting a random pattern

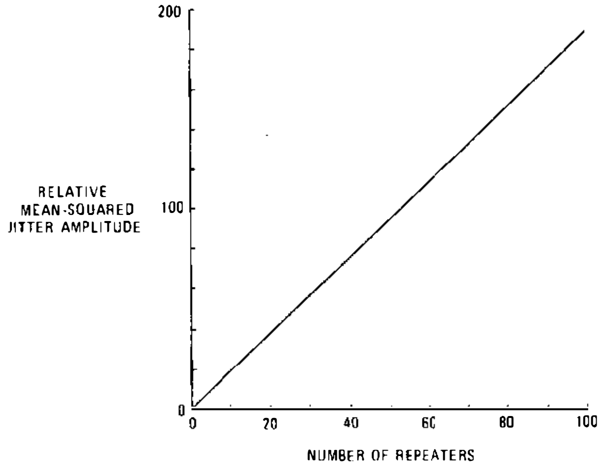

FIG. 4—Variation in mean-squared jitter amplitude with number of regenerators

Jitter due to Multiplexing and Demultiplexing

The digital muldexes† recommended by CEPT and CCITT, and based on the 2·048 Mbit/s first-order digit rate, permit the multiplexing of plesiochronous* signals by the process known as *positive justification*[8].

The multiplexer first brings the plesiochronous input tributaries to a common digit rate and timing relationship by the controlled addition of justification (or stuffing) digits. The synchronized tributary signals are digit interleaved, and justification control digits and a frame-alignment signal are added, to produce the aggregate output signal.

In the demultiplexer, the added digits are removed and the resultant digital signal, with gaps, is written into the tributary store. If this signal were used directly as the output of the demultiplexer, the gaps would represent very severe jitter. Therefore, the jitter is largely removed by reading the signal out of the store under the control of a timing signal, the gaps having been smoothed out by a phase-locked loop, which acts as a narrow-band low-pass filter to the jitter.

The jitter produced by the demultiplexing operation comprises fairly high, fixed-frequency components due to the routine removal of the frame-alignment signal and justification control digits, and a variable low-frequency component because justification takes place only at pre-determined instants, termed *waiting-time jitter*. After attenuation by the phase-locked loop, the only significant jitter remaining is from the latter component; this typically has a residual worst-case amplitude of approximately 0·2 UI peak-to-peak,

† Muldex—A contraction of digital multiplexer-demultiplexer
* Plesiochronous—Two signals are plesiochronous if their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits

in a bandwidth up to about 100 Hz, depending on the particular demultiplexer.

Other Sources of Jitter

Digital switches may be expected to produce noise-induced output jitter having a negligibly low amplitude. In addition, where digital switches are operating under the control of clocks that are synchronized, the synchronization system may make adjustments to clock phase at an exchange from time to time, resulting in jitter. However, the frequency of such jitter can be kept sufficiently low such that it has no detrimental effect on the operation of transmission equipment.

Finally, one effect of temperature variation on cables is to change the propagation delay; the resultant phase change may be of the order of some tens of unit intervals peak-to-peak over the course of a year. Clearly, the frequency of such jitter is extremely low, and the effect is more properly considered as one of drift or wander. Although no low-frequency limit has been formally set to mark the boundary between what is considered to be wander and jitter, a frequency of the order of 0·01 Hz has been proposed. It is certainly the case that transmission equipments, such as digital line sections and muldexes, are effectively transparent to these very low-frequency changes in phase.

EFFECT ON ANALOGUE SERVICES

Many of the services that will be carried on a digital network are analogue in origin; for example, telephony, sound-programme and television. Any jitter present on the input to digital/analogue converters displaces the analogue signal samples from their ideal position in time, which leads to distortion or noise on the reconstructed analogue signal. If the jitter were a sine-wave phase-modulation of a carrier, it would create additional sidebands in the baseband spectrum, spaced at integral multiples of the jitter frequency either side of the carrier frequency. Analysis of the magnitude of the impairment is complex for the jitter and signal waveforms likely to be encountered, but is considered in more detail in References 3, 9, 10 and 11, from which the results quoted below are taken.

For telephony signals encoded by pulse-code modulation (PCM), the distortion produced by jitter is somewhat analogous to quantizing distortion in that it does not give rise to idle-channel noise, but is present only when a signal is present. Assuming that a signal-to-distortion ratio of 33 dB is acceptable, this leads to a permissible jitter of 1·4 μs RMS[9] (≈3 UI RMS at 2·048 Mbit/s).

In the case of digitally-encoded frequency-division-multiplex (FDM) assemblies, jitter is more troublesome, because a signal in one channel affected by jitter components at frequencies higher than 2 kHz produces noise in adjacent channels. For jitter components having frequencies much less than 2 kHz, a higher amplitude of jitter is permissible, but no firm value has been established.

The subjective effects of jitter on the quality of broadcast-standard sound-programme and television signals have been investigated by the BBC[10, 11]. For sound-programme signals, jitter amplitudes up to 50 ns RMS could be acceptable when the jitter has a random white-noise spectrum from 30 Hz to 16 kHz, with a $\sqrt{2}$ increase in jitter amplitude permissible for every halving of the upper-limit frequency of the jitter spectrum. For colour television, a limit of 5 ns peak-to-peak has been proposed for random jitter.

The above figures should all be considered as indicating orders of magnitude only since, to establish firm performance limits for the effects of jitter on services, it is necessary to take account of the coding scheme and digit rate used by the services. Where it can be shown that the jitter generated in a network could produce unacceptable degradations in performance for a particular service, it is advisable to incorporate a jitter reducer as an integral part of the terminal equipment of that service. The remainder of this article is concerned with the performance of equipments whose inputs and outputs are digital signals in which the effects of jitter are considered independently of the various services that may be transmitted.

JITTER TOLERANCE OF EQUIPMENTS

Timing-Recovery and Decision Circuit Tolerance

To determine the tolerance of equipments to jitter at their input, it is necessary to consider the effects that jitter has on circuit operation. The operations that are performed on the signal at the input to an equipment are, typically, amplification, equalization, timing recovery and decision making, as shown in Fig. 5. In the decision circuit, the digital signal is sampled at an instant determined by the timing signal and the decision is made as to the logic level. These operations are applicable to all types of equipment—regenerator, line terminal equipment, multiplex equipment and digital switch.

Fig. 6 shows the relative timing of the *clock* and *data* signals at the input to the D-type bistable element (decision circuit), where it is assumed that, ideally, the rising edge of the *clock* pulse should occur at the mid-point of the *data* pulse. With ideal full-width rectangular *data* pulses and perfect *clock* pulses, the permissible misalignment between them would be ±0·5 UI. In practice, circuit imperfections, and the need to allow for other impairments such as noise, reduce the permissible misalignment to the order of ±0·15 UI or less.

The most significant feature of the operation of this type of

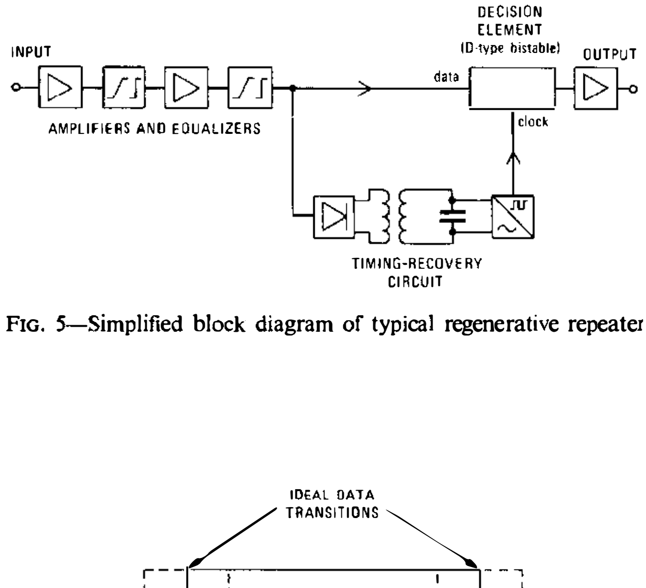

FIG. 5—Simplified block diagram of typical regenerative repeater

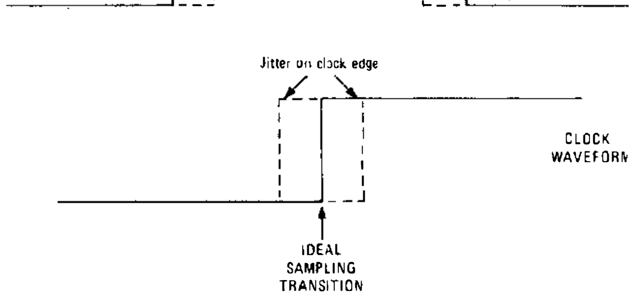

FIG. 6—Jitter on inputs to D-type bistable element

circuit is that it is not the absolute magnitude of the jitter on the *data* signal that determines whether or not errors occur; rather, it is the difference between the jitter on the *clock* signal and the *data* signal, which is referred to as *alignment jitter*. If it is assumed that the jitter on the incoming *data* signal has a spectrum given by $G(\omega)$, then the *clock* signal, and hence the signal passed on to succeeding parts of the equipment has a spectrum given by

$$C(\omega) = G(\omega)\, H(\omega),$$

where $H(\omega)$ is the jitter transfer function of the timing-recovery circuit.

The simple bandpass type of timing-recovery circuit commonly used behaves as a low-pass filter on the jitter spectrum (see Appendix).

The spectrum of the alignment jitter, $A(\omega)$, is given by

$$\begin{aligned} A(\omega) &= G(\omega) - C(\omega), \\ &= G(\omega)\{1 - H(\omega)\}. \end{aligned} \qquad \ldots\ldots(3)$$

The RMS value of the alignment jitter is given by

$$J_{\mathrm{RMS}} = \sqrt{\int_0^\infty |A(\omega)|^2 \mathrm{d}\omega}. \qquad \ldots\ldots(4)$$

Assuming sinusoidal jitter, a tolerance curve can be drawn; that is, the amplitude and frequency of a sinusoidal jitter component that would be just sufficient to cause errors when present on the input signal to an equipment. The shape of the curve can be inferred from equation (3). Assuming the peak-to-peak alignment jitter that is just sufficient to cause errors has an amplitude A then, when the frequency of the input jitter is high, $H(\omega)$ tends to 0 and the permissible amplitude of the sinusoidal input jitter tends to A. As the frequency decreases, $H(\omega)$ tends to 1, and the permissible amplitude of the input jitter becomes many times A. This characteristic is illustrated in Fig. 7(*a*). The frequency f of the break point corresponds to the half-bandwidth between 3 dB points of the timing-recovery circuit, and is given by

$$f = \frac{f_m}{2Q},$$

where f_m is the digit rate of the signal, and Q is the quality factor of the timing-recovery circuit.

In a simple regenerative repeater, the output of the decision circuit may be followed by amplification and equalization, but there are no subsequent operations that change the jitter tolerance from that shown in Fig. 7(*a*).

Equipments Incorporating Buffer Storage

In some types of equipment (for example, jitter reducers and multiplex equipments) the simple D-type decision element is replaced by a buffer store; data is written into the store under the control of the recovered timing signal, but read out of the store under the control of a different timing signal. In a jitter reducer, the *read* timing signal is obtained by passing the *write* (jittered) timing signal through a narrow-band phase-locked loop, which severely attenuates jitter components outside the passband of the phase-locked loop, thus performing jitter reduction. In a multiplexer, the *read* timing signal is derived by division from the timing signal that establishes the rate of the multiplexer output signal.

In these cases the tolerance to misalignment between *write* timing signals and data at the input to the buffer store indicates that the input jitter tolerance characterized by Fig. 7(*a*) still applies over a certain range of frequencies and amplitudes

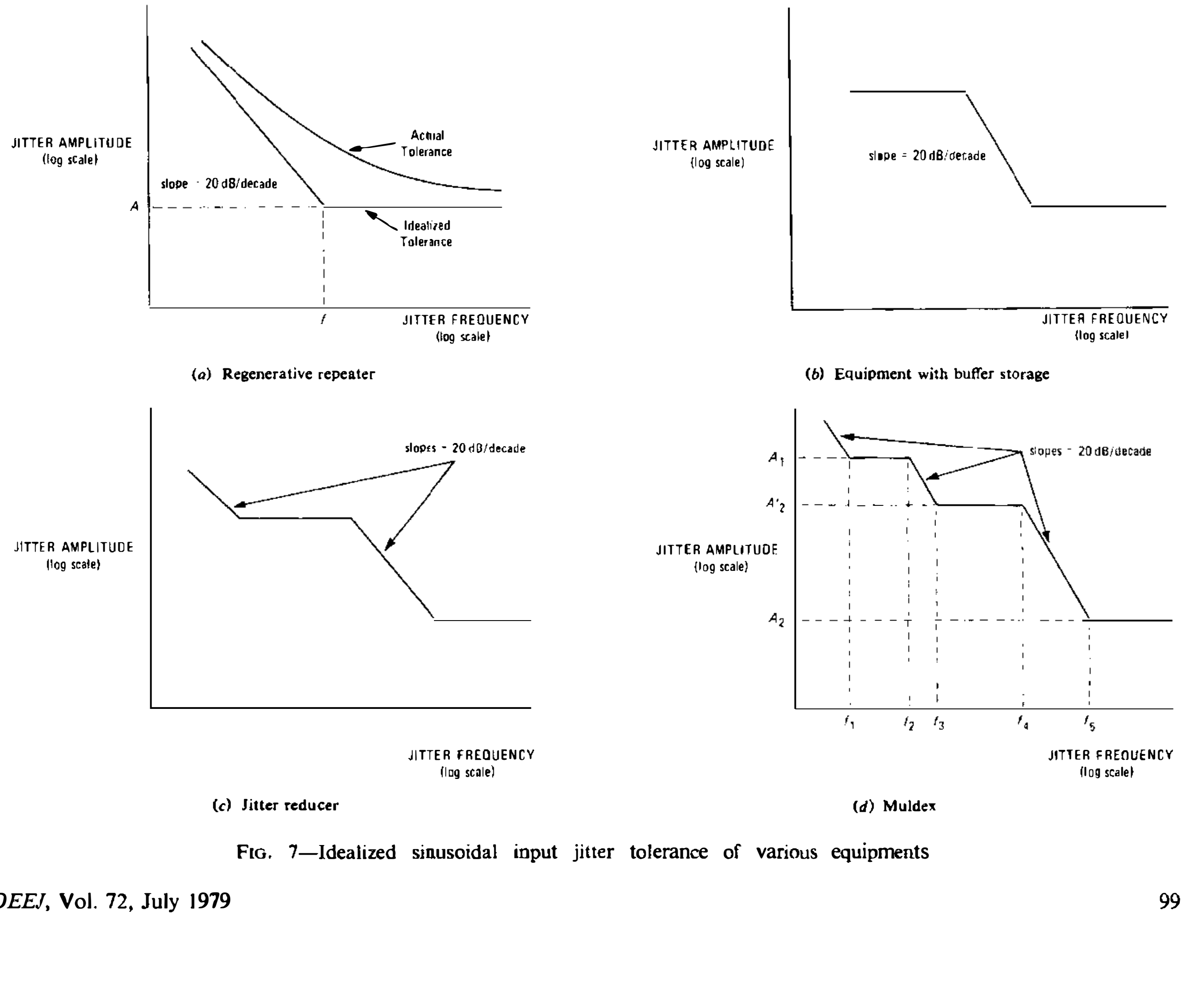

FIG. 7—Idealized sinusoidal input jitter tolerance of various equipments

There is, however, an additional constraint on input jitter tolerance arising from misalignment between the *write* and *read* timing signals. When the misalignment between these timing signals exceeds the available capacity in the buffer store, the store overflows (or underflows), resulting in some digits being irretrievably lost (or, if the store underflows, some digits being repeated in the output signal). It is important that this type of misoperation, known as ***uncontrolled slip***, be avoided, because it can generate many errors by causing succeeding demultiplex equipments or digital switches to lose alignment. Instead of increasing indefinitely with reducing frequency, the tolerance of such equipments to sinusoidal input jitter is truncated at an amplitude corresponding to the available buffer storage capacity, as shown in Fig. 7(*b*).

In a jitter reducer, this flat portion of the jitter-tolerance characteristic continues down to a frequency corresponding to the bandwidth of the phase-locked loop. Jitter frequencies within the passband are only slightly attenuated, thereby reducing the misalignment between *write* and *read* timing signals, which leads to the complete sinusoidal input jitter tolerance characteristic of Fig. 7(*c*).

The complete characteristic for a multiplexer and demultiplexer, connected back-to-back, is shown in Fig. 7(*d*). The increasing tolerance at frequencies below f_3 arises from the justification process, which permits jitter at sufficiently low frequencies to be passed on to the demultiplexer, where it is accommodated in the tributary store. The plateau at amplitude A_1 corresponds to the amount of excess storage available in the demultiplexer, and the tolerance increases again at frequencies below f_1, when jitter frequencies fall within the passband of the demultiplexer phase-locked loop.

SPECIFICATION METHODS FOR INPUT AND OUTPUT JITTER

To ensure full interconnexion compatibility between all the equipments forming a digital network, it is necessary to ensure that the output jitter at any interface in a digital path does not exceed the jitter that is tolerable at the input of the succeeding equipment. This has led to the definition of a performance standard for the minimum value of tolerance to input jitter that can be applied to all equipments. Likewise, a specification for maximum permissible output jitter at any interface has been defined to ensure compatibility with the above specification of input jitter tolerance.

Input Jitter Tolerance

The specification of input jitter tolerance is based on testing with sinusoidal input jitter and has the general form shown by the continuous line in Fig. 8. Agreement has been reached within CEPT for the specification parameters at the CCITT recommended digit rates of 2·048 Mbit/s, 8·448 Mbit/s, 34·368 Mbit/s and 139·264 Mbit/s. Using a defined input test signal, the amplitudes and frequencies of sinusoidal jitter that are just sufficient to cause misoperation of the equipment determine the maximum tolerable input jitter and should lie above the curve in Fig. 8. The specified curve is thus the *lower limit of maximum tolerable input jitter*.

The sinusoidal jitter used for test purposes does not simulate the noise-like jitter that is generated within the network, but it does provide information regarding peak-to-peak alignment jitter tolerance (A_2), timing-recovery circuit bandwidth (f_3) and buffer storage capacity, if any, (A_1).

The characteristic illustrated by the solid line in Fig. 8 is still considered incomplete, because no internationally agreed specification exists for tolerance to jitter frequencies below f_1. Proposals have been made for a tolerance increasing at 20 dB/decade from a frequency less than or equal to f_1, as shown by the dotted line in Fig. 8. Although equipments currently envisaged do possess such a tolerance, the need to

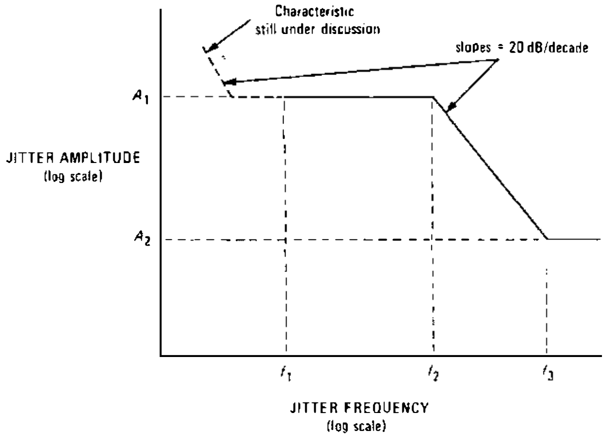

FIG. 8—Lower limit of maximum tolerable input jitter

specify this is still being discussed.

Maximum Permissible Output Jitter

The agreed method of specifying and measuring output jitter permits tests to be carried out on jitter waveforms actually generated in the network, even though the input jitter tolerance is established using jitter having only one frequency component present at a time.

Equation (3) demonstrates that, if the jitter present on the input to an equipment, $G(\omega)$, is passed through a filter having a transfer characteristic $1-H(\omega)$, then the output of the filter is equivalent to the alignment jitter that would be present in an equipment having a timing-recovery circuit whose transfer function is $H(\omega)$. When $H(\omega)$ is the transfer function of a low-pass filter having a cut-off frequency f, $1-H(\omega)$ is that of a high-pass filter with a cut-off frequency at f.

Applying this result to the input jitter tolerance characteristic of Fig. 8 where the output jitter from an equipment is filtered by a high-pass filter having a cut-off frequency f_3, the output jitter from the equipment under test will not cause errors at the decision circuit of the subsequent equipment, provided that the peak-to-peak jitter at the output of the filter is less than A_2. Similarly, if the output jitter is filtered by a band-pass filter having cut-off frequencies f_1 and f_3, the resultant jitter amplitude must be less than A_1 to ensure that the subsequent equipment does not misoperate.

This method of measuring output jitter in 2 frequency bands forms the basis for the specification of maximum permissible output jitter.

DISCUSSION

In the context of this article, the values agreed internationally for input jitter tolerance and maximum permissible output jitter are of lesser importance than the specification method. The choice of cut-off frequencies depends to a large extent on the Q-factors of timing-recovery circuits used within equipments. At digit rates of 8·448 Mbit/s and above, the choice has been based on the use of high Q-factor (>1000) timing-recovery circuits while, at 2·048 Mbit/s, low Q-factor (<100) timing-recovery circuits have been assumed.

Some compromise is necessary when establishing the jitter amplitude A_1 in Fig. 8. This is because pattern-dependent jitter from digital line sections can increase without limit as the number of regenerators is increased whereas, except at low frequencies, equipments such as muldexes have an upper limit to the amplitude of jitter that can be accommodated which is determined by the size of the buffer stores. Measurements show that peak-to-peak jitter amplitudes in excess of several unit intervals are possible from digital line sections having more than 100 regenerators. The value of A_1 has been fixed at 1·5 UI peak-to-peak for digit rates from 2·048 Mbit/s to 139·264 Mbit/s; this is believed to represent a reasonable compromise between the lengths of digital line section that are likely to occur, the size of buffer stores in equipments, and the additional cost of providing jitter reducers where these are shown to be necessary. For the more complex higher rate digital line sections, however, jitter reducers can be incorporated in line terminal equipments with little or no cost penalty.

The fixing of limits for tolerable input jitter and maximum permissible output jitter does not complete the discussion of jitter. In particular, limits must be established for the output jitter and jitter transfer characteristics of individual equipments. This requires further consideration of the accumulation of jitter within networks, taking account of the inherent jitter-reducing properties of some equipments. The phase-locked loops of demultiplexer tributaries, for example, effectively filter off all but the lowest frequency components of the jitter at the input to the demultiplexer and that passed on by the justification process from the corresponding multiplexer input. Because of this, each order of the hierarchy can, to some extent, be regarded as independent of the other orders, as far as jitter accumulation is concerned. Furthermore, digital exchanges act as perfect jitter reducers; jitter present at the input to the exchanges is absorbed, but the output signal is timed by the exchange clock which, for practical purposes, may be regarded as jitter free. All of these factors must be taken into account when devising planning rules for a digital network, and this is a matter of study, nationally and internationally.

CONCLUSION

This article has presented an outline of the nature of jitter in a digital network, and the approach to specification and measurement that has been adopted by European administrations.

The nature of jitter in a digital network may be compared with that of noise in an analogue network. Although these are both impairments that propagate through the network, the great advantage is that jitter can be reduced to any desired level to ensure that a satisfactory system performance is maintained.

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APPENDIX

The Jitter Transfer Function of a Single Tuned Circuit

The transfer function of a single tuned circuit at a frequency ω, relative to its transfer function at the resonant frequency ω_0, is given by

$$Y(\omega) = \frac{1}{1 + jQ\left\{\dfrac{\omega}{\omega_0} - \dfrac{\omega_0}{\omega}\right\}}, \qquad \ldots\ldots(A1)$$

where Q is the quality factor of the tuned circuit.

For small frequency deviations from ω_0, this is equivalent to:

$$Y(\omega) = \frac{1}{1 + 2jQ\Delta\omega/\omega_0}, \qquad \ldots\ldots(A2)$$

where $\Delta\omega = \omega_0 - \omega$.

The jitter on a recovered timing signal is equivalent to phase modulation. If this jitter is sinusoidal and of small amplitude, the spectrum of the jittered timing signal is as shown in Fig. 9. When this is passed through a tuned circuit of resonant frequency ω_0, the carrier component remains unchanged. However, the sidebands suffer attenuation and phase shift according to equation (A2), in which $\Delta\omega = \pm\omega_m$ for the upper and lower sidebands respectively, where ω_m is the angular frequency of the jitter.

The amplitudes of the 2 sidebands will then still be equal, but they will have suffered equal and opposite phase shifts. The signal is therefore given by

$$\cos\omega_0 t + \frac{A'}{2}\{\sin[(\omega_0 + \omega_m)t - \phi] - \sin[(\omega_0 - \omega_m)t + \phi]\},$$

where ϕ is the phase shift given by equation (A2), and A' is the new amplitude given by equation (A2).

This is equivalent to a carrier wave, $\cos\omega_0 t$, phase modulated by a signal $A'\cos(\omega_m t - \phi)$. The effect on the modulation is identical to a filter with response:

$$\frac{1}{1 + j\dfrac{\omega_m}{\omega_0/2Q}};$$

that is, a low-pass filter with a cut-off frequency equal to the half bandwidth of the tuned circuit.

With more general jitter waveforms, the effect is found to be similar, provided the peak-to-peak jitter amplitude is well below one unit interval. At large amplitudes, the filtering effect continues to occur, but harmonics and intermodulation products of the jitter also appear on the output signal.

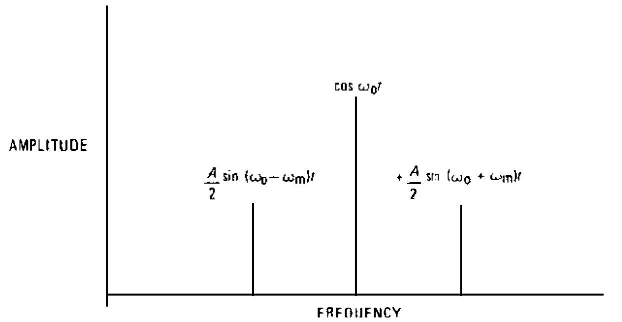

FIG. 9—Spectrum of a carrier signal $\cos\omega_0 t$ modulated by a signal $A\cos\omega_m t$

Development of an 11 GHz Digital Radio-Relay System

Part 1—Design Considerations

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UDC 621.371: 621.37.029.6: 621.376.4

Part 1 of this article describes the considerations that have led to the choice of design parameters of an 11 GHz digital radio-relay system. Part 2 will describe the configuration and parameters of the required system. The system will carry trunk traffic at 140 Mbit/s on each radio-frequency channel, and will use the sites and structures of the existing analogue 4 GHz and 6 GHz radio-relay network. A later article will describe the system which is being developed by GEC Telecommunications Ltd. for the British Post Office.

INTRODUCTION

Digital radio-relay systems will form a significant part of the digital main transmission network to be provided by the British Post Office (BPO). The 11 GHz digital radio-relay system will feature in the initial stages of the provision by the BPO of an integrated network of digital transmission and switching systems.

The existence of sites and structures used for the analogue radio line-of-sight network suggested the possibility of overlaying the 4 GHz and 6 GHz radio network with an 11 GHz digital network. Use of existing plant and accommodation will be cost effective and enable rapid provision of some of the digital-overlay network. Work began in 1972 directed towards this objective.

The 11 GHz phase-shift-keyed (PSK) line-of-sight radio-relay system to be described in this article provides 6 bothway radio-relay channels, each channel operates at a digital rate of 140 Mbit/s in the band 10·7–11·7 GHz, employing 4-phase modulation and coherent demodulation. Each radio-relay channel is capable of transmitting 1920 telephone channels or at least 2 television channels. Part 1 of this article describes in detail the various parameters that have been considered in designing an 11 GHz digital radio-relay system: Part 2 will describe the configuration and parameters of the required system.

GENERAL DESIGN CONSIDERATIONS

A digital radio-relay channel consists principally of a modulation stage providing a radio frequency (RF) output, RF transmit and receive filters (which form part of the channel combining and separating networks) and a receiver containing a demodulator. A block diagram of a digital radio-relay channel is shown in Fig. 1.

A gradual roll-off of the overall transmission characteristic has been shown to be advantageous when considering the efficiency of operation of a single RF channel[1, 2, 3]. The transmission characteristic of a channel is the cumulative characteristic of all the filtering in that channel. This filtering could include pulse-shaping at the baseband input to the modulator, RF transmit and receive filtering, intermediate frequency (IF) transmit and receive filtering and post-demodulator baseband filtering.

A system that makes the most efficient use of bandwidth requires that the maximum number of RF channels be provided in a given band. To provide the greatest number of channels, the filters specified for a practical system must restrict the channel bandwidth. This restriction of bandwidth keeps adjacent channel interference[4] at an acceptably low level, provides a suitable limitation of transmitter out-of-band energy, provides rejection of received out-of-band energy and image frequencies, and limits the receiver noise bandwidth. To achieve this, it is necessary to use filters whose roll-off characteristics are sharper than an ideal filter for a single RF channel. Filters with sharper roll-off characteristics spread received pulses over subsequent and preceding decision instants at the regenerator, so producing intersymbol interference; this is due, predominantly, to the group-delay distortion introduced by this type of filter characteristic. Group-delay equalization of some form is necessary to reduce intersymbol interference.

Baseband Pulse-Shaping Filtering

There are two main purposes for which baseband pulse-shaping filtering can be used:

(*a*) to provide filtering of the frequency spectrum (which requires that the modulator, up-converter (where used) and output amplifier shall all have linear characteristics), and

(*b*) to reduce the effects of spectral foldover.

When a carrier is modulated by a digital baseband signal, a digital spectrum is generated centred on the carrier frequency. The spectrum is repetitive at intervals of symbol-rate spacing on either side of the required carrier, the amplitude decreasing with spacing. The generated spectrum is continuous, and is reflected at zero frequency; this is known as *spectral foldover*.

Where an intermediate-frequency (IF) amplifier is used in

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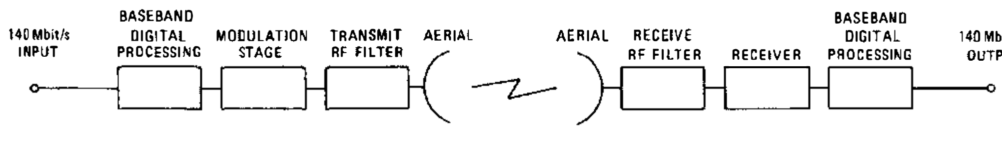


FIG. 1—Block diagram of a digital radio-relay channel

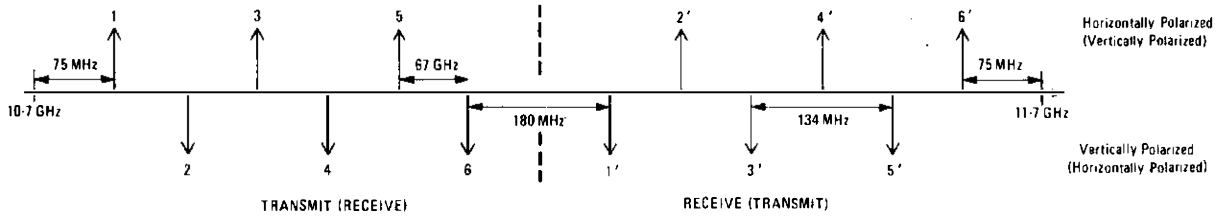


FIG. 2—Frequency plan of 11 GHz digital radio-relay system

the transmitter, it is necessary for the IF to be at least 6 times the symbol rate to ensure that the interference from the spectrum foldover is insignificant. If the pulses are shaped, the IF can be reduced. If required, the full spectrum can be restored by hard limiting at RF, or the shaping can be part of the filtering.

The technique of baseband pulse-shaping filtering is used in some systems but has not been adopted for the proposed 11 GHz system.

Transmitter IF Modulation and Direct RF Modulation

Including the bits for error monitoring, the 11 GHz system operates at above 140 Mbit/s. The system has a 4-level PSK modulator and operates at a symbol rate just above 70 Mbaud. Without shaping at baseband, the IF would need to be about 6 times 70 MHz; that is, 420 MHz. The 400–500 MHz band is a technically difficult and costly band in which to operate.

Direct RF modulation has the disadvantages that no back-to-back transmitter to receiver tests can be made, an IF test modulator is required and group-delay testing in the field requires modified test equipment. However, direct RF modulation overcomes the spectral foldover problem and dramatically reduces equipment costs in the transmitter. Receiver costs are also reduced because a receiver IF of 140 MHz, a standard CCIR (International Radio Consultative Committee) frequency, is now possible. Direct RF modulation has been adopted in the present design of 11 GHz transmitter.

Receiver IF Filtering and Post-Demodulator Filtering

The adoption of 140 MHz as the receiver IF introduces a requirement for post-demodulator filtering. Components of the spectrum at 140 MHz (and its second harmonic) will be present after the demodulator. However, a balanced demodulator will reduce the level of the 140 MHz component.

The combination of IF filter and post-demodulator filter must of course meet the same performance specification for that of a single IF filter suitable for a system. However, there are a number of factors which aid the realization of an acceptable design. When designing the filter, there will be an overlap of the spectrum from both the co-polar adjacent channels and the adjacent channels interleaved on the opposite polarization (the 11 GHz frequency plan is shown in Fig. 2). A table of carrier-to-interference (C/I) levels[3] must be produced for a system, together with a table defining the effect of the filters on the received pulse amplitude out of the demodulator (that is, *eye amplitude*[2]), and also a table of the rejection produced by the filters.

Distribution of Selectivity

The channel selectivity of the proposed system is distributed between transmit and receive RF channel filters and the receiver IF filter (including the effect of the post-demodulator filter). A distribution giving similar bandwidths for these 3 areas of filtering can minimize adjacent-channel interference, but some variation from this situation is possible with only a small increase in levels of adjacent-channel interference. The ratio of RF to IF filter bandwidths can be varied from unity (equal distribution of selectivity between the 3 filters) to about 1·8, while still maintaining sufficiently low levels of adjacent-channel interference.

Slightly less bandwidth at IF than in each RF channel filter is proposed, giving a lower noise bandwidth and an improvement in fade margin of about 1 dB compared with an equal distribution of selectivity.

Summary of Operating Conditions

The required operating characteristics of the system are given in Table 1.

TABLE 1
System Operating Characteristics

Parameter	Performance
Transmitter power	+10 dBW
Normal receiver power (input to down converter)	−60 dBW
Fade margin	40 dB
Noise bandwidth	80 MHz
Receiver noise figure at input to channel filter	8 dB
Carrier-to-noise ratio during 40 dB fade	18 dB
Normal error probability	better than 10^{-9}
Error probability during 40 dB fade	better than 10^{-5}

A carrier-to-noise ratio (C/N) of 18 dB can give a better error probability than 10^{-5}. However, the following section of this article shows why this value is necessary in order to provide a reasonable margin for C/I degradation.

FILTER DESIGN CONSIDERATIONS

Filter and Systems Parameters

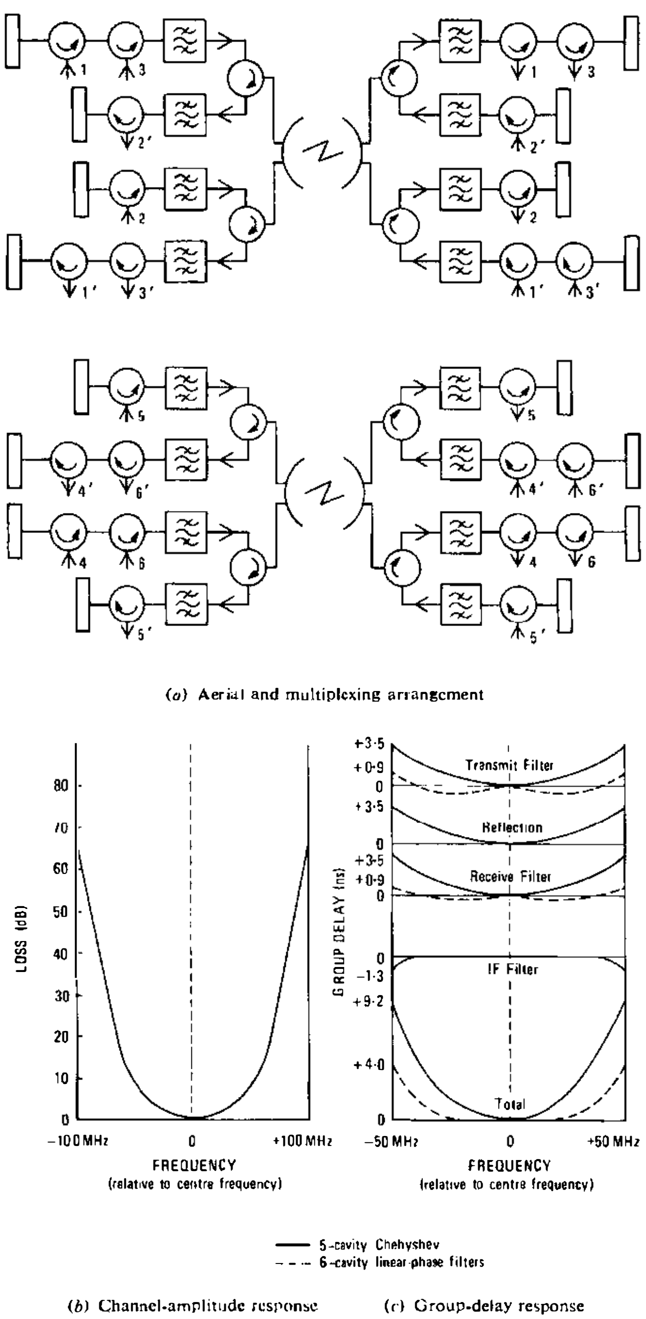
An initial postulation of filter and system parameters must be made; the 11 GHz filter structure has been derived on the basis that a 10 dB margin exists in C/I for normal signal levels when there is no noticeable degradation in C/N. This margin is obtained for a co-polar channel spacing of 1·74 times the symbol rate allowing for a transmission rate redundancy of up to 10·6% over the hierarchical data rate of 139·264 Mbit/s; that is, a total digital rate capability of 154 Mbit/s. This corresponds to a symbol rate of 77 Mbaud for a 4-phase system. The overall bandwidth utilization is therefore 1·68 bit/s Hz.

The channel frequencies are shown in Table 2. The aerial and multiplexing arrangement are shown in Fig. 3; the channel-amplitude and group-delay responses are also shown in Fig. 3.

TABLE 2
RF Channel Frequencies

Channel	Frequency (GHz)
1	10·775
2	10·842
3	10·909
4	10·976
5	11·043
6	11·110
1′	11·290
2′	11·357
3′	11·424
4′	11·491
5′	11·558
6′	11·625

Note: Throughout this article the convention of a channel with a prime (1′) is used to denote a channel in the upper half band; an unprimed channel number denotes the corresponding channel in the lower half band used for transmission in the opposite direction.



(*a*) Aerial and multiplexing arrangement

(*b*) Channel-amplitude response (*c*) Group-delay response

FIG. 3—Initial proposal for aerial and multiplexing arrangements

Filter Types

The filter calculations assume that the bandpass filters a adequately represented by reflecting the characteristics of t corresponding low-pass prototypes about the centre fr quencies. Table 3 describes the proposed filters.

The broad-band filters covering half the band are require to ensure sufficient rejection of interfering signals fro outside the 10·7–11·7 GHz band and from the local tran mitters. These filters reduce the power outside the 10· 11·7 GHz band and they also reduce interference due mixing products. It is possible to avoid the use of flanki filters (additional filters used purely to ensure that the sy metry of the filtering of each channel is within acceptat limits) by use of the group delay of the broadband filters the edges of their responses.

TABLE 3
Filter Types

Filter	Type
Transmit and receive RF filter	Chebyshev 5-pole 0·0004343 dB equ ripple transmission (that is, 1% r flection). 3 dB bandwidth = 1·75 B = 134·75 MI
Receive IF filter	7-pole Bessel with 3 dB bandwidth B = 77 MHz
Transmit IF filter	None
Broadband filters	Chebyshev 7-pole 0·0004343 dB equ ripple transmission. 3 dB bandwidth = 298 MHz

B = Symbol-rate bandwidth

Minimum Eye-Amplitudes

The eye amplitudes of the filter configuration described Table 3 are given in Table 4.

Eye amplitude is a good measure of equipment performan and theoretical studies have shown that the maximum possit value should be sought. Fig. 4 shows how the error perfor ance in the presence of thermal noise degrades rapidly wi reducing eye amplitude, but the effects are even more seve when interchannel interference is also present. Therefore, it necessary for the group-delay distortion to be equalized.

The value of eye amplitudes given in Table 4 should not regarded as design objectives but as the minimum acceptab Any improvement that can be achieved in this respect v considerably enhance the overall system performance.

TABLE 4
Eye Amplitudes

Configuration of Filters Described in Table 3	Eye Amplitude
With no group-delay equalization	0·74
With perfect group-delay equalization	0·88

Interference Requirements

Table 5 gives the calculated C/I levels for the postulated fil arrangement.

The critical interferences are those from adjacent chann on both the same and the opposite polarizations. It has b assumed that, under good conditions, a cross-polar isolati (XPI) of 30 dB can be achieved, although it is recognized t it would be unwise to rely too much on this figure.

Using the information given in Table 5, a resultant C/I

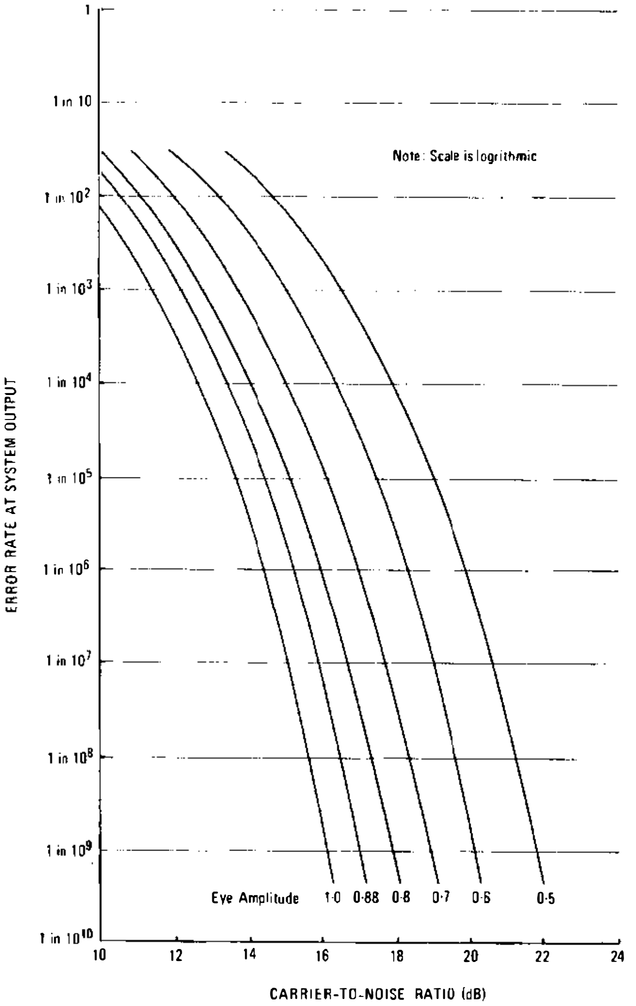


FIG. 4—Error rate at system output for given carrier-to-noise ratio

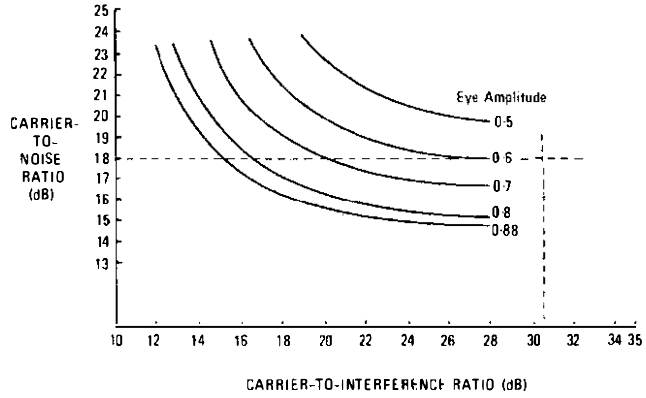


FIG. 5—Effect of adjacent-channel interference for an error rate of 1 in 10^5 at system output (interference to channel 5 from channels 4 and 6)

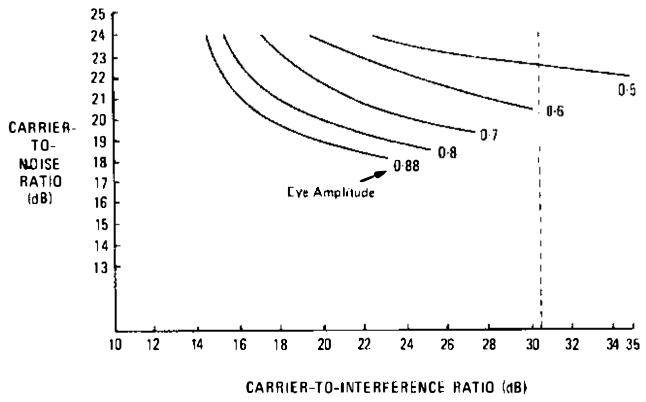


FIG. 6—Effect of adjacent-channel interference for an error rate of 1 in 10^9 at system output (interference to channel 5 from channels 4 and 6)

TABLE 5
Carrier-to-Interference Ratios

Interfering Channels	Isolation due to Filters (dB)	Other Losses	C/I (without selective fading or depolarization) (dB)
1′ into 3′ 5′ into 3′	35·6 35·6		35·6 35·6
2′ into 3′ 4′ into 3′	7·5 7·5	Assumes cross-polar isolation of 30 dB	37·5 37·5
6 into 1′	73·5	Aerial isolation loss = 70 dB. Waveguide and circulator loss = 10 dB	89
6 into 4′	177	Waveguide and circulator = 10 dB. Isolation loss between ports of dual-polarized feed = 40 dB.	162·5
5 into 4′	187·5	Isolation loss due to circulator = 20 dB	143
Total *C/I* (maximum in the absence of selective fading for a cross-polar isolation of 30 dB; that is, for channels 3, 4, 3′ and 4′)			30·5

30·5 dB has been predicted. From the curves given in Figs. 5 and 6, it can be seen that the 10^{-5} error probability objective for a C/N ratio of 18 dB and the 10^{-9} error probability objective for a C/N ratio of about 58 dB can both be met with a large margin.

The effect of 20 dB or worse C/I for the lower eye-amplitudes is not shown in Fig. 6, but it is known that the performance rapidly degrades in this region. The filter structure is therefore seen to have been postulated on the basis that at least a 10 dB margin exists in C/I for normal signal levels, and this margin is allocated for frequency selective fading.

It is not possible, at present, to estimate how often a system with the parameters described might exceed the maximum allowable error probability, but it is considered that the information given in Table 5 represents the best C/I margins that can reasonably be expected for a 6-channel scheme; any alternative choice of filters should show no significant degradation beyond this point.

Performance Requirements for the Broadband Filters

The half-band filters should provide a high level of rejection consistent with a small degradation in the performance of the radio channels.

The filters described in Table 3 meet the above requirements, even for interfering signals on receiver image frequencies.

TABLE 6
Effects of Filter Errors

Error	Rejection due to Filters (Interference 5′ into 3′) (dB)	Eye Amplitude	
		With No Group-Delay Equalization	With Complete Group-Delay Equalization
None	35·6	0·740	0·880
Shifting the centre frequency of each filter in the same direction by ±1 MHz		0·725	0·877
Increasing the bandwidth of every filter by 4%	32·9	0·717	0·902
Decreasing the bandwidth of every filter by 4%	38·5	0·677	0·850

TABLE 7
The Effect of the IF Filter on Eye Amplitude and Rejection due to Filters

IF Filter	Rejection Due to Filtering (dB)						Eye Amplitude (With/without Group-Delay Equalization)
	6′ on 4′	5 on 4′	3′ on 2′	5 on 2′	6 on 1′	6 on 4′	
7-pole Bessel (3 dB bandwidth = *B*)	35·6	187	7·5	137	73	177	0·740 0·880
5-pole Thompson (3 dB bandwidth = *B*)	35·6	187	7·6	137	73	177	0·747 0·878
3-pole Thompson (3 dB bandwidth = 0·955 *B*)	34·9	187	7·8	137	73	177	0·750 0·853
2-pole Butterworth (3 dB bandwidth = 0·962 *B*)	34·8	187	7·8	135	73	177	0·745 0·855

B = Symbol-rate bandwidth

Filter Accuracy

The accuracy to which the filter design must be realized is indicated in Table 6.

Alternative Types of IF Filter

The effect of changing the receiver IF filter is shown in Table 7.

It is evident from Table 7 that, on the criteria of C/I performance and eye amplitude, any of the above mentioned filters would be satisfactory.

Apportionment of Degradation

There are 2 main causes that result in degradation of the eye amplitude: propagation effects and imperfections in the equipment. The latter is described below.

It has been seen that the eye amplitude is reduced from 1·0 to 0·88 by the channel filtering because of restriction of bandwidth and that filter tolerances and frequency offsets have an effect. There will be further degradations because the modulator will have phase and amplitude inaccuracies. These can be defined by a contour within which phase and amplitude inaccuracies can be traded one for the other, allowing greater phase inaccuracies where amplitude inaccuracies are lower (and vice versa). There will be some degradation due to amplitude-modulation to phase-modulation-conversion, particularly in the travelling-wave amplifier. Demodulator imperfections include the effects of any data pattern dependency, recovered carrier-phase inaccuracies, and noise on the recovered carrier signal.

TABLE 8
Degradations of Linear-Phase Filters

Degradations	Eye Amplitude
Basic filter eye amplitude	0·88
Filter tolerances plus frequency offsets	0·05
Modulator imperfections; including TWA AM/PM 3°/dB within a contour specified	0·07
Demodulator imperfections, including effects of worst patterns and carrier recovery	0·03
Regenerator and timing recovery imperfections	0·03
Sum of degradations	0·18
Resulting eye amplitude	0·7

AM: Amplitude modulation
PM: Phase modulation
TWA: Travelling-wave amplifier

The regenerator could have an amplitude-conscious inde cisive region, which can effectively reduce the eye amplitud as can jitter on the recovered clock signal.

These degradations must be apportioned in a manne that permits practical implementation of the equipmen while maintaining a good eye-amplitude. Table 8 shows a apportionment of these degradations that achieves thes objectives in an 11 GHz system.

Under normal propagation conditions, degradations du to the channel combining networks and to interchanne interference will be additional small contributions.

PRACTICAL FILTER DESIGN FOR A SYSTEM

The filter design described in the previous section of this article provides the minimum design objectives for an 11 GHz system. There are other filter designs that meet the objectives.

Linear-phase filters of the Levy type[5] are preferred; these have pass-band group-delay characteristics that are adjustable at the design stage and have amplitude characteristics which are similar to those of the postulated Chebyshev filters. The reflection performance of a linear-phase filter is similar to that of an equivalent Chebyshev filter. Use of these filters can give a theoretical value for the eye amplitude of 0·88 without group-delay equalization. The improvement obtained by using 6-cavity linear-phase filters with the suggested aerial arrangement is shown in Fig. 3.

Further improvement is achieved with the aerial arrangement[6] shown in Fig. 7, where pairs of channels, separated by 268 MHz instead of 134 MHz, are multiplexed together on separate aerials. The linear-phase filters of this arrangement are 8-cavity filters, which also give an eye amplitude of 0·88. This arrangement allows broadband filters to be dispensed with unless a need is shown, in which case they can be added without affecting performance.

The advantages of the first aerial arrangement, as shown in Fig. 3, are that channels 1, 2 and 3 could be installed initially and not be affected subsequently during a second phase, the commissioning of channels 4, 5 and 6, when oscillators would be swept over the band occupied by channels 4, 5 and 6; also, cross-polar isolation could be adjusted for the frequency band of channels 1, 2 and 3 and this would be independent of the frequency band of channels 4, 5 and 6. Also, cross-polar isolation between channels 3 and 4 will need to be adjusted to optimum during the two phases of commissioning using the scheme shown in Fig. 3. The arrangement shown in Fig. 7 allows greater spacing between channels on the same polarization. This means less reflection distortion from the RF filters and eases the design of broadband filters. However, the cross-polar isolation of each aerial must be good over a broader band.

The technical advantages of the arrangement in Fig. 7 outweigh the doubtful commissioning advantages of the arrangement of Fig. 3. The arrangement in Fig. 7 has been adopted for the 11 GHz system.

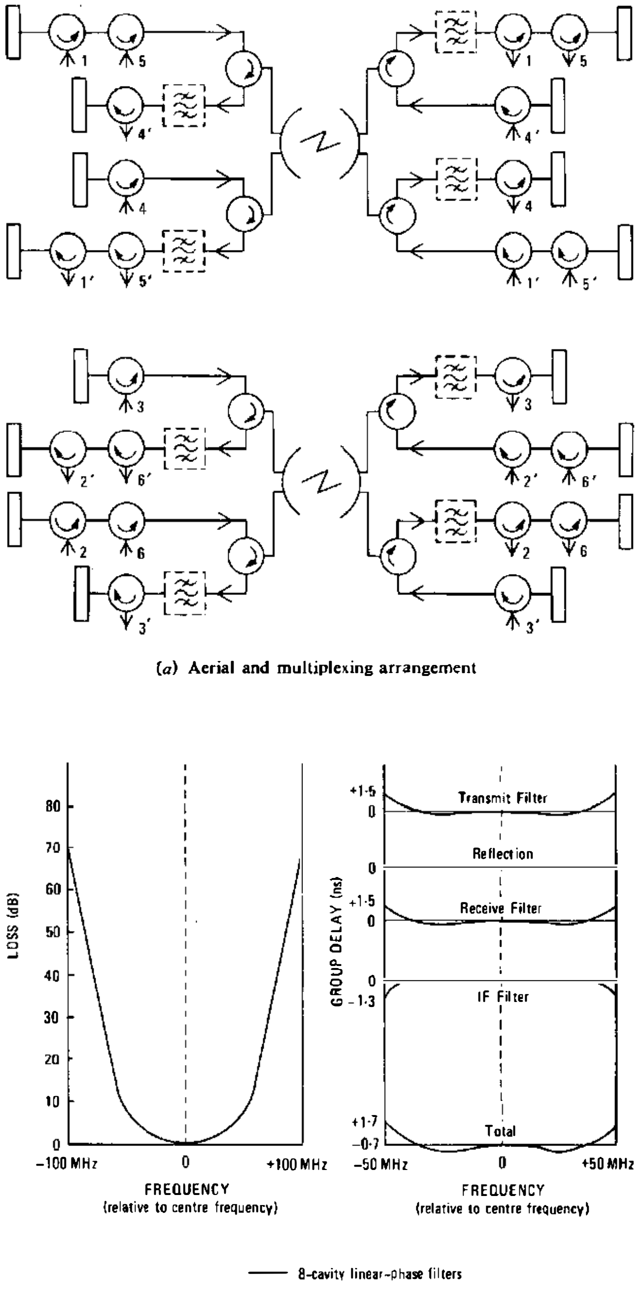
The post RF filtering, see Table 7, is split between an IF filter and a post-demodulator filter. The IF filter will therefore be slightly wider than that shown in Table 7, so that a combination of the IF filter and the post-demodulator filter provides the required shaping.

CONCLUSION

The characteristics of an 11 GHz digital radio-relay system have been established. Part 2 of this article will describe the configuration and parameters of the required system.

ACKNOWLEDGEMENT

The authors wish to acknowledge the contribution to this work of their colleagues in the BPO Research Department (R6) and in the Telecommunications Development Department (TD6) and, in particular, the contribution of Dr. M. C. Davies.



(a) Aerial and multiplexing arrangement

(b) Channel-amplitude response (c) Group-delay response

FIG. 7—The aerial and multiplexing arrangement adopted for the 11 GHz digital radio-relay system

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A New Digital 1VF Signalling Unit

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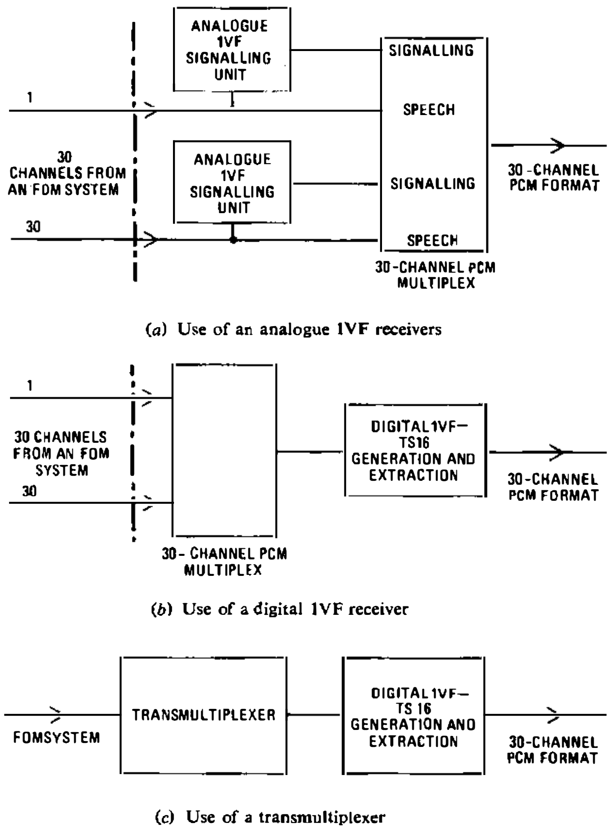
UDC 621.395.38 : 621.3.037.37

The British Post Office is to provide an integrated network of digital transmission and switching system for the UK telephone network. During the transition from an analogue to a digital network there will be a need to interface existing analogue transmission systems with digital transmission and switching systems. This article describes how digital filtering techniques have been used to construct an interface between voice-frequency signalling system and the time-slot 16 signalling system used in 30-channel pulse-cod modulation equipment. The performance requirements, filter design and some of the results obtained fro practical testing are presented. Further research work on how the cost of the unit can be reduced is als outlined.

INTRODUCTION

In the UK telephone network, analogue transmission is being increasingly replaced by digital transmission using pulse-code modulation (PCM). In the future, the British Post Office (BPO) proposes[1] to introduce an integrated network of digital transmission systems and digitally-switched telephone exchanges (known collectively as *System X*)[2], which switch PCM channels directly. Although the digital network is intended eventually to replace the present network, there will be a significant transition period when interworking between analogue and digital systems will be essential. The interface equipment must provide conversion between the digital and analogue forms of both the speech and the signalling. Part of the digital network, known as the *signalling interworking sub-system* (SIS), will deal with the signalling interface. Initially, this equipment will be a large proportion of a System X exchange but, as the digital network grows, the need for interworking will be reduced.

Existing analogue transmission systems employ frequency-division multiplex (FDM) between trunk exchanges; predominantly, information necessary for the routing of a call and for supervising its progress is sent using Signalling System AC No. 9 (SSAC 9)[3,4]. In the transit network, the line signalling system SSAC 11[5] is used. Both SSAC 9 and SSAC 11 send information in the form of bursts of a single voice-frequency (1VF) tone of 2280 Hz. The bursts of tone, which may be of 10 ms–900 ms duration, represent various signalling conditions in both the forward and backward directions of transmission. In a 30-channel PCM system, time-slot 16 (TS16) is used to provide a common time-shared signalling channel for all 30 speech paths by means of a 16-frame multi-frame[6]. To enable conversion between 1VF and TS16 signalling, a standard interface has to be established at the conversion point; this article describes such an interface.



(*a*) Use of an analogue 1VF receivers

(*b*) Use of a digital 1VF receiver

(*c*) Use of a transmultiplexer

Note: Only one direction of transmission shown

FIG. 1—Methods of converting from 1VF to TS16 signalling

POSSIBLE INTERFACES FOR 1VF TO TS16 CONVERSION

There are no particular economic or technical difficulties in converting the signalling from TS16 to 1VF. Digitally-generated tones at 2280 Hz can be introduced into each speech channel prior to decoding. In the reverse direction, there are 3 possible methods (see Fig. 1) of converting the signalling from an analogue to a digital form, as described below.

(*a*) Conventional analogue VF receivers can be used on each incoming channel to detect the signalling and separate it from the speech. Thirty channels (speech only) can then be combined and encoded using standard PCM multiplex equipment, in which the signalling is converted into a format similar to that already used in TS16.

(*b*) Thirty channels containing both speech and signalli can be digitally encoded (again using standard PCM mu plex equipment) and digital filtering techniques used detect simultaneously the presence of signalling tones in 30 channels, using time-division multiplex (TDM) techniqu Path splitting is then carried out digitally.

(*c*) A transmultiplexer can be used to convert FDM PCM, and digital filtering techniques used to detect the p sence of signalling tones in a similar manner to (*b*).

French researchers[7] claim considerable advances in development of transmultiplexers but, in the UK, althou work is in progress, a system has not yet been demonstrat

Method (*b*) is technically feasible and offers worthwl savings compared with method (*a*). The interface is showr more detail in Fig. 2. Thirty analogue baseband channels

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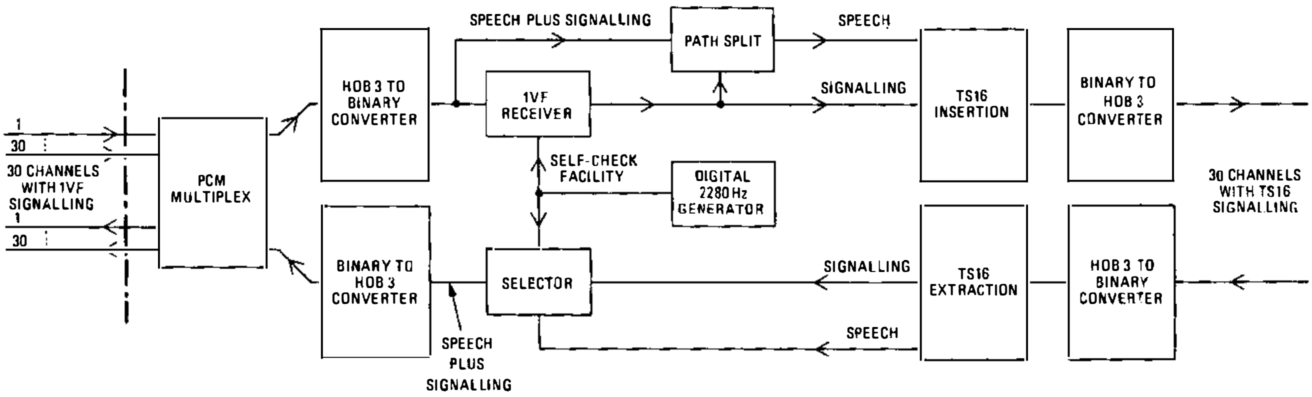


FIG. 2—1VF to TS16 signalling interface

combined in a PCM multiplex, which produces an output in HDB3 code† suitable for line transmission. The signal is converted to a unipolar form and each 8 bit A-law encoded sample is converted to the equivalent 13 bit linear code. Arithmetic operations in the digital filter circuits are much easier to perform on a linear code than on a non-linear code, such as A-law or μ-law. Valid signalling tones are detected by the 1VF receiver and used to operate a digital path splitting network to remove the encoded signalling tones from the speech time-slots.

Codes corresponding to the validated signalling tones are inserted into TS16. The speech samples are finally converted back into 8 bit A-law samples and into the HDB3 line-code format. The entire interface, excluding the method of conversion from analogue to digital (the PCM multiplex, as shown in Fig. 2), is known as a *1VF Unit,* and will be introduced into the field with the first digital main-network switching centre (DMNSC).

THE 1VF UNIT

The 1VF Unit can be considered as consisting of 2 parts: a TS16 to 1VF converter, and a 1VF to TS16 converter. The standard HDB3 line-code is used for communication between the 1VF Unit and the exchange. A common interface is used to convert the HDB3 signals into binary and the converse, to recover the 2·048 MHz clock and to detect the synchronization pattern. It also recovers and reinserts channel 0.

TS 16 to 1VF Converter

In the TS16 to 1VF converter, the signalling codes are removed from TS16 and used to gate samples from a digital 2280 Hz tone generator into the appropriate speech time-slots. A digital tone generator can be made by storing samples in programmable read-only memories (PROMs). These samples are selected in sequence by a counter running at the sample frequency 8 kHz, (see Fig. 3.) The output from such an arrangement (see Fig. 4) is the same as would be produced from a PCM coder (A-law). The number of samples required to produce an integer number of cycles, which repeats, can be found from

$$H = \frac{N \times f}{8000}, \qquad \ldots\ldots (1)$$

where H is the number of cycles (and is integer), N is the number of samples, and f is the tone frequency (2280 Hz ± tolerance).

The lowest value of H to satisfy this equation at f = 2280 Hz

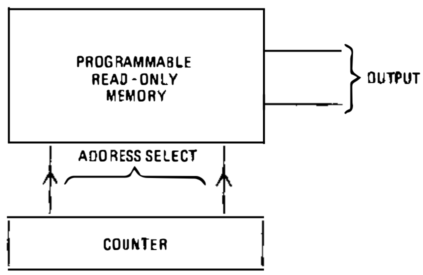


FIG. 3—Block diagram of digital tone generator

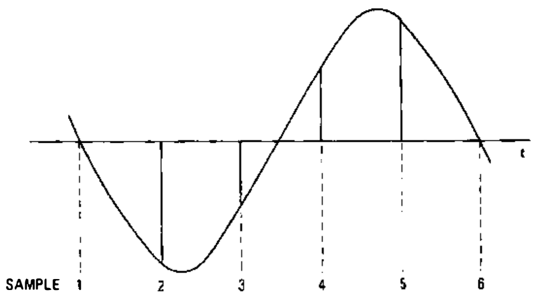


FIG. 4—Output from digital tone generator

is 57; therefore, N = 200 samples. However, it is possible to reduce this number of samples by using 2285·71 Hz, which is still within the specified frequency tolerance. Using this frequency, 7 samples only need to be stored.

This article will not deal further with the TS16 to 1VF translation; only the 1VF receiver is dealt with in detail.

1VF to TS16 Converter

The 1VF to TS16 converter is more complex, and it is here that digital-filtering techniques have been employed. The HDB3 serial digital stream is converted into binary, and the 2·048 MHz clock and the frame-start vector are recovered using the standard circuit previously mentioned. The binary words obtained for each channel will be in A-law form. These are fed in parallel into a PROM, which converts the 8 bit words into 13 bit linear two's-complement codes.

The next part of the circuit, the 1VF receiver, can be considered as a 2280 Hz band-pass and band-stop filter, known as the *notch circuit*; and a method of comparing the

† HDBn is one class of highly-redundant ternary codes, known as *high-density bipolar*, of the order n, where n is the maximum number of consecutive zeros in the HDBn signal. In this case, n = 3

filter outputs to decide if a valid signalling tone, and not speech, is present, known as the *guard circuit*. Subsequent short breaks in the signals are masked before the messages are passed to the next part of the circuit.

Messages that indicate if tone is present in a particular time slot are sent from the digital receiver to a control circuit. In the control circuit, these messages have to be timed to determine when splitting of the path is necessary. This is similar to the function provided by the analogue relay-set in preventing signalling tones being passed on to subsequent transmission links. The control circuit also reconstitutes the PCM frame, inserting messages in the appropriate TS16 that indicate if tone is present. The control circuit does not do any further timing; this is done in the exchange processor.

DIGITAL 1VF RECEIVER PERFORMANCE-SPECIFICATION

The performance specification of a digital 1VF receiver has been based on the performance requirements of existing analogue 1VF receivers. Relevant details of the specification are summarized below.

Frequency
The receiver shall operate to frequencies within the range 2280 ± 25 Hz and shall not operate to frequencies outside the range 2280 ± 75 Hz.

Transmission Levels
In the BPO main network, 2-wire switched circuits that use SSAC 9 for line signalling have 1VF receivers connected permanently across the 4-wire receive path of an associated 2-wire-to-4-wire hybrid. In the case of circuits used for connexions established over the 4-wire switched transit network, 1VF receivers (SSAC 11) are also permanently associated. Thus, in each case, the receivers are connected at points of known relative power-level and, hence, the dynamic range of receiver operation has been established.

Digital 1VF receivers will be connected via 30-channel PCM multiplex equipments, for which the nominal input test level is specified as −3·8 dBm†. (This level is specified in order to give the optimum dynamic range to speech signals.) Hence, the operate range of the digital 1VF receiver has been specified as −●·8 dBm to −18·8 dBm, and the non-operate power level as −28·8 dBm or less.

Immunity to Speech
A guard circuit is used to prevent false operation of the signalling detector by speech. This is achieved by comparing the power within the signalling frequency band, centred on 2280 Hz, with the power in the remainder of the telephony channel.

The receiver shall have a voice immunity of better than one false operation of 20 ms duration in two speech hours, and one interruption of 50 ms in 10 speech hours. (A speech-hour is 1 h of continuous speech and does not include those quiescent periods that occur in normal conversation.)

Immunity to Interfering Tones
Extraneous tones having frequencies outside the operating signal frequency range shall, when present at sufficient level, prevent or guard against operation of the receiver to a genuine signal.

The receiver shall operate if the signal level is greater than the guard tone level by more than the values shown in Table 1.

An operated receiver shall release if the guard tone level increases such that the signal level is not greater than the guard tone level by the values shown in Table 2.

† dBm—power level relative to 1 mW

TABLE 1

Signal-to-Guard-Tone Power Margins for Operation of Receiver

Guard-tone frequency (Hz)	500	750	1000	1250	1500	1750	2000	3000
Signal level above guard-tone level (dB)	16	18	20	20	20	20	15	17

TABLE 2

Signal-to-Guard-Tone Power Margins for Release of Receiver

Guard-tone frequency (Hz)	500	750	1000	1250	1500	1750	2000	3000
Signal level above guard-tone level (dB)	7	10	12	12	12	12	7	9

Response Times
The response times specified for the digital 1VF receiver are
(*a*) Turn-on delay: The receiver shall operate in less tha 10 ms.
(*b*) Distortion: The receiver shall give an output whos duration does not differ by more than ±5 ms from that c the input signal producing it.
(*c*) Short-break masking: Breaks in the signalling tor shorter than 4 ms shall be ignored. The performance of th receiver to breaks in the signal of greater than 4 ms duratio will be a function of the normal decay time of the receive but breaks of greater than 10 ms shall not be ignored. Apa from breaks shorter than 4 ms, the input signals must b continuous during the recognition time before being accepte as a valid signal.

THEORETICAL DESIGN OF THE RECEIVER

To provide the guard action required by the specification, tl present analogue receiver separates the range of sign frequencies from the rest of the speech band, so that tl signal and other power levels may be estimated and con pared. If the ratio of signal power level to other power leve is large enough then the receiver registers a valid signal. Tl same principle is adopted for the digital receiver, which us the digital filters as shown in Fig. 5. (The reader who unfamiliar with digital filters is referred to the Appendix fo a brief introduction.) With reference to Fig. 5, the networl giving the transfer function F(*z*) act as a bandstop filter remove the allowed range of signal frequencies, so that tl level of the frequencies in the rest of the band may be esi mated. The network giving the transfer function G(provides a band-pass filter, which passes the band of val frequencies so that the signal level may be estimated. Tl estimates of level are obtained by full-wave rectification ar low-pass filtering. The two levels are compared by su traction and sign extraction. By making the 2 low-pass filte identical they may be replaced by one filter after the su traction.

The chief design considerations are now examined in tur

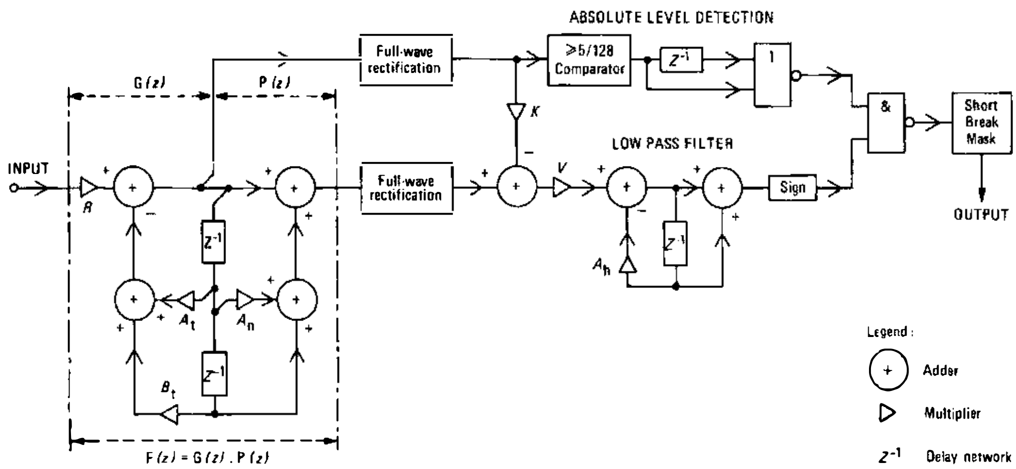


FIG. 5—1VF receiver flow diagram

Bandwidth of the 1VF Receiver

The filter section with transfer function P(z) (see Fig. 5) has a transmission zero at a frequency f_0, which is related to the coefficient A_n by

$$A_n = -2\cos(2\pi f_0/f_s), \quad \ldots\ldots (2)$$

where f_s is the sampling rate (8000 samples/s).

The frequency f_0 is specified as 2280 Hz, which leads to a value for A_n of 0·43628. For realization with real hardware, the coefficients must be approximated by binary numbers. If A_n is made equal to 7/16, then f_0 is about 2281 Hz, which is a close enough approximation.

It can be shown[9] that the bandwidth of the receiver (assuming perfect level detection) is given by

$$\Delta f = |f_1 - f_2|\text{Hz}, \quad \ldots\ldots (3)$$

where f_1 and f_2 are the band edges and are given by

$$f_{1,2} = \frac{1}{2\pi} f_s \cos^{-1}\left[-\frac{1}{2}(A_n \pm K)\right], \quad \ldots\ldots (4)$$

where K is the multiplier coefficient indicated in Fig. 5. The value of K is chosen so that the bandwidth given in the specification is met; that is, so that 50 Hz $< \Delta f <$ 150 Hz.

Guard Factor

The guard factor (m) of the receiver is defined as the ratio P/P_i which just causes an otherwise valid signal to be rejected; P is the power at the signal frequency f and P_i is the power of a single interfering tone. It can be shown[9] that the guard factor, as a function of f and the frequency f_i of a single interfering tone, is given by

$$m = 10\log_{10}\left[\frac{K^2 - P(j\omega_i)^2}{P(j\omega)^2 - K^2}\right] + 10\log_{10}\left[\left|\frac{G(j\omega_i)}{G(j\omega)}\right|^2\right] \ldots (5)$$

The first term in this equation gives the contribution of the filter section P(z). Since A_n and K have already been chosen, this contribution is fixed; it is, however, a function of the signal frequency $f = \omega/2\pi$. The quantity $P(j\omega)$ varies between 0 at $f = 2281$ Hz and a maximum of 0·0396 at $f = 2255$ Hz, giving a variation in m of Δm where

$$\Delta m = -10\log_{10}[1 - (0{\cdot}0396/K)^2]. \quad \ldots\ldots (6)$$

Equation (6) shows that to reduce Δm, K should be chosen to be as large as possible.

The second term in equation (5) is the frequency response of G(z) normalized to 0 dB at frequency f, and it must be designed so that m meets the specification. Coefficients A_t and B_t define the frequency response of G(z); appropriate value were found using a template-design method[9].

Level Detection

The level detecting circuits shown in Fig. 5 are about the simplest which can be used. Full-wave rectification is easy to implement in a digital processor; it is simply the process of making all data positive. The design of the low-pass filter is a compromise between adequate smoothing of the output on the one hand and the introduction of excessive round-off noise (due to having a highly-selective filter) on the other.

Determination of Scaling Coefficients

In the implementation of digital filters, care must be taken that overflow does not occur at any of the summation nodes. Such overflow can lead to severe distortion and, sometimes, large amplitude oscillations. Fortunately, it is possible to determine values for the scaling coefficients such that overflow cannot occur for any sequence of input samples. Suitable scaling coefficients were found to be $R = 1/4$ and $V = 1/16$. These values are negative powers of 2 and are thus very easily realized with binary hardware.

Data Word Length

Before the receiver could be realized, it was necessary to determine the internal data word length and to prove that the theoretical design worked. To this end, a simulation program was written. It was found that for a 16 bit (including sign) data word length, the receiver met the bandwidth, dynamic-range and guard-response requirements of the specification. It was also found that the maximum turn-on time, S_{1max}, of the receiver, the minimum turn-on time, S_{1min}, the maximum turn-off time, L_{1max}, and the minimum turn-off time, L_{1min}, were 4 ms, 2 ms, 875 μs and 250 μs respectively. These times are satisfactory and are discussed in the next section.

Short-Break Masking

The specification calls for the receiver to ignore breaks in the input signal of less than 4 ms but not greater than 10 ms. The requirements of the masking circuit, can be formulated as follows. Fig. 6 shows the effect of the masking circuit in introducing a turn-off delay of L_2 and a turn-on delay of S_2, where S_2 and L_2 are bounded by the following conditions.

To meet the 10 ms maximum turn-on time of the specification:

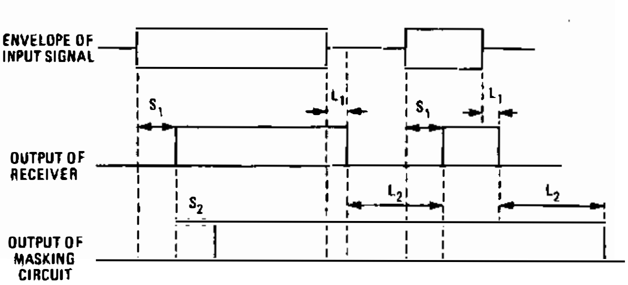


FIG. 6--Masking-circuit performance

$$S_{1max} + S_2 < 10 \text{ ms.} \quad \ldots\ldots (7)$$

To meet the part of the specification that defines the maximum change in pulse length as 5 ms:

$$L_2 + L_{1max} - S_{1min} - S_2 < 5 \text{ ms, and} \quad \ldots. (8)$$

$$L_2 + L_{1min} - S_{1max} - S_2 > -5 \text{ ms.} \quad \ldots\ldots (9)$$

To meet the short-break specification:

$$4 + S_{1max} - L_{1min} < L_2, \text{ and} \quad \ldots\ldots (10)$$

$$10 + S_{1min} - L_{1max} > L_2 \quad \ldots\ldots (11)$$

Thus, for instance, S_2 could be 6 ms and L_2 could be 10 ms. However, delays of this magnitude involve the use of a circuit that can 'remember' past outputs of up to 80 samples when the sampling rate is 8000 Hz. To reduce this, the sampling rate can be reduced by a factor n by taking only every nth sample from the output of the receiver. An effect of doing this is to increase the value of L_{1max} and S_{1max} by $(n - 1)/8$ms. It is convenient to choose n as a power of 2, and the largest value of n for which equations (7–11) have a solution is 8. Because of the reduction in sampling rate, S_2 and L_2 are constrained to be integer multiples of 1 ms. A solution of equations (7–11) is $L_2 = 9$ ms and $S_2 = 4$ ms. These requirements are easily met by a synchronous sequential logic circuit with 16 internal states.

The turn-on and turn-off times above were taken as being the times when the receiver output first changed state. Under certain conditions, when an interfering signal is present, ripples on the output can cause transient changes of state after turn-on and turn-off. If the 1-out-of-8 sample selection happens to coincide with a transient state, an increase in turn-off or turn-on time results. To prevent this, an additional process was introduced. This consists of averaging a set of 8 outputs in the sample reduction process. A set of 8 consecutive outputs is examined and, if 4 or more are at binary state *one*, the output from the averaging process is a *one*. The averaging process introduces further delay into S_1 and L_1, but this is not sufficient to invalidate the above requirements for the design of the masking circuit.

Absolute Level Detection

To confirm that sufficient level of valid tone is present it is necessary to include some form of absolute level detection in the receiver. This cannot be done at the output of the receiver because the output level is the difference between the level of the signal and that of any accompanying interference. Fortunately, it is very easy to provide absolute level detection by feeding the unsmoothed full-wave rectified output from filter G(z) to a comparator. The reason for this is as follows. If the receiver is to detect a valid signal then there must be a fairly pure 2280 ± 25 Hz tone present at the output of filter G(z). For a sinusoid in the given frequency band, one of any two adjacent samples is a substantial fraction of the amplitude of the sine wave. The worst case is given by a tone of 2305 Hz where the minimum sample value is 0·61749E (that is, 4·4 dB below E), where E is the amplitude of the sinusoid. Since this variation is less than the 10 dB difference between invalid and valid signal levels, it is possible to d tinguish between them. This is still true even when allowan is made for a small proportion of interfering tone appeari at the output of G(z). A reasonable choice of decision le τ is 5/128 (assuming the maximum amplitude that can represented in the receiver is unity).

1VF RECEIVER IMPLEMENTATION

A CCITT 2048 kbit/s Interface[6] provides 30 speech chann and 2 channels for signalling and synchronization. As far the application of a digital 1VF receiver is concerned, the lat two channels are redundant. However, they can be us internally to inject test tones to check its operation a processing of 32 time-slots enables convenient clock ra to be used. Consequently, it was decided to design t receiver so that it is multiplexed over all 32 channels. parallel processing technique was finally adopted. This u a clock rate of 256 kbit/s, which is the channel rate. Each the arithmetic functions required (that is, the adders a multipliers shown in the receiver flow diagram (Fig. 5)) realized by a dedicated combinational logic-array usi standard low-power Schottky (LSTTL) gates. At each clc pulse, the current input to the receiver and the output each delay-element ripple through the combinational lo produces a new output and new inputs to the delay eleme for processing in the next frame. Thus, calculations are fi performed on channel 1 and the results stored awaiting next channel 1 time; similarly, for channel 2, channel 3, e The shift registers storing the data ensure that data is o available at the output at the appropriate channel tir Because of delays inherent in logic gates, some re-timing necessary; however, the delay round a feedback loop is arranged to be less than the clock rate of 256 kbit/s, that 3·9 ms. Thus, the only timing waveform required for filters is a system clock of 256 kbit/s. Two's-complem coding of the data is used throughout the receiver from output of the A-law-to-linear converter.

Parallel Adders and Subtractors

The parallel adders are constructed from four 4 bit add using four D34LS283 gates, as shown in Fig. 7. (Note, the D series is functionally equivalent to the standard SN74 seri Subtraction of two's-complement numbers is achieved inverting all the bits of the number to be subtracted adding *one* to the least significant bit of the result (that forming the two's-complement) and then adding it to other number. The carry input on the least significant ad can be used to add the *one* to the least significant bit. Her for subtraction, a row of inverters only is required addition to the adder.

Multiplication

The coefficients for the 1VF receiver are simple bin numbers, thus obviating the need for complicated mu pliers.

Multiplication in the 1VF filters is achieved by shifting wiring and adding. If the most significant bit of a par word is wired to the most significant bit and to the next m significant bit (MSB-1) of the input to the next device, MS wired to MSB-2, MSB-2 to MSB-3, etc. leaving the l significant output unconnected, this has the effect of mu plying the output by a half. For example,

0110110111101010 → 0011011011110101
shift by 1 ≡ multiplying by 1/2.
1110111110001011 → 1111101111100010
shift by 2 ≡ multiplying by 1/4.

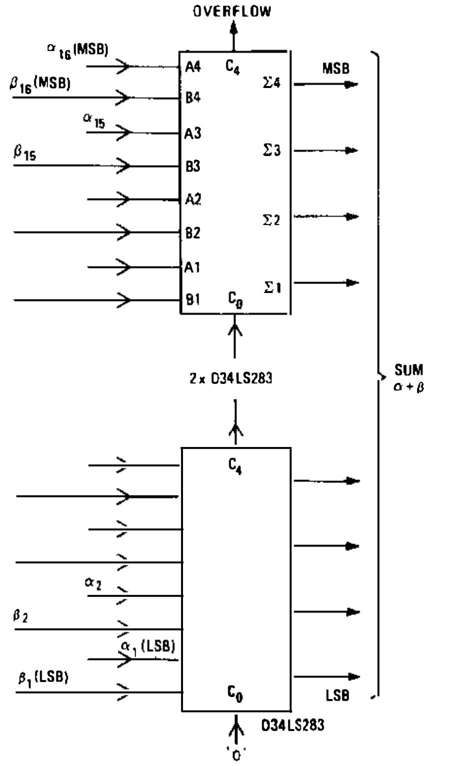


FIG. 7—16 bit parallel adder

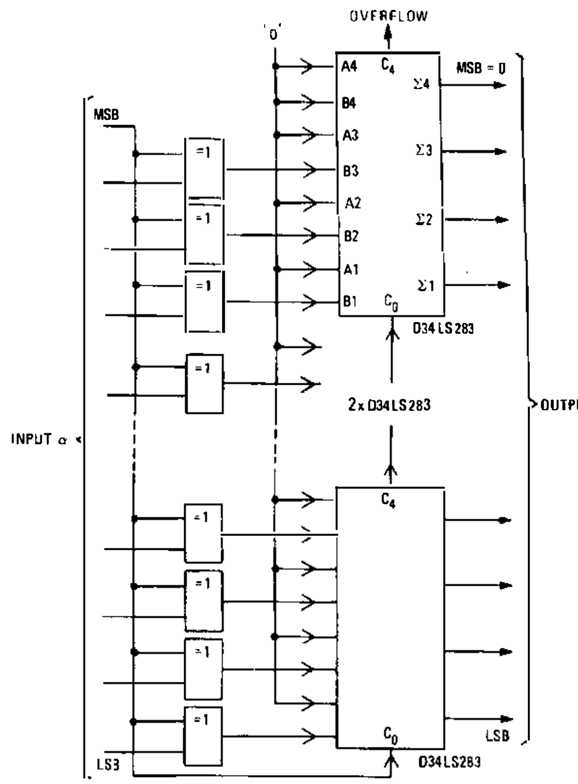


FIG. 9—16 bit parallel full-wave rectifier

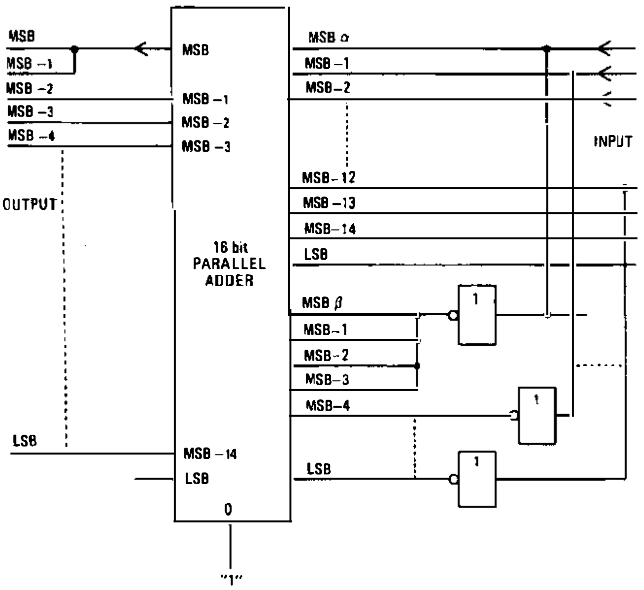


Fig. 8—Implementation of the operation $\times(1 - 1/8) \times 1/2$

The operation of *times* 7/16 can, for example, be rewritten as $\times$ (1 $-$ 1/8) $\times$ 1/2, this process requires a set of inverters, a shift of wiring by 3, a set of adders, and a further shift of wiring by one, as shown in Fig. 8.

Delay Elements

The delay elements for processing 32 channels need to be 32 bit long and capable of handling 16 bit in parallel (Although only 13 bit are needed to represent the linear code the extra bits are necessary to maintain the accuracy in the arithmetic.) Originally, 3 hex. 32 bit shift-registers obtainable in metal-oxide-semiconductor (MOS) technology were used. This however meant that an extra power supply at 12 V was necessary. These devices have now been exchanged for dual 32/64 bit shift-registers in complimentary metal-oxide semiconductor (CMOS) type MC14517, thereby eliminating the need for any power supplies other than +5 V.

Full-Wave Rectification

With a two's-complement negative word, full-wave rectification is achieved by inverting all bits and adding *one*. In a negative word, the MSB is *one*, hence, rectification of any data word is achieved by the EXCLUSIVE-ORing of the MSB with the rest of the data bits, and then adding the MSB to the LSB, as shown in Fig. 9. In practice, this addition could be ignored if a slight inaccuracy can be permitted, or it could be performed in a subsequent adder.

FAULT FINDING

During initial testing of the filter boards it was found that, although the logic design and construction is along conventional lines, fault finding of the circuits required different techniques to those employed on conventional sequential and combinational-logic circuits. The difficulty arises because examination of individual connexions presents little useful information. Correct operation of the circuit can be determined only by the examination of a set of, at least, the more significant digits and their conversion into analogue form. It was noticeable that virtually all the faults on the filter will cause the circuit to act non-linearly. Thus, when examined, sinewaves will tend to be distorted in a faulty system. This aids the testing as it is unnecessary to check the frequency characteristics until all the circuit is operating linearly.

Initial Testing

The testing of the prototype was carried out in stages. Firstly, all the integrated circuits were examined for correct logic levels. This was achieved by applying an input signal (within the signalling band) of a reasonable level to ensure every gate had both logic levels passing through it. This showed where any shorts and discontinuities in the wiring had occurred. The next stage was to test the circuit with a sine-wave input signal, but it was found that the most realistic frequencies were difficult to observe with 8 kHz sampling. It proved advantageous to build a special-purpose input card which sampled the input sine wave at 256 kHz and feed this signal into all 32 time slots. This has the effect of putting the sine wave into 32 filters. Resampling at any point in the circuit at 256 kHz will produce a correct but over-sampled signal since the system can be considered to consist of 32 identical filters, each filter being fed by a slightly delayed version of the input sine wave. A diagrammatic representation of this is shown in Fig. 10. Note, this is only a diagrammatic representation since there is only one filter actually present which is time-shared.

To monitor the filter performance, a number of digital-to-analogue converters were constructed which were wired to the highways accessible from the printed-wiring board edge-connexions. This enabled the major points in the receiver to be monitored. In some instances, it proved to be difficult to find the source of a circuit's non-linearity because the internal signal is changed by feedback, which obscured the source of the non-linearity. Removal of the feedback, which was achieved by disabling shift registers, solved this particular problem.

By using the above techniques it was possible to determine where any design or constructional faults occurred.

Maintenance

No alignment or adjustment of frequency generators will be necessary. Errors will be detected automatically and forwarded as error codes in TS16 to a processing unit in the exchange. The faulty card can then be replaced.

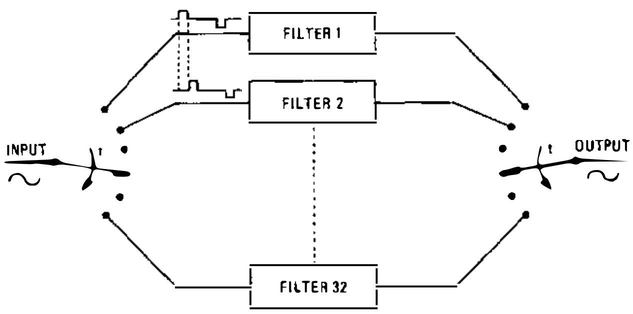


Fig. 10—Diagramatic representation of test procedure

PERFORMANCE TESTING

The aims of the testing programme have been two-fold firstly, to prove that the design of the digital receiver satis fied the performance requirements; secondly, to establisl the limits of operation. Initially, testing was carried out ii the laboratory to confirm that the design was satisfactory Subsequently, a feasibility trial was set up over a privat circuit between Plessey Telecommunications Limited a Liverpool and the BPO Research Centre at Martlesham, distance of approximately 350 km (See Fig. 11). Patterns o pulses were sent from Liverpool to Martlesham in order t simulate, as far as possible, the normal operating environmen of a 1VF signalling system. Both an analogue (SSAC9) an a digital receiver were connected to the private circuit so tha their performances could be recorded and compared. Th digital receiver was found to be at least as good as th analogue receiver in all respects and generally performe better[10].

The operate and non-operate levels for 2280 Hz and a the band edges were measured. The results are given i Table 3. The operate and non-operate frequency ranges wer measured for the maximum and minimum input levels. Th results are given in Table 4.

TABLE 3
Operate and Non-Operate Levels of the 2280 Hz Tone Detector

Frequency (Hz)	Operate Level (dBm)	Non-operate level (dBm)
2255	−25	−26
2280	−25	−26
2305	−25	−26

TABLE 4
Operate and Non-Operate Frequency Ranges for Extrem Input-Levels

Input Level (dBm)	Operate Frequency-Range (Hz)	Non-Operate Frequency Range (Hz)
−0·8	2220–2345	<2216 or >2348
−18·8	2225–2345	<2220 or >2350

Guard-Circuit Tests

A series of measurements were conducted to find the relati levels of an interfering tone at which the receiver would bo operate and not operate consistently. The tests were ma

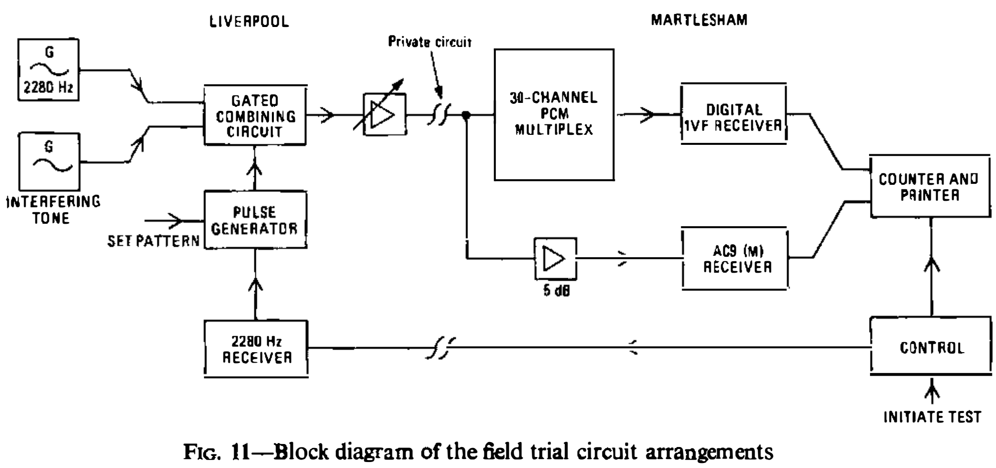
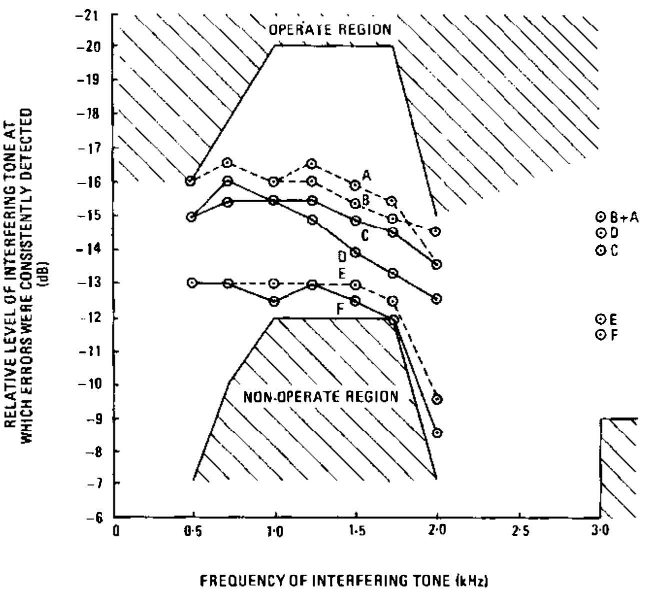


Fig. 11—Block diagram of the field trial circuit arrangements



A: Operate limit 2255 Hz at −18·8 dBm
B: Operate limit 2305 Hz at −18·8 dBm
C: Operate limit 2305 Hz at −0·8 dBm
D: Operate limit 2255 Hz at −0·8 dBm
E: Non-operate limit 2280 Hz at −18·8 dBm
F: Non-operate limit 2280 Hz at −0·8 dBm

FIG. 12—Limits of operation of guard circuit

more exacting by using a sequence of pulses of signalling tone which were on for 10 ms and off for 100 ms at frequencies of 2225 Hz and 2305 Hz when determining the operate point, and pulses which where on for 30 ms and off for 30 ms at a frequency of 2280 Hz when determining the non-operate point. The results are shown in Fig. 12, which also shows the design requirements. It is clear from Fig. 12 that satisfactory operation was obtained.

Response Times

The turn-on delay and the pulse distortion (that is the difference between the applied pulse length and the output pulse length from the receiver) were found by comparing input and output waveforms for all signalling conditions. Turn-on delay was found to be a maximum of 7·6 ms and pulse distortion a maximum of +4 ms. The short break masking action was tested by sending a large number of pulse trains along the private circuit. It was found that the receiver would consistently not-operate for signalling conditions of less than 4·1 ms and would consistently operate for signalling conditions of longer than 7·6 ms over the whole of the input level range.

Speech Tests

As part of the field trial, several hours of speech recordings were replayed and sent over the test circuit from Liverpool to Martlesham. A recorder was set to detect any operations of the signalling receiver which might have been caused by a deficiency in the guard circuit. No false operations were detected by either the analogue or the digital receivers.

TECHNOLOGY AND FUTURE DEVELOPMENTS

In the BPO network, 1VF signalling is the most common signalling system in the analogue network; there are over 500 000 relay-sets in use in the UK at present and the number in use is planned to rise to a maximum of 660 000. Although a large number of these sets will be replaced as digital plant is installed, it has been calculated that between 5000 and 10 000 1VF units will be required. (Note, one 1VF digital receiver will replace up to thirty 1VF analogue receivers). These figures take account of the fact that both types of equipment will be recovered and recommissioned elsewhere. It was decided, therefore, that it would be profitable to carry out a cost reduction exercise on the 1VF unit. On investigation it was found that only slight reduction in circuitry was possible by reconfiguring the arrangement for multiplication in the filters. This has now been incorporated in the latest model. It has also been found that buffering between the CMOS logic and TTL is unnecessary.

Some saving in circuitry has already been incorporated by implementing for example, two counters with PROM. This, however, does have the disadvantage of higher power consumption than using medium-scale integration (MSI) and standard LSTTL packages and a compromise must be sought. Various alternative technologies have also been considered and the findings are summarized below.

Uncommitted Logic Arrays

Uncommitted logic arrays (ULAs) have been described in a previous article[11] in this *Journal*. They are economic in quantities of only a few thousand and could prove more economic than custom design. ULAs prove beneficial in circuits which use many standard logic gates, they are not justified where many MSI/large-scale integration (LSI) packages are used. Indeed, the HDB3 circuits are already being replaced by some ULA chips. These circuits are, however, used in other units such as digital line terminations and, hence, can profitably be replaced. In the 1VF receiver, the most prevalent integrated circuits used are the D34LS283 adder and the CMOS 4517B shift register, both are MSI/LSI devices. The control circuit, although not described in detail in this article, does contain a lot of standard gates and it has been calculated that savings would accrue using ULAs in this area.

CMOS and Locally-Oxidized CMOS

On average, CMOS gates consume much less power than equivalent LSTTL gates. The other main advantage is that the power supply tolerance is very wide; devices approved to the Joint Electronic Devices Evaluation Committee Specification B are specified to work between 3 V and 15 V. The main disadvantage with CMOS is the long propagation time and this has lead to the development by Mullard of locally-oxidized CMOS (LOCMOS). At 5 V, the delay in a 16 bit adder in CMOS is excessive and would lead to retimers in the feed-back loop. This then implies the use of non-standard shift registers. This problem is overcome if the supply voltage is raised to 10 V, although some additional retiming in the 1VF receiver circuit would still be necessary. A similar situation would arise by the use of LOCMOS except that the voltage can be retained at 5 V. The rest of the 1VF Unit can also be re-engineered in LOCMOS. The result is that considerable savings in power can be achieved by using LOCMOS.

Custom Designed LSI

Custom designed LSI devices could be manufactured to replace any part of the circuit. The development costs tend to be so high as to prevent custom design becoming cost effective unless large numbers are involved. It has been calculated that some savings would result if the 1VF unit was redesigned using custom-designed LSI. However, considerable savings could be made if a LSI digital filtering chip was developed.

Common LSI Device for Digital Filtering

Digital filters are required in a number of applications. In particular, the BPO has a number of applications in signalling systems; for example, Multi-Frequency Signalling System No. 4. The BPO Research Department are currently developing a common LSI device for such digital filtering applications. It is anticipated that such a device, for a sampling rate of 8000 samples per second, will be multiplexed over 8 channels, hence 4 will be required for the 1VF receiver. By using this method the largest savings will result.

Microprocessors

Microprocessors are being used increasingly to replace logic circuits[11]. However, in this application they are not recommended. The reason for this is that

(*a*) the speed is limited, and

(*b*) a large proportion of the existing circuitry, such as data reformatting, will still be required.

CONCLUSIONS

A 1VF unit has been developed to convert between 1VF in-band signalling and TS16. An attempt has been made to show how the more complex part, the receiver, has been designed; it has been proved that this design adequately meets BPO requirements. Work is now in an advanced state of development but, as so many 1VF units will ultimately be required in the network, a study of the possibility of using alternative technologies, in order to produce a cheaper unit, has been made. This study revealed that there is scope to reduce the cost of the unit.

ACKNOWLEDGEMENTS

Acknowledgement is made to Plessey Telecommunications Limited who are collaborating with the BPO in the design and development of the signalling interworking sub-system (SIS) and to colleagues working on SIS in the Integrated Systems Strategy Department of the BPO.

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APPENDIX

Introduction to Digital Filtering

The introduction of PCM transmission has established the concept of encoding analogue waveforms as a sequence of digitally encoded sample amplitudes; what may not be so widely appreciated is that a sequence of samples can be processed to produce a filtered version of the original waveform. This Appendix is intended to introduce the basic concepts of such processing, which is called *digital filtering*.

The principle of digital filtering is illustrated in Fig. 13; a waveform $v(t)$ is encoded by an analogue-to-digital converter to form a

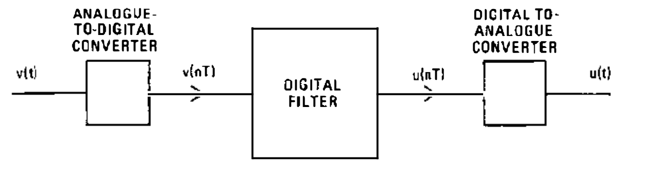

FIG. 13—Digital filtering of an analogue waveform

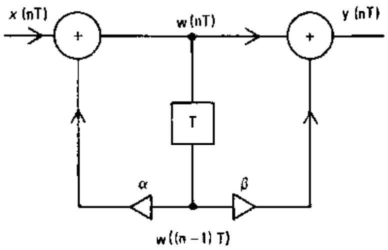

FIG. 14—Simple digital filter

time-sequence of PCM samples of amplitude $v(nT)$, where T is the time between sampling instants and n is an integer; the samples $v(nT)$ are processed digitally to produce another sequence of samples $u(nT)$ which, when decoded by a digital-to-analogue converter, produce a waveform $u(t)$. (Note: quantization noise is ignored). The waveform $u(t)$ is a linearly filtered version of $v(t)$, that is, the spectrum of $u(t)$ contains the same frequency component as $v(t)$, but modified in amplitude (which could be reduced to zero) and phase, and no new frequencies are generated. (It should be noted that, in the application described in this article, the analogue-to-digital converter is already provided by the PCM multiplex equipment and the digital-to-analogue converter is not required because the output from the receiver is simply a logic level indicating the presence or absence of a tone).

In its simplest form, the digital processing consists of 3 elemental functions: the addition of sample amplitudes, the multiplication of sample amplitudes by a constant, and the delaying of samples by integer multiples of T. A simple digital filter flow diagram indicating how a number of these elemental functions may be interconnected is shown in Fig. 14. The flow diagram is a pictorial way of representing the operations.

$$y(nT) = w(nT) + \beta \cdot w(nT-T), \text{ and} \qquad \ldots\ldots(A1)$$

$$w(nT) = x(nT) + \alpha \cdot w(nT-T). \qquad \ldots\ldots(A2)$$

In continuous-network theory, it is convenient to handle differential equations by application of the Laplace transform; likewise, in discrete-network theory, equations of the kind above are best handled using the z-transform. The z-transform, $Y(z)$, of a sequence $y(nT)$ is defined by

$$Y(z) = \sum_{n=-\infty}^{\infty} y(nT)z^{-n} \qquad \ldots\ldots(A3)$$

By using equation (A3) it is easily proved that:

(*a*) if $y(nT) = y_1((n-i)T)$, then $Y(z) = z^{-i}Y_1(z)$,

(*b*) if $y(nT) = k \cdot y_2(nT)$, then $Y(z) = kY_2(z)$, and

(*c*) if $y(nT) = y_3(nT) + y_4(nT)$, then $Y(z) = Y_3(z) + Y_4(z)$.

Applying these results to equations (A1) and (A2),

$$Y(z) = W(z) + \beta \cdot z^{-1} \cdot W(z), \text{ and} \qquad \ldots\ldots(A4)$$

$$W(z) = X(z) + \alpha \cdot z^{-1} \cdot W(z). \qquad \ldots\ldots(A5)$$

Algebraic manipulation yields

$$T(z) = \frac{Y(z)}{X(z)} = \frac{1 + \beta \cdot z^{-1}}{1 - \alpha \cdot z^{-1}}, \qquad \ldots\ldots(A6)$$

where $T(z)$ is the pulse transfer function of the filter. It can be shown that the frequency response $T(j\omega)$ of the filter is given by putting

$$z = \exp(j\omega T),$$

where ω equals $2\pi f$ and f is frequency; therefore,

$$T(j\omega) = \frac{1 + \beta \exp(-j\omega T)}{1 - \alpha \exp(-j\omega T)}. \qquad \ldots\ldots(A7)$$

Hence, the amplitude response is $|T(j\omega)|$ and the phase response $\arg(T(j\omega))$.

High Voltage Power System for Telecommunication Plant: A Safety Aspect

M. J. CARTER†

INTRODUCTION

This article briefly describes the main principles incorporated in new safety procedures which must be observed by British Post Office (BPO) staff when carrying out work involving high-voltage (HV); that is, power systems above 650 V. Most BPO HV power systems are supplied at 11 000 V 50 Hz, although a few supplies are taken at 6600 V.

Provided all rules and working procedures are strictly adhered to, apparatus operating at HV is perfectly safe to operate and maintain. Unfortunately, where HV is concerned, failure to observe the rules and procedures can lead to serious or fatal accidents. Because of this, control and working procedures must be specified in detail and rigidly observed.

HISTORY

In the mid-1960s, HV supplies to BPO premises were confined to a few major centres. However, since that time, the telecommunications system has expanded considerably, and has led to a large increase in power demand. This has resulted in many centres taking their power supply at a high voltage.

The question arises why, in view of the possible dangers, are HV supplies used in BPO premises? The answer rests with the UK Electricity Supply Authority for, above a demand of about 0·5 MW, it is not economic for them to provide a medium voltage (240/415 V) supply and, in this circumstance, only an HV supply is made available.

LEGISLATION

It was recognized that, with an increasing number of HV installations, the existing instructions to BPO staff concerned with the operation of such plant should be critically examined to ensure that the instructions provided adequate guidance. Legislation, including the Health and Safety at Work Act 1974, made this task all the more important, and it became apparent that the standard of information, supervision and training could be improved. This led to the publication of new instructions covering telecommunications power plant HV work within the BPO. These instructions define the control structure and procedures, specify the responsibilites of staff involved in HV work and lay down basic working methods. The paramount aim is to provide safe working procedures for all BPO staff and to ensure that apparatus meets the requirements of the statutory regulations. (The Electricity (Factories Act) Special Regulations 1908 and 1944 is the general title of the statutory regulations which apply.)

SAFETY PRINCIPLES

Working procedures to meet the statutory regulations have long been established and still form the basis of the new instructions. However, considerable attention was given to improving the structure under which these procedures are applied, and the following principles evolved:

(*a*) The authorization to carry out work must be given in writing; that is, an *authority-to-work*.

(*b*) No one is given the authority to authorize himself to carry out work.

(*c*) A written guarantee must be given to persons required to work on apparatus that the apparatus has been rendered safe; that is, a *permit-to-work*.

(*d*) Persons required to work on HV apparatus, or in the vicinity of HV plant, must have a certificate defining their duties.

DESIGNATION OF PERSONNEL

The statutory regulations require that only *Authorized Persons*, or *Competent Persons* under the immediate supervision of an Authorized Person, may undertake work on HV plant, where technical knowledge and experience is required in order to avoid danger. It follows therefore that the appointment of Authorized and Competent Persons must be carefully considered and restricted to trained and qualified engineering personnel familiar with the apparatus on which they are required to work. In respect of HV plant, Authorized and Competent Persons in the BPO must hold an appropriate certificate indicating their competence to do such work; the certificate must be renewed annually.

Principles (*a*) and (*b*) are directly linked and obviously could not be met if an Authorized Person were allowed to authorize himself to work. This led to the introduction of another person in the authorization hierarchy termed the *Engineer (HV)*. An Engineer (HV) is not directly involved in work but is enpowered to issue a written authority-to-work.

In addition to the 3 categories of person already mentioned, 2 more were considered necessary; the *Senior Engineer (HV)* and the *Access-Certificate holder*.

The Senior Engineer (HV) is responsible for the issue of the certificates that define the duties of staff qualified to work on high voltage plant, the production of local instructions where special procedures are necessary and, in addition, bears responsibility for the investigation of any accidents which may occur.

Access-Certificate holders are trained personnel who are only allowed to work on non-HV apparatus which may be near to, but not in the immediate vicinity of, HV apparatus. This category of personnel was introduced to meet service requirements where it was felt that operational efficiency could be enhanced without risk provided that only adequately trained staff were employed on clearly defined duties.

PROCEDURE

The authority-to-work defines all work to be carried out and draws attention to any special precautions or instructions that must be observed. It is issued to an Authorized Person, who must read the content aloud to the issuing Engineer (HV) immediately prior to the commencement of work in order to ensure that the work is fully understood. An authority-to-work is the only document under which work on HV apparatus can be carried out and is the only authority under which a permit-to-work may be issued.

The permit-to-work is a written declaration by an Authorized Person that he has rendered HV apparatus safe to enable work to be carried out. A permit-to-work must not be issued unless covered by an authority-to-work, and then only after the Authorized Person has carried out all safety procedures in the presence of those who will perform the work.

ACKNOWLEDGEMENT

During the preparation of the new BPO instructions, due regard was paid to existing well-tried procedures and to the many helpful and constructive suggestions made by many BPO power engineers.

† Operational Programming Department, Telecommunications Headquarters

An Impulse Generator for the Simulation of Interference Caused by Secondary Lightning Effects

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UDC 621.319.53: 621.316.9

This article outlines the background, operation, construction and safety features of an impulse generator developed by the British Post Office. The generator can automatically deliver the full CCITT specified impulse for prototype tests for power-fed repeaters. It is mains operated, transportable and has been designed with safety as a prime requirement. Consideration in the design has been given to possible modification to provide other high-voltage tests.*

INTRODUCTION

CCITT Recommendations K15 and K17[1] provide guidance on protection requirements and tests to be performed on telephone transmission equipment to simulate the effects of large interfering transient voltages, such as those encountered from the secondary effects of lightning discharges. In the past, vacuum-tube thermionic devices used in telephone transmission equipment were able to tolerate large voltage transients that might appear across them, and would continue to operate in a satisfactory manner. With the advent of semiconductor devices came the problem of protecting the relatively delicate semiconductor junction from the adverse effects of such large transient voltages.

Various forms of transient-voltage suppressors are in use, and these may take the form of gas-discharge tubes[2, 3, 4] non-linear resistors or semiconductor diodes[2].

The need for international agreement on tests to prove the effectiveness of these protection devices is, therefore, readily apparent.

CCITT REQUIREMENTS

The test normally required to be performed on telephone transmission equipment to simulate high-voltage (HV) transients is to apply an impulse to the input or output of the equipment under test. This impulse is derived from the discharge of a previously-charged capacitor through a resistor-capacitor network, which provides shaping of the impulse. A typical impulse generator circuit is shown in Fig. 1.

Early test requirements specified only the magnitude of the impulse, the impulse shape being undefined. Later requirements defined not only the magnitude, but also the impulse shape and duration. CCITT Recommendation K17 defines the following characteristics of the impulse:

(*a*) magnitude in kilovolts,

(*b*) risetime in microseconds, defined as the virtual front time or 1·67 times the time to rise from 30% to 90% of the peak value,

(*c*) decay time in microseconds, defined as the time interval between the virtual origin (see Fig. 2) and half the peak value, and

(*d*) waveshape, defined as the difference of two exponentials with negative exponents chosen to give a nominally linear rising front with an exponential decay.

The actual values of these parameters are varied according to the nature of the test and the type of equipment; for example, transmission equipment, such as repeater and power-feeding equipment, requires a more severe test than does exchange equipment, which is normally protected by the lightning arrestors and fuses at the main distribution frame[5, 6] Recommendation K17 also specifies that the test on prototype equipment is more severe than the tests conducted on production equipment, and this is achieved by increasing the magnitude and decreasing the risetime of the impulse. The number, polarity and time interval between successive impulses are also specified. Table 1 is an extract from the current CCITT requirements and Fig. 2 defines a typical impulse voltage.

DESIGN PARAMETERS

Because of the paucity and high cost of commercially-made impulse generators, the BPO embarked on a programme to design and develop an impulse generator that would fulfil the following requirements:

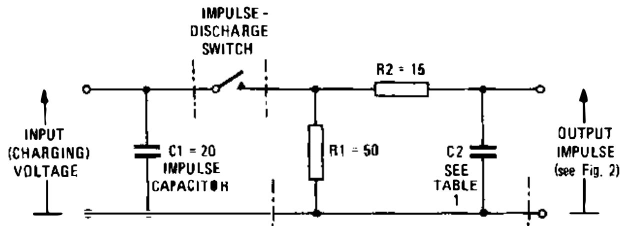
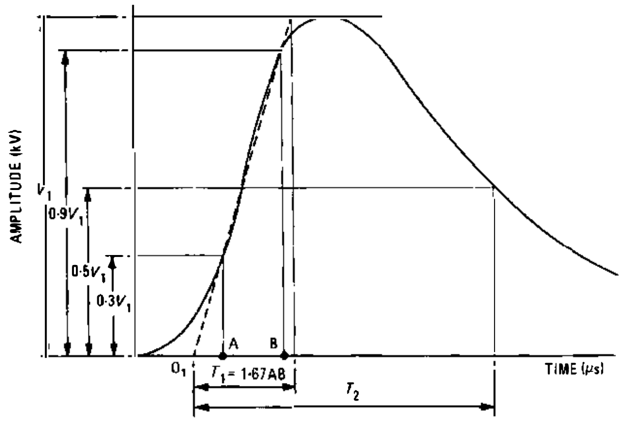


FIG. 1—CCITT impulse generator circuit



V_1: Peak voltage in kilovolts
O_1: Virtual origin
T_1: Nominal risetime in microseconds
T_2: Nominal time for impulse to decay to half of peak value in microseconds
The impulse characteristic may be defined by $V_1 \times T_1/T_2$

FIG. 2—Definition of standard waveform of impulse voltage

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* CCITT—International Telegraph and Telephone Consultative Committee

TABLE 1
Design Characteristics

	Prototype Tests	Acceptance Tests
Waveform (see Fig. 2)	10/700	100/700
Peak voltage (kilovolts)	5	3
C2 (microfarads)	0·2	2·0
Number of pulses	10	2

Note: The test is carried out with the polarity reversed at consecutive pulses, with a time interval of 1 min between the pulses; the number of pulses applied to each test-point in the different cases is shown in the bottom line of the table.

(*a*) intrinsic operator safety,
(*b*) operating simplicity,
(*c*) performance of the full CCITT 5 kV 10/700 μs impulse test for prototype equipment, including successive polarity reversals,
(*d*) provision of audible and visual alarms to monitor test status,
(*e*) expansion capability to cater for future additional impulse and high voltage tests, and
(*g*) transportability.

To enable costs to be minimized and avoid undue development work, it was decided at an early stage to employ as many commercially-made components as possible, using a minimum amount of modification.

ADDITIONAL FACILITIES

In addition to the design parameters, the impulse generator provides the following:

(*a*) an impulse waveform of 4 kV 5/130 μs,
(*b*) further waveforms, by adding more discharge capacitors and/or shaping networks on the spare output-switch contacts (a total of five contacts are available),
(*c*) the selected waveform is available at either polarity with an adjustable magnitude of between 3–5 kV, and
(*d*) the output can be provided by either manual or automatic switching (triggering) of the impulse generator circuit.

In the automatic mode, the following facilities are provided:

(*a*) the number of impulses can be preset from 1–99; the test ceases when the preset number of impulses has been reached, and is indicated by the operation of an alarm (this facility also operates in the manual mode),
(*b*) the time interval between impulses can be preset from 3–72 s (the lower limit is dependent on the charge-up time of the capacitor, and hence the maximum voltage required),
(*c*) automatic alternation of polarity between successive impulses (the initial impulse polarity is selectable), and
(*d*) audible and visual monitors and alarms to show the test status, together with output sockets to monitor the output voltage and provide a synchronous trigger signal for an oscilloscope.

OPERATION

A block diagram of the generator is shown in Fig. 3. The mains input is via a filter socket. The key-operated mains switch has three positions; OFF, MAINS ON and CHARGE. The MAINS ON position supplies power to all circuits except the high-voltage power supply unit. The spring-biased CHARGE position supplies power to the high-voltage power supply unit if the 24 V interlock circuit is unoperated. The mains-monitor circuit prevents operation of the equipment if either the mains earth is missing or if the mains live and neutral connexions are reversed.

The output is derived from the rectified mains (300 V) and is fed to a switching invertor whose output transistors switch this voltage through the high-voltage transformer. The switching is achieved by pulse-width modulation (PWM) of the base drive current in the output transistors. The PWM drive is derived from the control circuit and is provided by a comparator circuit, which compares a sample of the high-voltage output with an internally generated voltage whose magnitude is selected by the SET VOLTS control.

The PWM invertor output is transformed to a maximum value of 2·5 kV AC, depending on the SET VOLTS output control setting. A Cockcroft and Walton multiplier circuit doubles this voltage to a maximum value of 5 kV DC. The voltage-doubler circuit also contains the solenoid-operated polarity-reversing switch which reverses the connexion of the high-voltage transformer to the multiplier circuit and, hence, the polarity of the rectified 5 kV DC output. This voltage is applied to the impulse capacitor via a surge-limiting resistor and a resistor-capacitor voltage-divider network, which provides a voltage sample for the PWM control comparator circuit. A high-power resistor, known as the *dump* resistor, is connected across the output by the normally closed contacts of the DUMP switch—a mains-operated solenoid-controlled high-voltage switch, which is used to discharge (*dump*) the charge on the impulse capacitor in the event of mains or 24 V interlock circuit disconnexion. It is operated only when

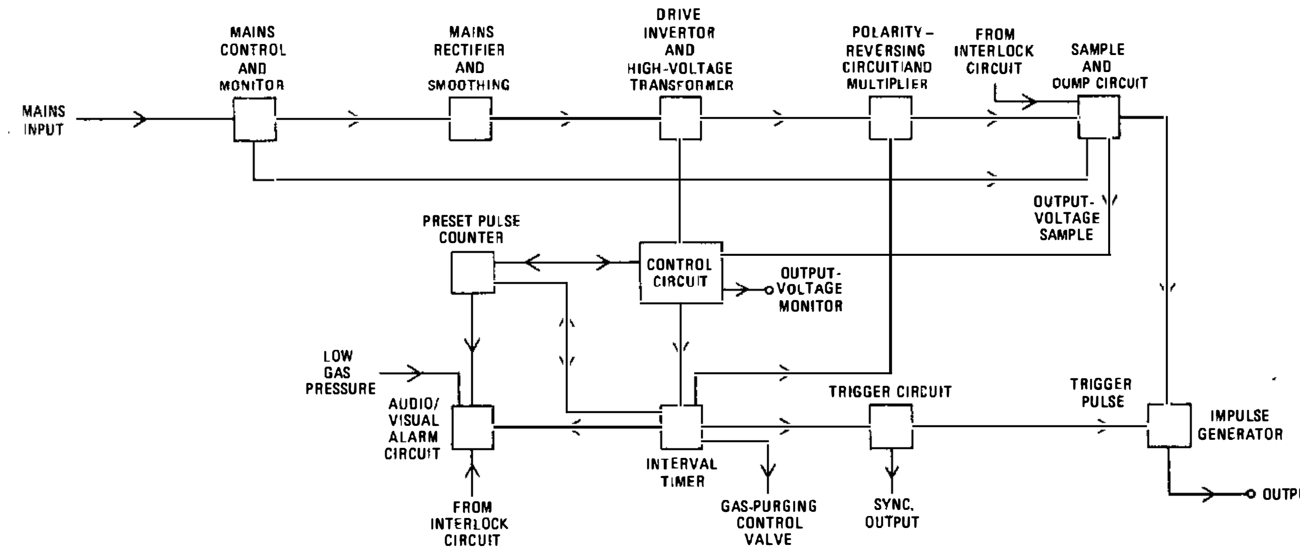

FIG. 3—Block diagram of BPO impulse generator

the mains monitor and 24 V interlock circuits are operating correctly, and the spring-biased CHARGE position of the front-panel key switch has been selected. This position must be re-selected if the dump switch is caused to release (close) during use of the impulse generator.

The dump switch is fail-safe in operation, in that its return to the normally closed (unenergized) position is by gravity with spring assistance. A tilt switch has been incorporated into the mains circuit of the impulse generator to prevent its use at angles greater than 75° from the vertical position.

The impulse generator circuit uses a high-voltage 5-position rotary switch (IMPULSE CHARACTERISTIC switch), manually operated from the front panel, to select an impulse capacitor and a shaping network. These may be connected in any combination by suitable strapping on the high-voltage switch wafer. Currently, two impulse characteristics are catered for; these use the extreme switch positions. Of the remaining 3 positions, the centre is earthed via a resistor and the positions in either side of centre used to release the dump switch during alterations of the IMPULSE CHARACTERISTIC switch. Impulse capacitors not used for a particular test are short-circuited using a high-voltage reed switch and resistor; this prevents any appreciable voltage appearing across them after discharge, due to dielectric relaxation.

The impulse switch used to discharge the impulse generator circuit is a triggered spark gap, which is described later in this article. The triggered spark gap can be operated manually or automatically.

In the manual-trigger mode, the impulse generator circuit is discharged by direct operation of the trigger push-button. The polarity of each pulse is set by the POLARITY-OUTPUT switch. The preset pulse counter normally used in the automatic-trigger mode, may be used to provide an audible and visual alarm for any preset number of impulses from 1–99. A single trigger (*one-shot*) facility is also provided. When operated, it inhibits the high-voltage power supply unit from recharging the impulse capacitor after one discharge, until it is reset.

In the automatic-trigger mode, the trigger circuit is under the control of the interval timer until the number of impulses selected on the preset pulse counter has been reached. When this occurs, the interval timer is stopped, and the audible and visual alarm operates. The polarity of the first impulse can be selected; thereafter, automatic polarity alternation occurs after each impulse. Reversion to the manual mode can be made at any time.

CIRCUIT DESIGN AND SPECIAL FEATURES

Impulse Circuit

The power-supply unit has an output of 100 W and is capable of charging the 20 μF impulse capacitor to 5 kV within 3 s (250 J stored energy).

The impulse generator circuit must withstand the large voltage gradient across it (up to 5 kV) and be capable of delivering a high peak current (this may be in the order of 500 A with a rate of change of 50 A/μs).

Both the impulse capacitors and the shaping network components have been selected from components designed for pulse-discharge working. All component interconnexions are by short, low-inductance, high-voltage leads.

Impulse-Discharge Switch

The requirements of the high-voltage impulse discharge switch (see Fig. 1) used to discharge the impulse capacitor into the shaping network proved to be difficult to meet. The correct operation of this switch is crucial in obtaining an output of the correct shape. Ideally, the switch should possess the following characteristics:

(*a*) zero transition time between open and closed positions, without contact bounce,

(*b*) insulating materials that possess high dielectric strength,

(*c*) the ability to handle high peak currents,

(*d*) low inductance,

(*e*) a high degree of isolation between operating side (trigger) and switching side, and

(*f*) operation from some convenient low-voltage source.

To meet the above requirements, the devices available fall into two categories. The first category comprises electromechanical switching devices; the second comprises those devices that rely on breakdown properties of gases for their action.

The electromechanical high-voltage switches are either constructed along lines similar to the low-voltage relay, but with contacts enclosed in an evacuated envelope, or are in reed relay form.

The electromechanical switches fail the first requirement. Their transition time is in the order of milliseconds; exceptionally it is possible for operate times of 500 μs to be achieved, but 10–30 ms is more usual. In addition, as the contact gap reduces during the operate phase, arcing occurs, though in a vacuum this is less serious than in a gas. The most serious drawback to using electromechanical relays for this purpose is contact bounce, and this cannot be obviated.

The gas switch relies for its operation on the avalanche effect of an electrical discharge in a gas. Two electrodes in a gaseous medium are separated by such a distance that, when the normal operating voltage is applied across them, breakdown (and hence conduction) is just inhibited and the switch is in the OFF state. To switch the device into conduction, an electrical discharge is initiated between a third (trigger) electrode and one of the main electrodes. This primary discharge ionizes the surrounding gas and produces free electrons. These are swept across the main electrode gap by the high electric field, conduction occurs and is maintained by the avalanche effect until the voltage between the main electrodes drops below the sustaining voltage of the gap.

This device can take the form of either a sealed glass or ceramic envelope containing a gas such as cadmium or mercury vapour, or a vented envelope normally containing air, but which may be filled for use with an inert, or relatively inert, gas such as nitrogen or carbon dioxide. Both types are triggered spark gaps, the former type may also be known as *Ignitron*, *surge diverter*, *sealed triggered spark gap* or *cold cathode triggered spark gap*. The latter type may be known as a *Triggertron* pressurized or vented triggered spark gap.

The operate time of these devices is in the order of 100 μs, but both types require more complex switching circuitry compared with their electromechanical counterparts, and also have asymmetrical switching (breakdown) characteristics. Additionally, the vented types require a gas supply and control equipment if they are to be operated in the gas-filled mode.

Two-electrode self-discharged spark gaps are not suitable as high-voltage switches in this context as the self-breakdown point is not readily definable or repeatable.

A third type of high-voltage switch has recently become available. This is the high-voltage thyristor. Isolation between the anode and the cathode and the gate electrode is maintained by optically coupling the gate electrode to the triggering source, and this is built into the device. The main disadvantages of these high-voltage semiconductor devices is that they have a 5 kV maximum voltage rating, and are polarized.

Of these devices, the vented triggered spark gap was chosen as the high-voltage switch because of its ability to handle high energy pulses (up to 14 kJ).

This device, together with its trigger transformer and isolation capacitor, is shown in Fig. 4. The main electrodes are detachable for cleaning and the trigger electrode is a car sparking plug with the side electrode removed. A non-resettable totalizing counter is associated with the trigger circuitry. This shows the cumulative discharges and provides an aid for regular maintenance of the spark gap. The trigger-

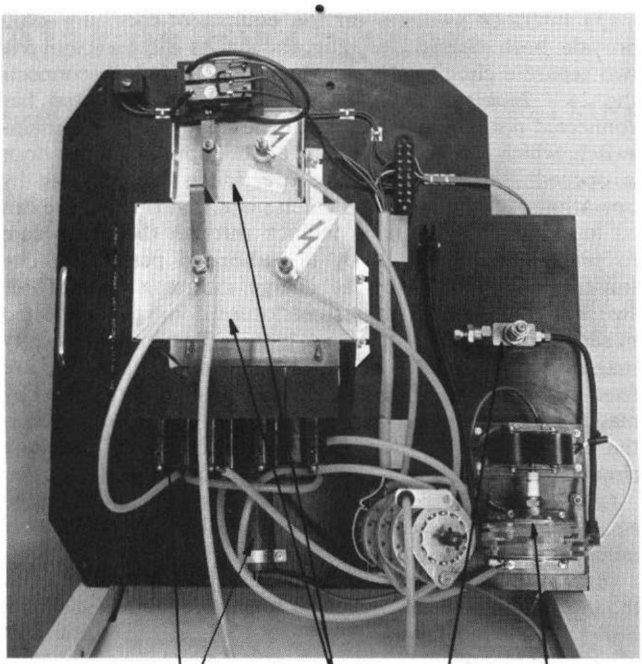

FIG. 4—The high-voltage tray

ing pulse is supplied from a thyristor-controlled pulse transformer and has a voltage peak in the order of 30 kV with an energy content of approximately 50 mJ.

Gas Pressurization

To exclude dust and damp, and to provide reliable and repeatable operation, the triggered spark gap requires pressurizing, and occasional purging, with an inert gas. Carbon dioxide and nitrogen are suitable readily-obtainable gases. Nitrogen was chosen and a small cylinder (0·04 m^3 of free gas) is contained within the tester. Gas control to the triggered spark gap gas inlet is by a cylinder needle valve and high/low-pressure adjustable regulator. On the outlet side, a solenoid-operated gas valve and a non-return valve control the flow of gas exhausted to the atmosphere. A pressure gauge on the high-pressure side of the regulator monitors the gas-cylinder contents (approximately 12·5 MPa when full), and a contactor pressure gauge on the low-pressure side monitors gas pressure in the triggered spark gap. To enable the gap to operate consistently, at its lowest operating voltage (3 kV), the gas pressure should be kept low—just above atmospheric pressure. Purging is required before starting a test and this is done by momentarily operating the PURGE push-button, after the gas has been turned on at the cylinder valve and the regulator has been adjusted to give the required pressure. The PURGE push-button operates the solenoid valve and allows gas to be vented to atmosphere through the non-return valve. The low-pressure gauge shows a pressure drop during purging when the non-return valve operates. Thereafter, during the test, the solenoid valve momentarily operates during each trigger pulse. An adjustable contact on the low-pressure gauge can be used to provide an audible and visual alarm should the gas pressure to the triggered spark gap fall below a preset value.

MECHANICAL CONSTRUCTION

Cabinet

The complete impulse generator is shown in Fig. 5. The approximate overall dimensions are:

height (minus trolley base)	1200 mm
width	625 mm
depth (to front of control panel)	750 mm

The weight is approximately 50 kg.

To aid mobility, a loosely-mounted four-wheeled trolley can be located within the base of the cabinet by a lip on the base extrusions engaging the protruding nuts of the castor mountings. The two front castors are braked to prevent movement during operation. The use of a loose trolley allows the height of the impulse generator to be kept low when the trolley is removed (as is necessary, for example, when transporting by motor vehicle), but allows the control panel to be operated at a comfortable working height with the trolley *in-situ*. A pair of folding handles mounted on each side further aid manual handling.

In order to render the impulse generator safe enough to be used outside the laboratory environment, it was considered mandatory to provide a test compartment large enough to enclose completely the equipment or components under test. The front and rear panels of the test compartment are transparent, enabling a visual check for flashover and other breakdown effects to be made during the tests. The interior

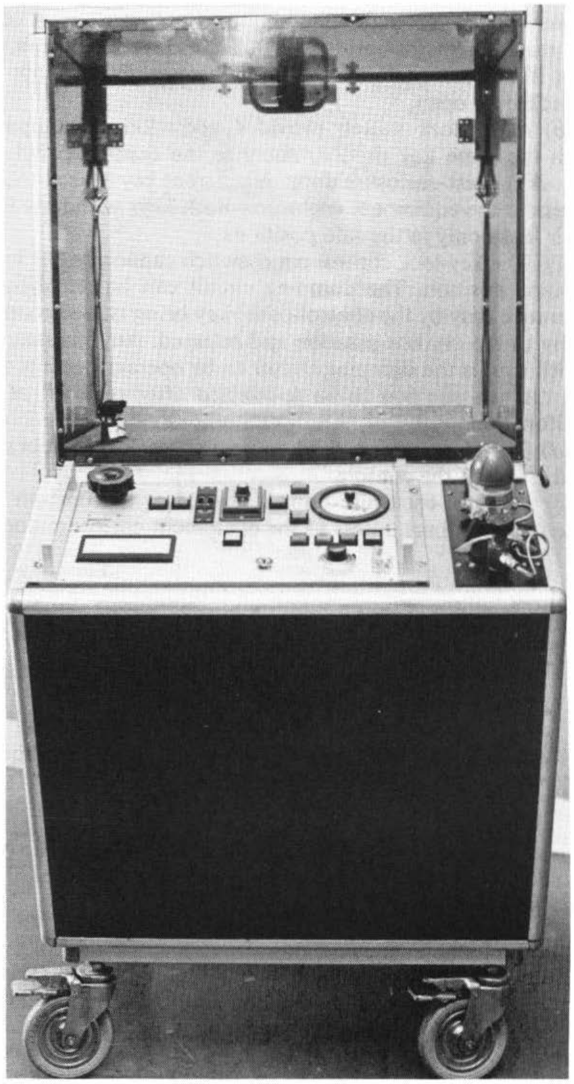

FIG. 5—The BPO impulse generator

size of the compartment (approximately 600 mm wide × 500 mm × 500 mm) was designed to accommodate 3 shelves of BPO 62-type equipment, stacked vertically.

Chassis Unit and Control Panel

All components, other than the gas cylinder, pressure regulator and high-voltage impulse circuit components, are mounted within a chassis unit. This unit was purchased as a proprietary high-voltage capacitor-charging unit, and was enlarged using the original chassis constructional system to accommodate a second 483 mm (19 inch) front panel. These, together with the adjacent front panel containing the gas-cylinder valve and pressure regulator, form the angled control panel of the impulse generator.

To retain a uniform control-panel appearance, the additional switches and lamps are of the same type as those used on the capacitor-charging-unit front panel. The switches are of the illuminated push-button type and can perform up to two separate lamp functions, using a split-lens screen and barrier on the illuminated button. The lamps arc of matching design.

SAFETY CONSIDERATIONS

The impulse generator has been designed to be used outside the laboratory environment and an extremely high degree of operator safety has been provided. The main safety features are:

(*a*) Automatic fail-safe charge dumping and inhibiting of power-supply unit high-voltage output occurs on removal of the mains or mains earth, or if a mains reversal occurs, and also if the test-enclosure or equipment-enclosure door are unlocked or open.

(*b*) A key-lock switch provides operation of equipment with the same key used to energize the control panel and unlock the test-enclosure door. A different key is used to gain access to the equipment enclosure. Both keys withdraw from their locks only in the safe positions.

(*c*) The key-lock control panel switch cannot be left in the CHARGE position. The dumping circuit can be rendered inoperative only by the control-panel key being turned momentarily to the CHARGE position and released. Any malfunction which causes the dumping circuit to be operated necessitates the CHARGE position to be re-selected after removal of the malfunction.

(*d*) The test-enclosure and equipment-enclosure doors are at the rear of the console.

(*e*) The test-enclosure door is hinged at the bottom and when opened, bars access to the equipment-enclosure door.

(*f*) Interlock switches on the equipment-enclosure door provide both charge dumping and mains disconnexion via two separate circuits. The key-lock door switch disconnects the 24 V interlock circuit when unlocked; a pivoted bar connected near the hinged side of the door operates a mains switch, which removes the mains at the input when the door is opened. This switch can be overridden for servicing by operation of a spring-loaded catch plate, but this feature can be barred by the use of a padlock through the catch-plate to prevent its operation by unauthorized personnel. The test-enclosure door provides charge dumping only. Three switches operated by the test-enclosure door are connected in series with the 24 V interlock circuit. Two are heavy-duty magnetically-operated reed switches (normally open) and are fixed on either side of the door frame. These are operated by magnets fixed on either side of the door. The third switch is the key-lock door switch, which breaks the 24 V interlock circuit when unlocked.

(*g*) The detachable mains lead can be stored within the equipment enclosure and is thus inaccessible until the door is unlocked.

(*h*) The output terminals have been placed remote from the test-enclosure door opening.

CONCLUSION

The impulse generator has performed as designed and has proved safe and reliable.

To date, it has been used on coaxial-line-system power-feeding equipment to verify that the protection afforded to components mounted on printed-wiring boards by on-board transient-protection devices (for example, gas-discharge tubes and Zener diodes) is effective.

It has also been instrumental in locating printed-wiring board design faults, such as inadequate spacing between tracks, that allow flash-over to occur under transient-impressed conditions.

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Book Review

Transmission Systems, TEC Level II. D. C. Green, M.TECH., C.ENG., M.I.E.R.E. Pitman Publishing Ltd. 138 pp. 120 ills. £3·20.

The author states in his preface that this book is intended to provide an introduction to transmission systems in line with the requirements of the standard Transmission Systems II syllabus, laid down by the Technician Education Council (TEC).

It can be fairly stated that he has succeeded in this, and the basic principles and application of most modern transmission systems are clearly described. The more general student may, however, need to make reference to other texts to determine, for example, the principles of operation of an amplifier or why an attenuator introduces loss. There are also, unfortunately, a number of uncorrected errors in the text; some diagrams could have been more explicit and the description of a 2-wire negative-impedance repeater as a device which provides amplification by effectively lowering the line resistance is not one that would achieve universal agreement.

However, the book can be recommended for those students following the TEC course who require a simple but comprehensive introduction to present-day transmission systems.

T. A. BENNETT

Alarms By Carrier

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UDC 621.395.743: 654.9

This article describes an alarm-by-carrier system which is being developed by the British Post Office. The system provides for the transmission of fire and intruder alarms from subscribers premises to a central control point (for example, the operations room of a local Fire or Police Authority).

From a protected premises, the alarm system is routed over the same cable pair as that used for the subscriber's telephone line; this is achieved without degradation to either service by transmitting the alarm signals at carrier frequencies.

INTRODUCTION

At present, the majority of alarm signals from automatic fire and intruder detectors are transmitted from the protected premises to Fire or Police Authority operations rooms; the transmissions are routed over private circuits, or recorded messages are sent over the public switched telephone network using emergency-call (999) auto-diallers. The private circuits are provided by the British Post Office (BPO) and rental charges are payable by the user.

Although private circuits offer a secure transmission path, line rentals tend to restrict their use to relatively short lines. Moreover, some Police and Fire Authorities are reluctant to accept direct connexions of this type because of the ever-increasing accommodation demands of the terminal equipment. Although costs tend to be lower using the auto-dialler, the method offers considerably less security, coupled with a significant increase in transmission time. The alarm-by-carrier (ABC) system, which is being developed by the BPO, is aimed at overcoming some of these disadvantages.

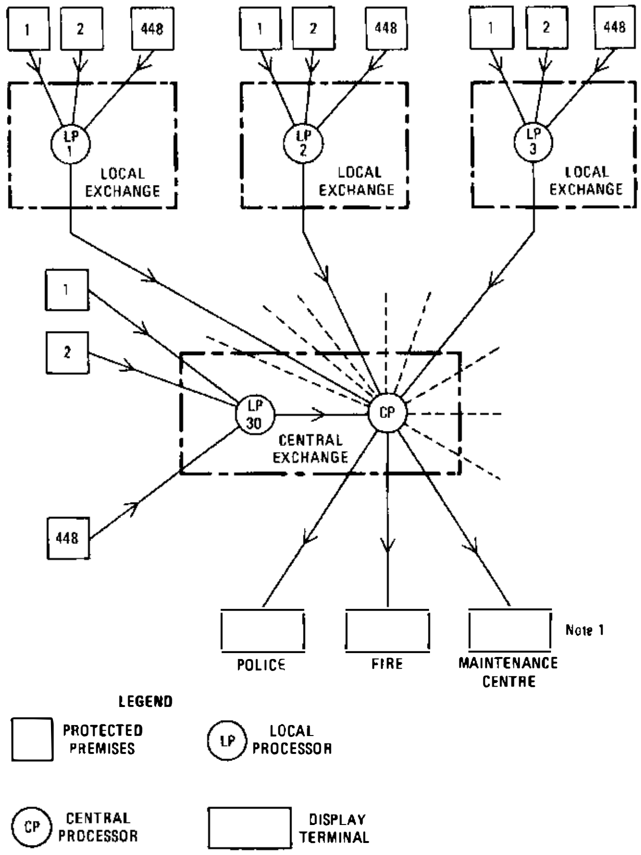
Within each ABC network, rental charges will be independent of distance. This is made possible by making use of existing circuits to transmit alarm signals from the protected premises to the local exchange and by use of time-division and frequency-division multiplexing techniques over the longer junction circuits. Equipment accommodation requirements at each location where alarm conditions are monitored and from which action is initiated (known as an *action point*) are minimized by combining all the outputs onto a single teleprinter.

For security reasons, specific references to operating frequencies and code patterns are omitted from this article.

NETWORK CONFIGURATION

The configuration of a typical ABC network is shown in Fig. 1. For operational convenience, a network will be centred on a telephone exchange sited as near as possible to the local fire and police operations rooms. Up to 30 local exchanges, each equipped with an alarm-signal processor, can be connected to a processor at a central exchange. The processor at each local exchange will be capable of accepting inputs from up to 448 protected premises. Therefore, the maximum capacity of each ABC network will be 13 440 customers. Capacity is available within each local processor for the connexion of a number of local miscellaneous alarms (for example, exchange alarms) if required.

Alarm signals are transmitted at carrier frequencies from the protected premises to the local exchange over a working telephone pair. Time-division and frequency-division signalling techniques are used on private circuits that interconnect local and central exchanges and the central exchange and action points.



Note: Up to a maximum of 15 display terminals (action points) can be connected to each alarm-by-carrier network

Fig. 1—Configuration of a typical alarm-by-carrier network

Alarm signals, generated either by manual call-points provided by the BPO or by automatic detection equipment provided by privatealarm companies, are routed automatically to the appropriate action point, where they appear on a special ABC terminal display-and-print unit. Transmission time averages less than 4 s.

The ABC system contains comprehensive line and equipment fault monitoring facilities, outputs from which are routed automatically to a display-and-print unit located at a BPO maintenance centre.

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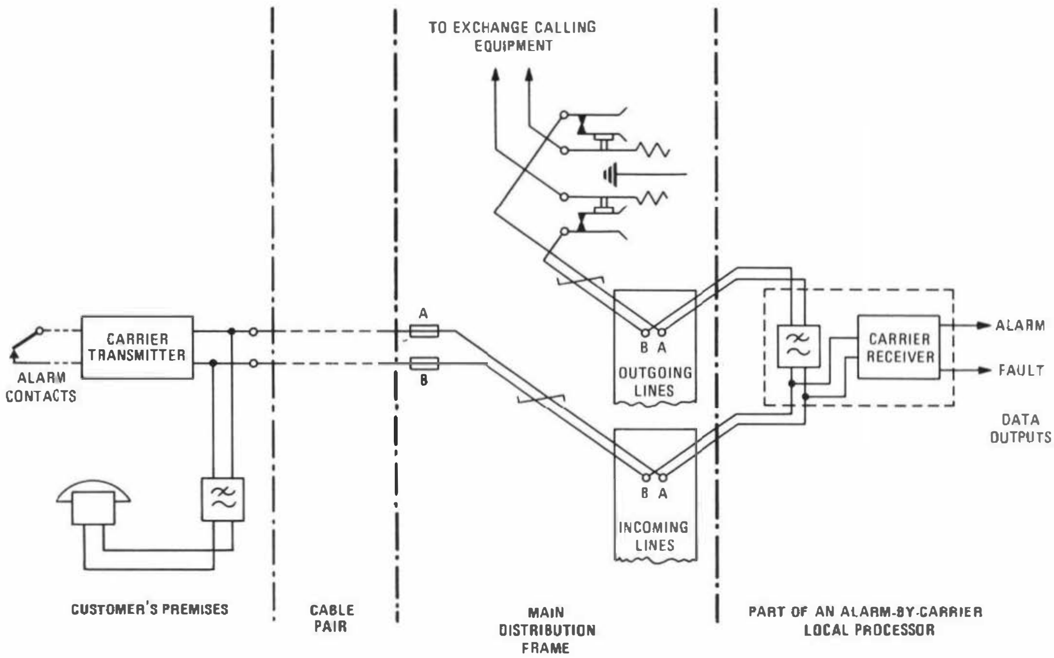


FIG. 2—Local-end connexion of alarm-by-carrier equipment

LOCAL-END TRANSMISSION

The transmission performance of cable pairs used to connect customers' premises to a local telephone exchange is generally satisfactory at frequencies up to 150 kHz without the need for intermediate amplification[1]. A block diagram showing the connexion of an ABC equipment to a telephone cable pair is shown in Fig. 2.

Customers' equipment comprises a carrier-frequency transmitter and a nickel-cadmium battery contained in a plastics case suitable for wall mounting. The unit transmits a modulated carrier-frequency continuously, modulation being controlled by operation of the alarm generator contacts. A separate low-pass filter isolates the telephone circuit from the carrier transmitter. Power is supplied by a 10 V, 225 mA h, nickel-cadmium battery, which is trickle charged over the local line[2]. The charging circuit is disconnected automatically whenever the telephone is required for normal use.

The carrier equipment does not inhibit normal use of the telephone pair, neither does the use of the telephone interfere with alarm-signal transmission.

Two versions of the call point provided by the BPO are available (see Fig. 3), both are activated by pressure on a flexible membrane and are similar to the familiar fire-alarm devices that require a user to break the protective glass-front. The Police call point is installed remote from the carrier transmitter, but the fire call unit forms an integral part of the carrier-frequency sender. The fire call point is also equipped with a *return* signal supervisory lamp.

The carrier receiver connected at the exchange end of the telephone pair will give DC outputs to indicate the presence of carrier and the state of the modulating signal. Failure of the carrier causes a *line-fault* signal to be generated, and a change in the modulating signal gives an *alarm* output.

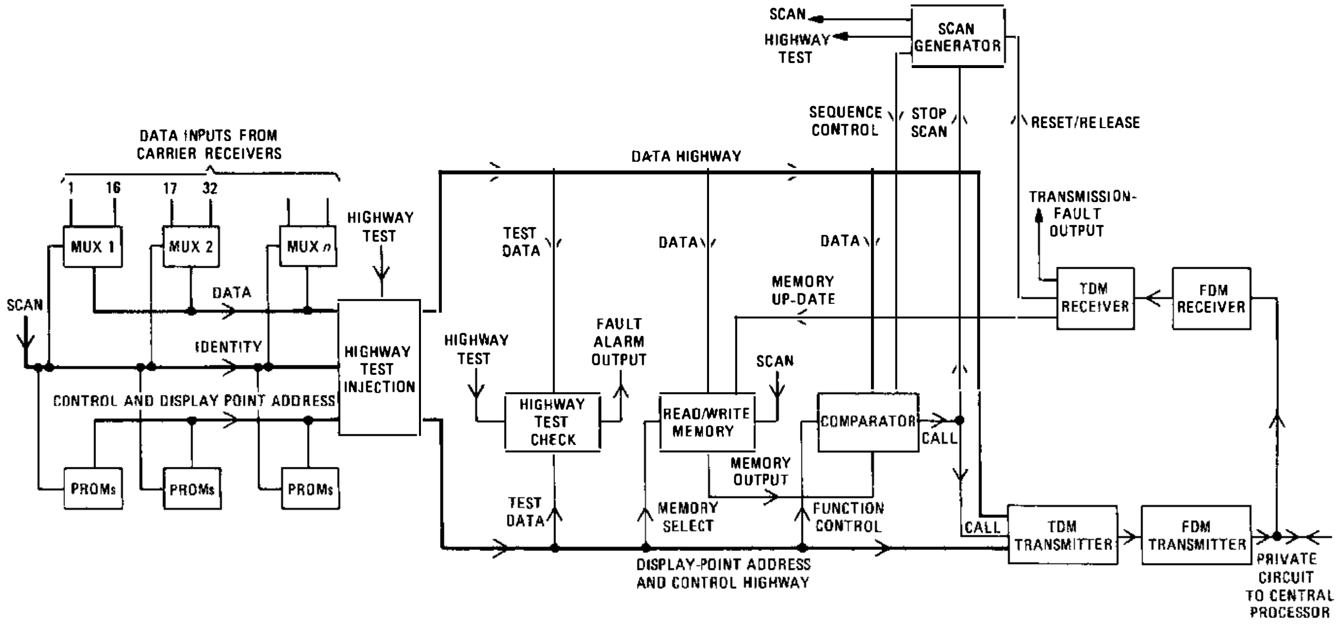
Receipt of an alarm condition causes a signal to be sent back over the telephone pair to the carrier transmitter unit, where it is detected and can be used, if required, to light the *return* signal indicator. The fault and alarm outputs are connected to the common processing equipment. Carrier receivers and processing equipment are mounted on standard type-62 equipment racks installed in the exchange and are powered from the exchange 50 V battery.

When used with privately-provided automatic alarm-signal generators, the carrier sender is mounted in a steel case equipped with a terminal block to provide a common access point. The steel case is protected against malicious attack and can output a local alarm in the event of tampering.

FIG. 3—Call points provided by the BPO

THE LOCAL PROCESSOR

When fully equipped, the processor at the local exchange comprises 4 type-62 equipment racks. The majority of rack space is used to accommodate the carrier receivers. Common equipment required for data processing and line transmission is mounted on the first rack, together with 112 carrier receivers; the other 3 racks are provided as required. Racks are interconnected using plugs and sockets, thereby allowing for



MUX—Multiplexer equipment
PROM—Programmable read-only memory

TDM—Time-division multiplex
FDM—Frequency-division multiplex

Fig. 4—Block diagram of a local processor

growth of the system without interruption to service or the generation of false alarms.

A block diagram of the local processor is shown in Fig. 4. Data inputs comprising the alarm and fault outputs of the carrier receivers and outputs from any miscellaneous alarm sources are assembled in blocks of 16, associated with which are programmable read-only memories (PROMs). The functions of the PROMs are

(*a*) to label the data inputs with the binary-coded address of the terminal at which the message is to be displayed,

(*b*) to permit the data inputs to be handled either in pairs or blocks of 4, and

(*c*) to determine if the selected data is to be routed to both the display terminal nominated by the binary address of (*a*) and the BPO maintenance terminal or to the nominated terminal only.

For data required only at the BPO maintenance terminal (for example, fault and test data), the message is addressed to that terminal by a nominated binary-coded address.

Data inputs are scanned continuously. During a complete sequence each data input is scanned 4 times: the first scan is used in checking the various information highways; the second scan examines the first data bit of either the data pairs or the blocks of 4; the third scan examines all other data inputs; and the fourth scan determines those messages to be duplicated to the BPO maintenance terminal. These functions are controlled by the comparator and a sequence control derived from the scan generator.

The highway-test sequence establishes that the data, the data identity, and the control and address highways are functioning correctly by injecting a test signal at the highway test-injection point and checking the validity of the data in the highway-test check circuit. The data input multiplexers (MUXs) and their associated PROMs are then scanned in sequence under the control of the scan generator. As each data input is switched to the data highway, it is compared with the contents of a read/write memory which is being scanned in synchronism. Each data input is identified uniquely by the binary scan used to switch the MUXs. Whenever a difference is detected between the input data and the memory, the comparator stops the scan on that data input and loads identity, alarm data, call and address information into the time-division multiplex (TDM) and frequency-division multiplex (FDM) transmitter for transmission to the central processor. When the central processor has examined the message, *control* signals are returned to the local processor. If the message is accepted, the read/write memory is updated to the current state of the data input being examined. The scan generator is then reset to scan 1 and released, and the *call* signal removed. If, however, the message is not accepted by the central processor, the returned signal releases the scan generator and removes the *call* signal. The memory is therefore not updated and, since the scan generator is not reset, it continues to examine the data inputs in sequence, returning in due course to the original message, which is then retransmitted. The next data change accepted by the central processor will then initiate a highway test, followed by re-examination of the data inputs on scan 2.

Two forms of testing are used in the local processor: the highway test and the remote test.

The Highway Test

The highway test is used to test that each line in each highway is able to be switched from logic *one* to logic *zero* when the MUXs and PROMs are inhibited. If the highway test fails, further scans of data are inhibited and a *local fault* signal is extended to the BPO maintenance terminal via the TDM/FDM transmission system.

The Remote Test

The remote test is generated at a BPO maintenance terminal and signalled via the central processor to all local processors. The remote test generates an *alarm-data* signal at a specified input to a selected local processor. The local processor signals this alarm to the BPO maintenance terminal. Correct receipt of this message initiates transmission of a *clear-data* signal to the local processor, which signals back to the BPO maintenance terminal. Provision can be made to access each local processor in turn, either automatically or manually, to perform either testing or local-control functions including, ultimately, customer apparatus interrogation.

To guard against line failures, duplicated transmission paths are provided between local and central processors; automatic changeover and alarm facilities are provided. The TDM/FDM links have both parity and signal-level monitors.

To minimize the risk of power supply failure, diversification has been preferred to duplication. Each power unit feeds a limited number of carrier equipments and their associated data multiplexers. Failure of one power unit is signalled via a separately-powered data MUX to the BPO maintenance terminal and does not affect the remaining inputs to the local processor.

THE CENTRAL PROCESSOR

The assembly of a basic central processor serving one local processor and one display terminal, together with common control equipment, is shown in Fig. 5. Additional local processors and displays are served by duplicating the respective terminations connected to the highways. The principal functions of the central processor are

(*a*) to identify *call* signals originating from local processors or display points,

(*b*) to route messages to the display termination identified by the binary address code,

(*c*) to check that the display termination is free to accept a message, and

(*d*) to return control information to the local processor that originated the call.

Operation of the processor is cyclic; the scan generator is stopped only under fault conditions.

Information received from the local processor is presented to the central-processor input-gates from the output of the related TDM receiver. Each termination is enabled in turn by signals derived from the scan generator, which also generates local-test *control* signals and a binary code to identify the local-processor termination being examined. The *enable* signal first causes the gate to generate *test* signals which are passed to the data and address highways. The test signal validity is checked by the local-test check circuit associated with the display termination and a separate check circuit connected directly to the highways. The gate input is examined next to establish if a *call* signal is present. Identification of a *call* signal causes the data and address information to be switched onto the highways for the remaining period of the *enable* signal.

Each display termination store is programmed to recognize a specific address code. The display termination which recognizes the address code received from the local processor then tests to see if the associated store is empty or full.

If the store is empty, the data is loaded into the store and control signals are returned to the local-processor termination, which then sends memory up-date and reset information back to the local processor. A circuit within the local-processor termination ensures that, once a *call* signal has been identified by the central processor, it will, on subsequent scans, be ignored until it has been removed and re-established by the local processor. This is to ensure that the same message is not repeatedly loaded into the display termination. Should the store be full, a *release* signal is returned to the local processor and a flag is set in the store to indicate that a further message is waiting to be displayed. With data loaded into the display-termination store, the data, together with a *call* signal, is transmitted via a TDM/FDM link to the display point. When the display point has recorded the message, an

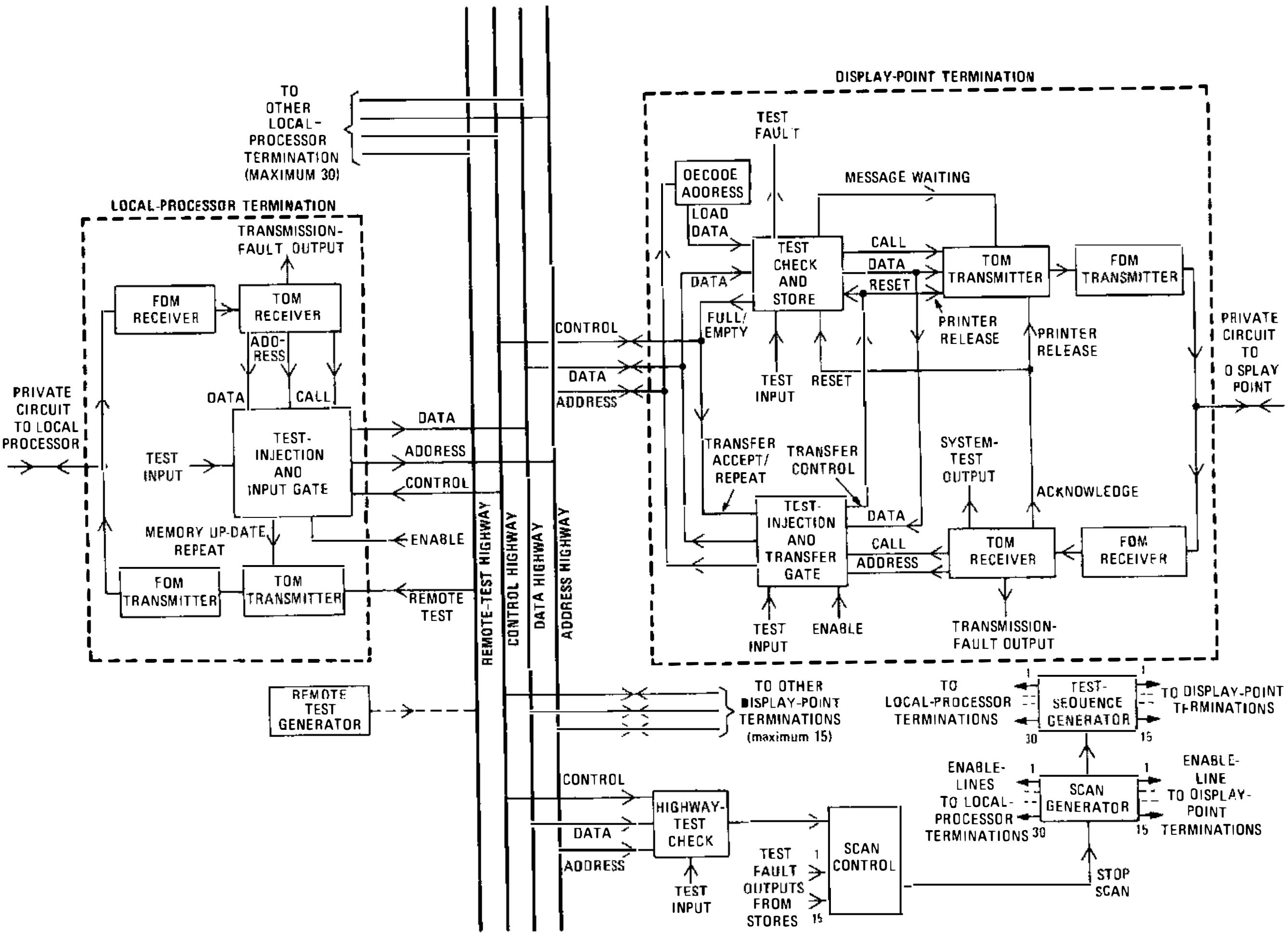


FIG. 5—Block diagram of a central processor

acknowledge signal is returned to the display termination which

(*a*) clears the store, and

(*b*) is then returned to the display point to clear the display.

If it is required to transfer a message to a second display point, the address of the selected new display and a *call* signal are returned to the display termination in place of the *acknowledge* signal. The data output from the store is hard-wired to the input of a gate, which performs in a similar manner to a local-processor termination gate. When this gate is supplied with *call* and *address* signals, it is enabled in the same manner as a processor termination gate and passes information to the data and address highways. If the second display termination is free, the message is loaded into the new store, and control signals are returned to reset the original display store and cancel the *call* and *address* signals from the original display point. If the second display termination is full, a control signal is returned to the original display point to regenerate the *call* signal.

The local test, which is operative during the first part of an enable period, inhibits the normal operation of the gates and causes them to apply a logic *one* followed by a logic *zero* to each line of each highway. The test-check circuits are enabled during this period, and any line which fails to signal the logic levels in the correct sequence at the correct time causes the test-check circuits to output an *alarm* signal and stop further input gates being enabled.

Remote testing of the local processors covers the operation of most parts of the central processor. Each display point can also generate a test message to a predetermined local processor, which will check the operation of that display point's central-processor termination and the display point.

Power supply arrangements are similar to those in the local processor.

THE DISPLAY POINT

A complete display terminal comprises 2 display-and-print units (see Fig. 6) and an associated modem unit containing the TDM and FDM line transmission equipment. The display-and-print units are microprocessor controlled and are operated either in parallel or in a main and standby mode. Interlock circuits prevent both units being switched to standby; if the working unit is disconnected, the remaining device switches automatically to the working mode. Disconnexion of both units (or one, where no standby unit is provided), signals a fault condition to the central processor.

The principal functions of the terminal equipment are shown in Fig. 7 (one unit only is shown). On receipt of a *call* signal from the central processor, the accompanying data is loaded into the visual display and the printer units and, at the same time, audible and visual alarms are activated. Depending upon the message content, either the ACKNOWLEDGE or TRANSFER keys will be operated by the user (both keys having been enabled by the incoming message). Operation of the ACKNOWLEDGE key causes the message stored in the central processor to be cancelled and a *control* signal to be sent back to the display terminal, which causes the received message to be printed and the display and alarms to be cleared. Alternatively, operation of one of the 6 interlocked TRANSFER keys signals a call and the transfer address to the central processor, and silences the audible alarm. The transfer address is read

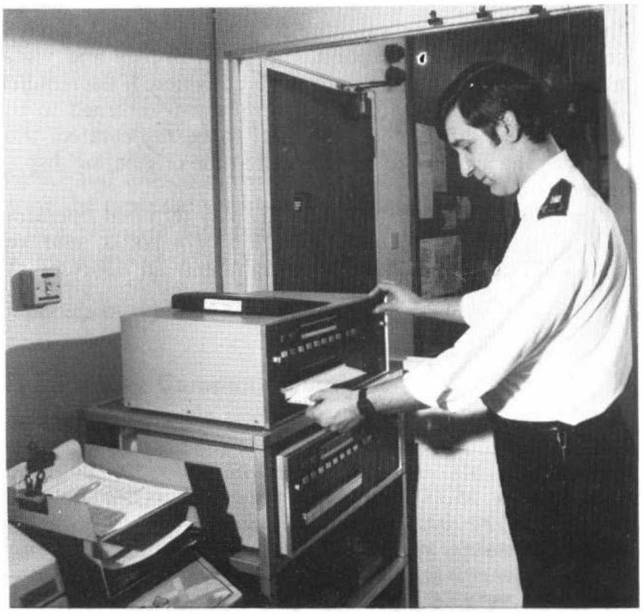


FIG. 6—The display-and-print unit

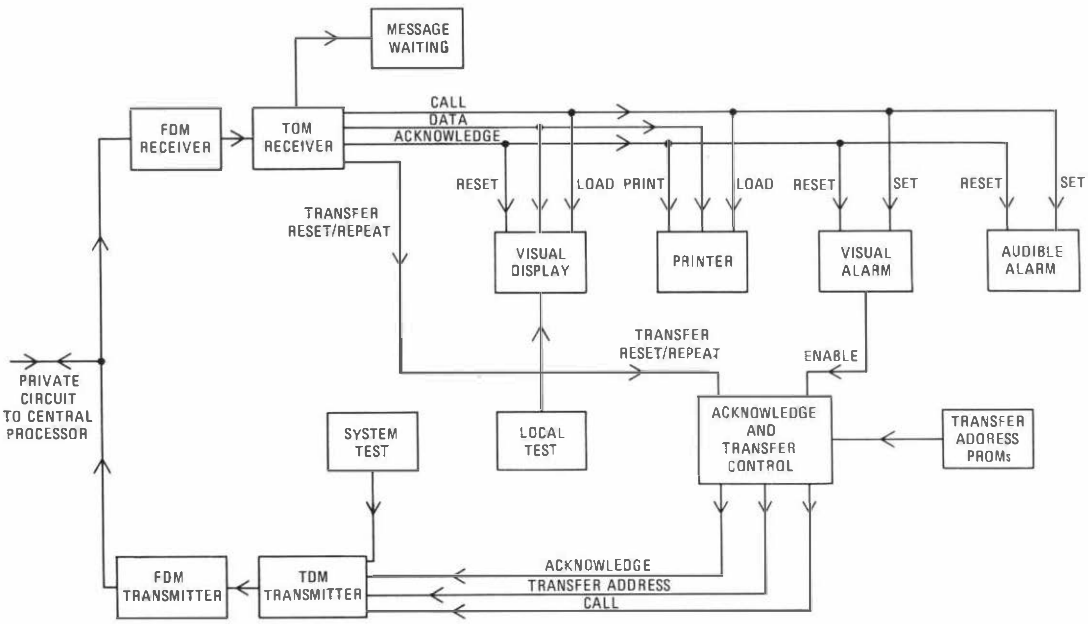
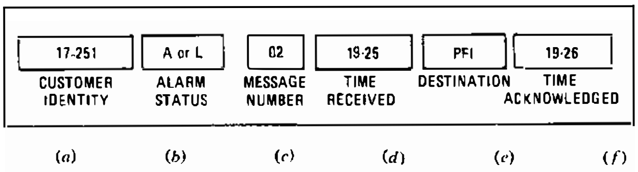


FIG. 7—Block diagram of display-point equipment functions



(a)—In the coded identity of the calling customer, the first 2 digits identify the local processor and the last 3 digits identify the particular customer.
(b)—Identifies the type of alarm (A: Alarm, L: Line Fault).
(c)—Message log up-dated by 1 for each incoming message and automatically reset to 00 at 2400 hours.
(d)—Time of message receipt at the display terminal.
(e)—Code of receiving terminal. Where messages are transferred, the code of appropriate terminal would be printed.
(f)—Time at which the acknowledgement or transfer was effected.

FIG. 8—A typical message print-out

from a PROM housed within the display-and-print unit. The central processor treats the call in the same way as a local processor call. If the central processor is able to load the message into the new display store, a *control* signal is returned to the display point, the visual display and visual alarm are cancelled, and the printer is activated. If the required display-point store is full, the *control* signal returned to the display point causes the *call* signal to be regenerated, thus allowing the message to be accepted at the originating display terminal, if required.

Two tests are available to the display terminal operator: a local and a system test. Operation of a LOCAL TEST key causes all supervisory lamps to light and all digits of the visual display to be presented sequentially from 00 000 to 99 999. Operation of the SYSTEM TEST key causes a test message to be generated at a nominated local processor which is received over the system and printed in the normal manner.

Testing can be carried out at any time the display terminal is not in receipt of a message. The visual-message display contains the coded identity of the calling customer together with the type of alarm. The printed output includes additional "housekeeping" information. A typical message is shown in Fig. 8.

CONCLUSIONS

Extensive trials of the ABC system have established a fundamental system reliability; simulated traffic conditions were used in the evaluation. A system designed to transmit fire and intruder-alarm data must not only be inherently reliable but must also be able to accommodate the various operational requirements of fire and police forces. It is only after an extended in-service period that a complete assessment can be made of the system's effectiveness. The system will be available for public use at selected locations during 1979; expansion of the service offered is planned for the early 1980s.

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The Third World Telecommunications Exhibition: TELECOM 79

Editorial Review

BRITISH TELECOMMUNICATIONS ON SHOW TO THE WORLD

The third World Telecommunications Exhibition, TELECOM 79, will be held at the *Palais des Expositions*, Geneva, from 20th to 26th September 1979. The exhibition has been organized by the International Telecommunication Union. Other events to be held in conjunction with the exhibition include the third World Telecommunications Forum and the first World Book Fair on telecommunications and electronics.

The exhibition will occupy some 70 000 m^2 of floor space and, with more than 500 exhibitors from some 40 countries, will be the largest telecommunications exhibition ever held.

For the first time ever, the British telecommunications industry is to present a co-ordinated display of its systems, equipment and capability to the world. Five leading firms are joining with the British Post Office (BPO) to show their products and services at TELECOM 79. The companies are GEC Telecommunications Limited, Plessey Telecommunications Limited, Standard Telephones and Cables Limited, Marconi Communication Systems Limited and Pye TMC Limited.

The co-ordinated display of British telecommunications on show at TELECOM 79 centres on the world's first public demonstration of a working System X exchange†, supported by a range of modern digital transmission systems and new designs of customer apparatus appropriate to the coming digital era; for example, digital PABXs and Prestel, the BPO's viewdata service. The management and maintenance aids used by the BPO will also be on display.

The display has been designed to demonstrate British strategic thinking about the way future telecommunications networks and services will evolve. It will also embrace the extensive research and development programme under way in Britain, the user facilities becoming available and how the accumulated British telecommunications knowledge and experience can be made available to overseas customers.

† System X—A family of digital-switching telephone exchanges that will provide the switching element of an integrated network of digital transmission and switching systems.

Announcing the plans on behalf of all the partners in this joint British enterprise, Sir William Barlow, Chairman of the British Post Office, said, "Combining forces in this co-ordinated presentation at Geneva enables Britain to promote its telecommunications capability as a total concept. We are projecting a unified front to show the world that Britain intends to resume its leading position in the arena of world competition for telecommunication markets."

He continued, "We shall show that Britain is still a great commercial nation, with a wealth of innovative talent in the advanced technology that will revolutionize the world's telecommunications systems and services. This collaboration at TELECOM 79 is a real 'first' for British telecommunications."

". . . the most important item will be System X---one of the most significant and exciting developments in world telecommunications today. Our flexible approach to its design—enabling us to include the latest facilities and apply the most up-to-date technologies—will put System X ahead of other digital systems currently under development when it becomes available in 1981."

"System X and TELECOM 79 are great opportunities for Britain", Sir William added. "We believe that System X is the product we so urgently need to sell to the world. We in the BPO have already demonstrated our faith and confidence in it in a big way. We are investing £150M in its development and have set the lead with a firm supply programme for our own UK network, which is among the world's largest."

"We will be showing how System X can be adapted to the different service and operational needs in Britain and abroad; how System X is not just another exchange system—but a complete approach, in which computer aids in design, planning and operations are helping to cut costs and reduce the time taken to respond to new technology, and to the diverse and ever changing needs both of our own customers and overseas administrations."

The largest single telecommunications development project ever undertaken in Britain, System X is a collaborative project between the BPO, GEC, Plessey and STC. These 4 organizations have formed a new company—British Telecommunications Systems Limited—to promote System X overseas.

At Geneva, more than 2500 m^2 of exhibition space has been booked for the British stand.

In addition to the BPO and the 5 leading companies, there will be 27 other organizations exhibiting under the aegis of the Electronic Engineering Association (EEA) in conjunction with the British Overseas Trade Board (BOTB).

UK EXHIBITORS

In addition to the joint display, the BPO and the individual companies will each have stand areas for their individual exhibits.

The British Post Office

The BPO will be promoting its overseas consultancy service—the work it does to help other countries plan and run their telecommunication systems.

At any one time, some 250 BPO telecommunication experts are working abroad on assignments which cover almost every expertise required in running a public telephone business. The world-wide experience gained in this way is fed back to the BPO—enhancing its ability to cope with virtually any problem faced by any administration anywhere on the globe.

At every stage of its work, the BPO's telecommunications consultancy service can call on the huge wealth of resources and expertise devoted to planning and operating Britain's vast telecommunications network, valued at some £12 000M.

While the BPO's overseas assistance has traditionally been to provide highly-specialized staff to deal with a particular technical problem, or lead a team assigned to manage a particular task, it is now changing character. As a result of many requests from overseas administrations, the BPO is now undertaking major consultancy projects which require teams of experts embracing many different specialisms.

GEC Telecommunications Limited

The "digital 80s" is the theme of the GEC stand. A total network capability in digital transmission systems up to 140 Mbit/s will be displayed, including microwave-radio systems, line transmission systems for coaxial cable and optical fibre and a complete range of digital multiplex equipment.

Analogue transmission equipment will also be displayed with 6 GHz microwave-radio equipment and frequency-division multiplex equipment, representing a comprehensive range of radio and line systems for up to 2700 channels.

The facilities and versatility of digital business-communication systems will be demonstrated by 2 complementary PABXs, which between them cover a size range from 4 to over 5000 lines. Both equipments use digital switching and stored-program control.

In the subscribers' apparatus field, a wide range of terminals, including digital and analogue telephones, small business systems and payphones will be connected to both digital and analogue switching systems. These will demonstrate the potential versatility of digital switching technology.

In a viewdata demonstration, both domestic and business terminals will be connected through both digital and analogue switching systems to a central computer that will provide hundreds of typical viewdata pages.

The Plessey Company Limited

Plessey will be exhibiting a wide range of products, demonstrating the company's competence over a wide range of advanced technology in communications. The Transmission Division will be showing 30-channel PCM systems with higher-order multiplexing equipment and an optical-fibre system. Public telephone switching will be represented by the PENTEX electronic exchange, which was developed specifically for export markets from the BPO TXE2 system. Also for use in the public network, a new telex system—based on the Plessey 4660 system recently brought into public service by the BPO at its international exchange in London—will be on display.

Plessey Office Systems Limited will be exhibiting the new PDX and K1 systems, both successfully launched last year, and now sold widely in export markets. The company will also be exhibiting a small business system.

Plessey Electronic Systems Limited will be showing its capability to supply various types of satellite ground stations, including an INTELSAT Standard B installation together with satellite terminals suitable for domestic systems, and units suitable for TV distribution networks. In addition, there will be a display of its capability in the field of maritime satellite communications shore stations.

Standard Telephones and Cables Limited

Standard Telephones and Cables Limited (STC) will be demonstrating the company's activities in the fields of telephone exchange switching, landline and undersea transmission, fibre optics, viewdata, subscriber's terminals and apparatus, communications cable and PTT test and operator equipment.

Many of the products will be included in working demonstrations—some of them operating in the public telephone network.

Major displays will feature TXE 4A electronic telephone exchange equipment, TV transmission over an undersea telephone cable system, data transmission via an optical-fibre link, and the testing of telephone lines and subscribers' apparatus from a remote point. Other exhibits will highlight STC's microprocessor-based Operator Position Assistance System (OPAS), which speeds the tasks of handling telephone calls involving the operator, and the company's purpose-designed business viewdata terminal. A special display will feature STC's full project management capability worldwide, including any civil works that may be involved.

Marconi Communication Systems Limited

Highlighted on the Marconi Communication Systems Limited display will be the new 30-channel PCM equipment which has been designed and developed by Marconi in conjunction with the BPO to be suitable for both home and export markets, and which will have its first showing at TELECOM 79. In recent years, Marconi has supplied over £25M worth of 24- and 30-channel PCM equipment to the BPO and other UK and overseas customers. Additional line equipment on display will include 300 bit/s and 600/1200 bit/s MODEMs and supergroup CODEC equipment.

Marconi will also be featuring a range of the latest radio communications equipment, including 1 kW and 10 kW HF transmitters and an MF/HF receiver from the Marconi fast tuning (MFT) range of radio communications equipment, ably supported by the latest receivers from Eddystone Radio Limited (a member company of Marconi Communication Systems Limited). More than £35M worth of MFT equipment has been sold throughout the world in the last 2 years.

Marconi, as the major supplier of satellite earth stations in the UK, handed over to the BPO a new design 11/14 GHz OTS station at Goonhilly Downs, Cornwall, and the first of a series of new INTELSAT stations at Madley, Herefordshire, at the end of last year, and is currently commissioning the second Madley terminal. The Company is prominent in the design and development of equipment for the next generation of 11/14 GHz systems and will be displaying a 2 Mbit/s data terminal, a 120 Mbit/s TDMA modem, and a model of the 19 m antenna installed at Goonhilly Downs. Also on display will be a Marconi "Arion" maritime shipborne satellite terminal.

The latest line-of-sight radio-relay equipment from the Company's range of microwave products will be displayed, together with models representative of the tropospheric-scatter installations that Marconi has supplied to the BPO to provide communications to offshore North Sea Oil installations.

Pye TMC Limited

Pye TMC is participating on the joint BPO and Industry stand with a wide range of subscribers' apparatus and switching equipment.

Highlights in the display will be a working demonstration of the new Small Business System, developed and manufactured by Pye TMC for the BPO and which has considerable export potential; the VISA viewdata business terminal, a desk-top equipment purpose-designed for the office and incorporating a keyboard and a printer; new generation dial and key-phones and Planset; MF instruments; and a range of autodiallers.

Supplementing these equipments will be a voice response system which stores digitized speech on a silicon chip, and a range of main telephone exchange enhancement equipments, including an electronic regenerator, call transfer and metering units.

Many of the equipments displayed incorporate Pye TMC-developed MOS-LSI circuits, and this activity will be represented by typical purpose-designed silicon chips and logic circuit diagrams.

THE ELECTRONIC ENGINEERING ASSOCIATION

The following companies are exhibiting at TELECOM 79 under the aegis of the Electronic Engineering Association (EEA). A brief description of the products to be displayed by each company is given. Further information can be obtained from the EEA at Leicester House, 8 Leicester Street, London WC2H 7BN.

Company	Product
Airtech Ltd.	RF filters and duplexers
Balfour Beatty Power Construction Ltd.	Masts and tower construction
Barclays Bank Ltd.	International banking facilities
Barkway Electronics Ltd.	Audio intercommunication systems
British Aerospace Dynamics Group	Communication satellites
Carr Fastener Co. Ltd.	Connectors and terminal blocks
Crystalate (Holdings) Ltd.	Connectors, audio equipment, power units
Data and Control Equipment Ltd.	Telex, telegraph and data peripheral equipment
Decca Radar Ltd.	HF cable test equipment, microwave switches
Evered and Company (Metals) Ltd.	Waveguide construction
Farnell Instruments Ltd.	RF test equipment
Feedback Instruments Ltd.	Telephone answering and recording equipment
Institution of Electrical Engineers	Technical publications
IPC Electrical and Electronic Press Ltd.	Technical publications
IPC Science and Technology Press	Technical publications
M-O Valve Company	Surge arresters
Multitone Electric Company Ltd.	Paging systems
Muirhead Data Communications Ltd.	Facsimile communication equipment
National Westminster Bank Ltd.	International banking facilities
Racal-Dana Instruments Ltd.	RF instrumentation
Racal-Milgo Ltd.	Data communication equipment
Salford Electrical Instruments Ltd.	Loading coils, components, test equipment
Sperry Gyroscope	Computer-aided message-switching systems
Telepower Systems Ltd.	Power plant
Trend Communications Ltd.	Data communication equipment
Western Electronics Ltd.	Masts and towers
Williams and Glyn's Bank Ltd.	International banking facilities

The Mayfield Incident

J. W. HAWKINS†

INTRODUCTION

Mayfield is a village some 14·5 km south of Tunbridge Wells in the South Eastern Telecommunications Region. The exchange, an unattended small automatic exchange (UAX 14) which opened for service in 1952, was situated on the northern fringe of the village, next to the village hall but with no houses immediately adjacent to it. Opposite the site stands a large convent school for girls.

On Monday 27 November 1978 at approximately 07.50 hours, an explosion occurred which completely destroyed the exchange. Fig. 1 shows the site later in the same day before any clearance work had been carried out; the cable trench is in the foreground. A very high-energy explosion was indicated as the site was completely devastated and debris was scattered over a wide area. Pieces of brickwork approximately 0·5 m^2 were thrown across the adjacent main road and also into the field adjacent to the exchange. The slope of the ground shielded the village hall from the main effects of the blast, but the wooden hut used by the Mayfield Band, situated between the exchange and the hall, was extensively damaged. Many of the windows of the girls' school on the other side of the main road were blown in by the blast.

Miraculously, no traffic was passing at the time and the only injury reported was to one girl slightly injured by flying glass. The Fire Brigade were the first known people on the scene and Area Management received its first information when the Brigade Headquarters at Lewes telephoned the group switching centre (GSC) at Tunbridge Wells. Maintenance engineers were soon on site, followed shortly afterwards by planning staff from Tunbridge Wells to determine means of restoring service.

THE EXCHANGE

There was no visible evidence or smell of fire on the site, but first arrivals reported a strong smell of gas. The explosion appeared to have occurred near the front of the building as all the apparatus racks and the roof beams were blown towards the rear. The main distribution frame was moved in a 90° arc from its original position, dragging some cables through the lead duct seal. Channel irons which had previously carried wooden trap-door entries to the cable trench showed severe downward deformation. Although difficult to prove conclusively, it is strongly suspected that natural gas from a leaking gas main, ignited by a spark from exchange equipment, was the cause of the explosion. Cable entry to the building was by means of a 9-way earthenware duct terminating in a shallow cable trench approximately 1 m deep. The duct end was sealed with a lead-sheet seal and the cables were plumbed to this, or in the case of plastic-sheathed cables, sealed with mastic. This all appeared to be in good condition apart from the pulling of the cables due to the explosion. The cable trench, which had been extended towards the front of the building after the exchange had been built, was lined inside with an asphalt tanking. Inside this tanking had been built a false wall of 115 mm (4½ inches) brickwork terminating at floor level, and to which cable bearers and the duct seal were fixed. At the point where the duct entered the building, there was a loosely filled crevice of approximately 50 mm between the asphalt tanking and the false wall. A piece broken from the top of the earthenware duct in this gap allowed a free passage of gas from the duct into the building that would not have been discovered in the regular tests carried out on duct seals.

A few hours after the explosion, Gas Board engineers discovered a fracture in a 150 mm cast-iron gas main in the footpath outside the exchange at a point where it crossed over the exchange lead-in with a clearance of only 50 mm. From this point the duct entered the building with no intermediate joint boxes.

† Tunbridge Wells Telephone Area

FIG. 1—The scene shortly after the explosion

THE RESTORATION PLAN

It was immediately evident that no equipment at the exchange was usable and a temporary replacement exchange would be required. It was decided that 3 mobile non-director exchanges (MNDXs) (mobile strowger exchanges) were required to restore service to all Mayfield's 950 customers. A means of restoring an emergency telephone service to the village was required until these could be brought into service. Temporary cables were laid along the hedgerows to the nearby exchange of Rotherfield and by 11.50 hours a payphone was working in the village hall, together with a second line for site control. Later on the same day, a specially equipped caravan was brought from the Guildford Area in which more payphones and direct exchange lines were installed, to which telephone subscribers were given free access.

THE TEMPORARY EXCHANGE

The MNDXs were despatched from a storage site in the Guildford Area and the first arrived at Mayfield at 15.00 hours on the day of the explosion, followed by the other two the following day. The exchange site was too small to park these without clearing the debris of the old exchange, which would have prejudiced site investigation and hampered subsequent rebuilding. A few hours after the explosion, permission was obtained to use the car park of the village hall as a temporary exchange site. As the mobile exchanges arrived, they were placed in position and work started immediately. Power was initially supplied from a 32 kW mobile generator brought from Tunbridge Wells, but later in the week this was replaced by a permanent mains supply installed by the Electricity Board. Initial work consisted of grading-out selector levels and uniselector gradings. As soon as the second and third mobile exchanges arrived, tie cables were installed between them and the first. Additional selectors and relay-sets were brought in from other exchanges to augment the fitted equipment. By midnight on the first day, junction circuits to the GSC at Tunbridge Wells were completed. Shortly after the disaster occurred, a recorded announcement had been connected to the incoming level from the GSC. This was retained and a new level opened, to which traffic was diverted under the control of operators. Each mobile exchange provided service for 400 lines in the same number range as the UAX 14, and, as soon as the first was ready, emergency lines were reconnected. Those emergency lines which did not fall in the range of the first 400 lines were allocated spare numbers to give them service. The 25 emergency lines in the village had service restored by 17.30 hours on the 28 November. Connexion of the remaining lines followed; half were connected by 09.00 hours on Saturday 2 December and the rest by 12.00 hours on the next day. These restored lines were tested by operators using instruments installed in the village hall. By 18.00 hours on Saturday 2 December the incoming levels from Tunbridge Wells and Heathfield were re-opened and the operator-controlled level retained for operator use. In the days following the reconnexion of full service, other miscellaneous facilities, such as extended alarms and test numbers, were added. Service observation facilities were also added, as it was considered that customers would tend not to report faults, believing the restoration to be only partially complete. The speed of restoration of service was limited by the rate of connexion of external cables and the number of men who could work simultaneously in the restricted space available in the mobile exchanges.

EXTERNAL CABLES

All the underground cables to the exchange were routed through the undamaged exchange manhole in the carriageway of the main road. All cables were extended from here to the temporary exchange site approximately 120 m away, except for one 300-pair local cable which was intercepted and diverted directly to the mobile-exchange site. Sufficient spare duct capacity was available in the highway, but a short length of duct was laid from an existing joint box to the village hall site. One 1200-pair local cable was used and junction requirements were catered for by two 160-pair cables, one 104-pair cable and one 60-pair cable. Cables were cut in the exchange manhole and the ends brought above ground, as the presence of gas prevented jointing below ground. As the work progressed, this proved useful as it enabled jointing to be carried out on three cables simultaneously, which would not have been possible in the manhole. The first junctions and the emergency lines were connected using the 104-pair cable directly from the exchange manhole to the main distribution frame (MDF) in Mobile Exchange No. 1. To connect all the subscribers, a more flexible method was required to enable lines from each of the 3 mobile exchanges to be extended to any point in the distribution network and to interconnect various through-circuits on the junction cables. Two Cabinets Cross Connexion No. 3 were installed close to the mobile exchanges, the junction cables being terminated on one and local cables on the other. A 400-pair tie cable was run from these cabinets to each mobile exchange and terminated on the exchange side of the MDF, thus obviating the need for line-side to exchange-side jumpers.

In the cabinets, cables were terminated on Strips Cross Connexion (plastic strips through which cable pairs are threaded and wire joints made with crimped connectors). The street cables were terminated in cable order and the cables from the mobiles in exchange numerical order. The cross connecting was effected by leaving a long tail on the exchange-side pair and running this as a jumper to connect to the required distribution pair, leaving only one pair of wire joints for each line. The size of the cabinet shells slowed the work of terminating and jumpering, and it was quickly decided to remove the tops and backs to allow more working room. An additional jumper field was then erected above the roof level which allowed more room for jumpers and for connexions between local and junction cabinets. A sectional wooden hut was purchased and erected over the two cabinets after the initial connexions had been completed. Air seals were fitted to the cables and air applied initially from bottles, which were later replaced with cable pressurization equipment installed in the hut. Also installed in the hut were equipment racks to provide amplifying points on coaxial and PCM routes which were being installed by contractors at the time of the explosion.

Records from the Installation Control were used to prepare schedules to reconnect lines. Cable pairs were identified back from the distribution points to the exchange manhole by jointers using pair-locating equipment and two-way radios. After restoration, the completed cable joints were reinforced with wooden splints and the bight of cable passed through the entrance to the exchange manhole. Final sheath closure was then carried out in the manhole.

COMMUNICATION WITH THE COMMUNITY

The village residents were first informed of the reason for the failure of their telephone service by police loudspeaker cars which toured the area. This was followed next morning by a letter from the General Manager's Office delivered to all householders by the Postal service. After the completion of the mobile exchange, the Regional Director, Mr. Barker, met and thanked all his staff who had worked on the project. Representatives of the local community were invited to this meeting and expressed their great satisfaction at the speed of restoration of their telephone service. This satisfaction was later expressed in more tangible form when the residents organized a party for the Post Office staff which included entertainment by the Mayfield Band and the local Womens' Institute.

SITE CONTROL

Soon after the initial report of the explosion the Head of Maintenance, Mr. Gray, took charge of operations on the site. An Incident Control was set up in the Telephone Area Office to report progress to the Regional Headquarters. Communication to the site was initially by radio using a vehicle from the Underground Maintenance group. During the first morning the radio link was augmented with an exchange line to Rotherfield and later with lines to Tunbridge Wells, using junction cables and a portable incident rack which had been specially constructed at an earlier date for use in just such an emergency.

The village hall was made available for a control centre and was extensively used by all groups. Planning staff prepared jointing schedules on site and, later in the week, a miniature Repair Service Centre was set up in the hall, using records brought from the main centre at Tunbridge Wells. The kitchen facilities of the hall were also used by the Post Office Catering Division to provide a day and night service of hot meals and drinks for the staff on site throughout the week. Work continued round the clock during the week and many of the staff worked long hours.

PERMANENT EXCHANGE REPLACEMENT

The Strowger equipment was already scheduled to be replaced with reduced-height TXE2 equipment in the existing building. This TXE2 equipment will now be housed in a new Q-type building to be built on the site of the original exchange, for which planning permission has been obtained.

CONCLUSIONS

The complete restoration was carried out by staff of the Tunbridge Wells Telephone Area with the co-operation and support of Regional Headquarters and other Areas who lent equipment. A 950-line exchange was virtually restored in six working days, an achievement of which all concerned can feel justifiably proud. It is planned to have the new TXE2 exchange in service by the end of 1980.

The Introduction of a Pentex Exchange into the Public Network

G. P. MATTY, B.A.(HONS.)†

At 08.00 hours on 5 December 1978, a new non-director (ND), 6000-line exchange entered public service at Werrington in the Peterborough Telephone Area. The exchange is a *Plessey Pentex ERM*, a large local exchange and one of the range of complementary systems marketed by Plessey Telecommunications Ltd. (PTL) for overseas administrations. The Pentex exchange replaced an existing order, with PTL, for a TXK1 exchange as a result of a PTL request for a public-service trial facility in the British Post Office (BPO) network, in order that the Company could demonstrate the system to potential overseas buyers. GEC Telecommunications Ltd. requested a similar facility, and a *GEC RS22* small local exchange has been in public service at Clipston in the Leicester Telephone Area since 26 January 1978.

A brief description of the Pentex ERM exchange will be given in a later article in this *Journal*.

The common-control equipment is similar to that of TXE2, but a separate incoming junction processor, with separate registers, has been provided.

† Peterborough Telephone Area

The Pentex system was provided under a specially negotiated contract. In addition to cost aspects, agreements were reached with PTL on commissioning and acceptance specifications; long-term procurement of specialist components and equipment for extensions; technical back-up, post-design service facilities and feedback on system performance; documentation requirements; test gear and special tools to be supplied; future modification strategy; and training of BPO staff.

During the period of the contract, progress was monitored by regular meetings between the BPO and PTL.

The installation of the Pentex exchange started on time early in 1977, and commissioning commenced in late 1977. Towards the end of the project, and following a successful multi-call sample, Telecommunications Development Department performed compatibility testing on transmission, pulsing, and junction and line limits. The tests were successfully concluded and the exchange entered service on 5 December 1978. To date, the exchange has performed to the expectations of both the BPO and PTL. The installation of a further extension of 2000 lines is planned to start in late 1979, and future extensions are planned for an ultimate capacity of 20 000 lines.

Institution of Post Office Electrical Engineers

General Secretary: Mr. R. Farr, THQ/NP9.5.4, Room S 04, River Plate House, Finsbury Circus, London EC2M 7LY; Tel: 01-432 1954

RESULTS OF 1978–79 ESSAY COMPETITION

Prizes and Institution Certificates have been awarded to the following competitors for the essays named.

The Council of the Institution records its appreciation to Messrs. A. W. Welsh, A. H. Blois, H. C. Hornsby, C. Johnston and D. W. Stenson for undertaking the task of adjudication and providing summaries of the winning entries.

The prize-winning essays are held in the Institution's central library and are available to borrowers.

Section 1

Essays submitted by members of the Institution in all British Post Office (BPO) grades below the Senior Salary Structure and above the grades in Section 2 below.

Prize of £30 and an Institution Certificate

Mr. D. D. Hornsby, Assistant Executive Engineer, Telecommunications Headquarters, Telecommunications Personnel Department: *Watch Out, Watch Out, There's a Micro About!*

The essay briefly sketches the development of the microprocessor from the early mechanical calculators through to the silicon chip. Present and possible future applications are considered and the social impact of these is discussed. The author concludes that new possibilities, and jobs, will emerge. The changes will, however, be associated with personal upheaval for individuals.

This was a lucid, easily read presentation, well researched and giving a personal view of a new "industrial revolution".

Prizes of £10 and an Institution Certificate.

Mr. E. G. Clayton, Assistant Executive Engineer, Norwich Telephone Area: *The Use of History in the Post Office.*

Starting with the proposition that Telecommunications requires people, the author develops his theme that too little is recorded of the people who install, maintain and use the telephone. He illustrates his arguments to show the sort of historical records that can be built up to put flesh on the bare bones of industrial archaeology in the Post Office.

Mr. J. G. Wardle, Assistant Executive Engineer, Midland Telecommunications Region Headquarters: *Switched Telecommunications Services—Design and Planning.*

The essay sets out the many factors that play a part in the design and provision of the switching network in the United Kingdom. Problems, such as compatibility with existing plant, long-term forecasting and economic considerations, and the switching hierarchy, are discussed. The author's treatment of these topics is, perhaps, stereotyped but thorough.

Section 2

Essays submitted by BPO engineering staff below the rank of Inspector.

Prize of £20 and an Institution Certificate

Mr. M. F. Cruise, Technical Officer, Blackburn Telephone Area: *Telecommunications in the Arab World.*

A topical, well-researched essay surveying the market for telecommunications systems in the Middle East, in which the possible development of networks in most Arab countries over the next decade is discussed. The existing and prospective contracts for equipment and consultative services are described, indicating the potential for UK participation.

Prizes of £12 and an Institution Certificate

Mr. G. Clifford, Technical Officer, Bradford Telephone Area: *Vehicular Traffic Control and the Post Office.*

This essay deals with the effects of modern traffic-control systems on the Post Office, firstly as a major user of roads and secondly as the provider of circuits for video monitors and the computerised control of traffic signals.

Mr. F. Eastham, Technical Officer, Blackburn Telephone Area: *The Hero of Little Brow.*

A night's cable-jointing activity is described in the form of a short story, bringing out technical details and some of the conditions under which jointers operate. As the title implies, there is some drama and a twist at the end of the story.

Prize of £6 and an Institution Certificate

Mr. D. E. F. Blandford, Technical Officer, Portsmouth Telephone Area: *Are You Being Served?*

This essay sets out to give the reader an understanding of the causes of line-plant shortages and their effects on the provision of telephone service. It includes a description of a variant of the standard methods for controlling the waiting list, as used in the Portsmouth Telephone Area.

Certificates of Merit

Mr. W. Headdon, Technician Class 1, Tunbridge Wells Telephone Area: *The Craft of Box Building in the Tunbridge Wells Telephone Area.*

Mr. D. A. Heath, Technical Officer, Southampton Telephone Area: *Keeping the Customer Satisfied.*

Mr. S. J. Wilson, Engineering Instructor, Scottish Telecommunications Board Engineering Training Centre: *A Practical Exercise in Transmission for the Trainee Technician (Apprentice).*

1979–80 ESSAY COMPETITION

Prospective entrants for the next Essay Competition (the details of which will be announced in the October 1979 issue), may like to know that Council has authorized an increase in the prize fund to £100 for each Section instead of £50.

HONORARY MEMBERSHIP

Mr. A. B. Wherry, past General Secretary of IPOEE, has been elected to Honorary Membership in recognition of his considerable services to the Institution over many years.

THE FEDERATION OF TELECOMMUNICATIONS ENGINEERS OF THE EUROPEAN COMMUNITY (FITCE)

By the time this note is read, members should have received my letter dated May 1979 introducing the above Federation. Any member who has not seen a copy should contact their Local Centre Secretary. It is my intention to report progress on the IPOEE bid to join the Federation and on related matters in subsequent issues of the *Journal.*

R. E. FARR
Secretary

The Associate Section National Committee Report

SIXTH NATIONAL TECHNICAL QUIZ COMPETITION FINAL

The sixth national technical quiz competition and awards evening took place at the Institution of Electrical Engineers Theatre, Savoy Place, London on Friday 20 April, 1979. The guests included Mr. Peter Benton, Managing Director, Telecommunications, and his wife, Mrs. Ruth Benton.

Following introductions by Master of Ceremonies Norman Clark, London Centre delegate to the National Committee, came the presentation of awards.

The first award was the Cotswold Trophy, which is presented each year to the Centre, Area or Region that does most to further the aims of the Associate Section, this being the seventh time the award had been presented. The Chairman of the National Committee, Mr. Eric Philcox, invited Mrs. Benton to present the trophy to Mr. Peter Kime, Chairman of the Chester Associate Section Centre, the centre that polled the greatest number of votes this year. The citation referred to a high-quality programme of lectures, visits, an impressive display set up to celebrate the Silver Jubilee, and a quiz timer built for a project.

The next award was the E. W. Fudge Trophy for the Project Competition. The project for 1978–9 did not attract a great deal of support from the regions, so a suitable project of another type was sought. It was found that the London South Area, over the last two years, had built a TXE4 simulator, and after much consultation between the Project Organizer, the National Executive Committee, and Regional delegates it was decided that the London South Area were very worthy winners. Mr. Joe Anning, National Project Organizer, asked Mr. Peter Benton to present the trophy to Mr. Bob Beadle, who represented the winners.

After a short interval, the main business of the evening was reached with the introduction of the Technical Quiz Final by its organizer for the past six years, Mr. Kevin Marden. The teams for 1979 were Cornwall, representing the South West Telecommunications Region, and London East, representing the London Telecommunications Region; the captains of the teams, Mr. Capper and Mr. Ahlquist respectively, introduced their teams to the audience.

An immediate lead was taken by London East and was maintained throughout the contest. The final outcome was a win for London East by 36½ to 32 points. The Bray Trophy was presented by Mr. Benton to Mr. Ahlquist.

Later in the evening about 100 people attended the National Awards Dinner where the guest of honour was Dr. Philip Bray. After a very pleasant meal, Mr. Eric Philcox presented Mr. Gilbert Rimmington and Mr. Brian Hickie with gifts for past services to the National Committee since its inception nearly eight years ago.

All members of the National Executive Committee would like to thank everyone involved in making the evening a success.

M. E. DIBDEN
Secretary

Associate Section Notes

CAMBRIDGE CENTRE

The 1978–79 session has been very successful following a decline of interest in recent years. The programme started in June 1978 with two visits to Lotus Cars Ltd. of Norfolk where members saw the production of the world-famous sports cars. There followed a visit to Pye Telecommunications Ltd. at Cambridge, makers of two-way radio equipment as used by the police and taxi operators. In September, a party of members toured the British Post Office Research Centre at Martlesham and enjoyed a brief look at systems of the future. The next visit was to the USAF base at Alconbury to view the workings of a reconnaissance unit. The final visit of the session was to the Mid-Anglia Police Headquarters at Hinchingbrook where, among other things, we saw a demonstration of the new police computer.

In November, we were given a lecture on *Prestel* by Mr. K. Clarke of the BPO Research Centre at Martlesham.

The Centre's next event was a reversal of roles with the Centre playing host to a party of representatives from firms which members had previously visited. Following an introductory talk by the General Manager of Cambridge Telephone Area, Mr. A. Hull, about 90 guests were taken on a tour of Cambridge Trunk Exchange.

The annual general meeting for 1979 was held in March and the following officers and committee were elected.

President: Mr. D. Ashman.
Chairman: Mr. P. Howlett.
Vice-Chairman: Mr. G. Matheron.
Hon. Secretary: Mr. P. Young.
Assistant Hon. Secretary: Mr. B. Cole.
Hon. Treasurer: Mr. P. Gray.
Committee: Messrs. D. Ford, M. Corby, L. Salmon, B. Matthews and S. Hurt.

The meeting was followed by a talk on the *Work of a General Manager* given by Mr. A. Hull.

The programme for 1979–80 will include visits to Measham Colliery, the RAF Establishment at Bedford, the Ford Motor Company, the PO Tower and underground railway, Boosey and Hawkes Ltd. (musical instrument makers) and a trout farm. Lectures have been arranged on *Fibre Optics* and *System X*. It is hoped to hold an evening meeting during the winter where members can demonstrate their hobbies and interests.

I hope that all members will continue to give support to the Centre in the way in which they did last year. If any information is required, please telephone me on Cambridge 65231.

P. YOUNG

GUILDFORD CENTRE

Since the end of September 1978, the centre has arranged no less than 22 functions. These have included 14 quizzes, 2 lectures, 2 visits, 3 film-shows and a Christmas party.

The Centre's involvement with quizzes has been particularly heavy. After winning the Bluring Trophy in the South-Eastern Telecommunications Region technical quiz we proceeded to the national quiz for the Bray trophy. After managing to reach the second round we were beaten by Grimsby. However, the team still faced the final of the inter-regional quiz between London Telecommunications Region and South-Eastern Telecommunications Region. In this we were successful in retaining the trophy for the third year running. A great deal of time and effort goes into arranging these technical quizzes, and it is a pity that this is not matched by support from the membership.

The Centre's general-knowledge quiz runs from strength to strength. With over 40 teams of 4 members entering this year, the quiz secretary, Dave Leedham, has been kept very busy arranging heats and composing literally thousands of questions.

Between the various quiz competitions, we have had to fit in the other functions; the 2 lectures, one on *Lasers and Their Application in Telecommunications* and the other on *Measurement and Analysis Centres*, attracted fairly small audiences and it is hoped that the forthcoming talk on *System X* will attract a larger attendance.

The 3 film-shows held since last autumn have been fairly well attended. The first one, with a programme suitable for all the family, attracted an audience of 70 members.

There have been only 2 visits since the end of September, one to HMS *Dolphin*, the submarine museum at Gosport, and one to the new sewage and refuse incinerator works at Basingstoke. As always, the visits were well supported.

The committee has endeavoured to arrange a balanced programme and have ensured that the technical content has been maintained. The Centre is very much alive, but more support for the technical functions would encourage the committee.

R. STONE

LUTON CENTRE

The centre has seen a gradually increasing interest over the past few years with a corresponding increase in membership.

In the past session we have had a full programme which has included visits, film-shows and talks on various subjects. There have been 12 meetings, and during the winter some film-shows, mainly on the theme of transport. All the meetings have been well attended and some members have been disappointed because the demand for places on some visits has exceeded the number available.

Activities have included a visit, by 30 members, to the British Rail works at Derby where we were able to see heavy engineering work carried out on locomotives and rolling stock. Construction of the Advanced Passenger Train was also in progress and members were able to make a close inspection of the new train. This was followed by a visit to the Post Office Tower. In January a double visit was arranged: to the Euston power signal box in the morning and to the Victoria line underground depot at Northumberland Park in the afternoon. At Euston, members were able to see one man controlling trains in and out of the station with the aid of a large illuminated control panel. At Northumberland Park, we were able to look over the stock of the first public automatic tube line in this country and to see various servicing operations being carried out. In March, a party of members visited the Post Office Marine Division at Southampton. We were shown over the Cable Ship *Monarch*, which was unloading cable from a recovery operation, and shown round the depot to see the shore-based side of the division.

Great interest was shown in a talk on *Microprocessors* given by Mr. T. Grange of Bedford Area. He brought along a Teletype and a "black box" which he had programmed to play a simple game. In view of the interest, Mr. Grange has kindly consented to speak on the subject again at a later date. Great interest was also shown in a talk and demonstration of *Prestel*.

Future visits are planned to the Post Office Research Centre at Martlesham and to a coal mine.

W. H. WEBB

NEWPORT CENTRE

On 23 March 1979, the annual Associate Section four-centre general-knowledge quiz for the Four Rivers Shield took place, with teams from Bristol, Cardiff, Gloucester and Newport participating. The evening opened with an address of welcome by the Chairman of the host centre, Cardiff, Mr. D. Corp.

The guest question-master was Mr. Arfon Haines Davies, television personality from Harlech Television.

After a very exciting and close contest, the Newport team of G. Essery (Captain), R. Payne, K. Sullivan and T. Withers emerged as winners, just beating Cardiff by 72 points to 69. Gloucester were third (46 points) and Bristol fourth (45 points). At the end of the contest Mr. E. Davies, General Manager Cardiff Telephone Area, presented the shield to the winning captain and the evening concluded with a buffet and discoteque.

K. I. FLEET

OXFORD CENTRE

The Centre now has 11 years behind it, and I am pleased to report that its activities continue to attract new members.

The 1978 summer-visits programme was well supported. The visits included the Post Office railway, the Post Office Tower and the Post Office Research Centre at Martlesham.

A programme of lectures was arranged for the winter and included subjects as diverse as *Antique Clocks*, *Canals* and *Early Telegraphy*. An interesting talk on his journey through the Middle East, illustrated by slides, was given by one of our members.

Once again, the Centre represented the Eastern Region in the National Technical Quiz. After reaching the semi-final, we were narrowly beaten after an exciting contest by Truro (representing the South-West Region).

In the newly instituted Regional General Knowledge Quiz, we have been successful in the two rounds played so far, and eagerly await the third round.

E. I. WARHAM

SOUTHAMPTON CENTRE

The committee elected for the 1978–79 session was:

Chairman: Mr. R. Genge.
General Secretary: Mr. R. Playdon.
Events Secretary: Mr. C. Grant.
Treasurer: Mr. T. Axton.
Librarian: Mr. M. Walker.
Committee: Messrs. P. Bates, J. Green, K. Mann, D. Rolfe, T. Stockwell and R. de Turberville.

A fairly successful programme was arranged for the session with lectures on *Optical Fibres* by Mr. B. White of the Post Office Research Department and on the *Mary Rose* by Mr. A. McKee, the Director of Excavations. Visits have taken place to the Independant Broadcasting Authority at Crawley Court, Winchester and the National Maritime Institute at Hythe.

R. W. PLAYDON

SOUTHEND CENTRE

The past 12 months have seen the firm establishment of the Centre and, as a result of our activities, there has been an influx of new members to bring the total to 260.

Visits have been arranged to Capital Radio, the BBC Television Studios, Telephone Cables Ltd., the Post Office Research Centre at Martlesham, Vauxhall Motors, the Shire Horse Centre, Kodak Ltd., and the Whitefriars Glassworks.

A full programme of visits has been planned for the coming year and we have entered the Regional quiz. For the time being, it has been decided not to organize any lectures as we feel uncertain of the response, but hope, with the growing interest being shown, to include lectures as part of a later programme.

D. W. PARSONS

Forthcoming Conferences

Further details can be obtained from the conference department of the organizing body.

Institution of Electronic and Radio Engineers, 99 Gower Street, London WC1E 6AZ. Telephone: 01-388 3071

Video and Data Recording
24–27 July 1979
The University of Southampton

Land Mobile Radio
4–7 September 1979
The University of Lancaster

Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1H 9JJ. Telephone: 01-839 1211

International Progress in Postal Mechanization
6–8 November 1979
The Institution of Mechanical Engineers, London

Institution of Electrical Engineers, Savoy Place, London WC2R 0BL. Telephone: 01-240 1871

Submarine Telecommunications Systems
26–29 February 1980
The Institution of Electrical Engineers, London

Communications 80: Communications Equipment and Systems
15–18 April 1980
National Exhibition Centre, Birmingham

Secretariat 1980 International Zurich Seminar, Miss D. Hugg, Dept. ENF, BBC Brown, Boveri and Co. Ltd., CH-5401 Baden, Switzerland. Telephone: +41-56-299038.

International Zurich Seminar on Digital Communications (Digital Transmission in Wireless Systems)
4–6 March 1980
Swiss Federal Institute of Technology

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Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Copies of the syllabi and question papers are not sold by *The Post Office Electrical Engineers' Journal*, but may be purchased from the Department of Technology, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

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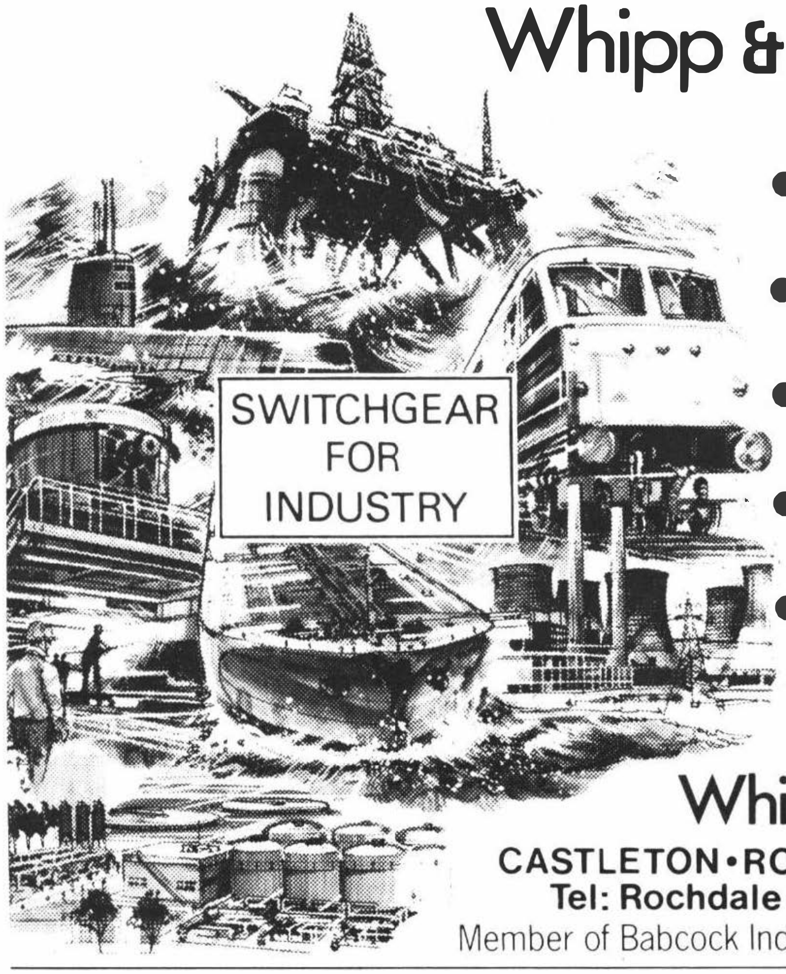

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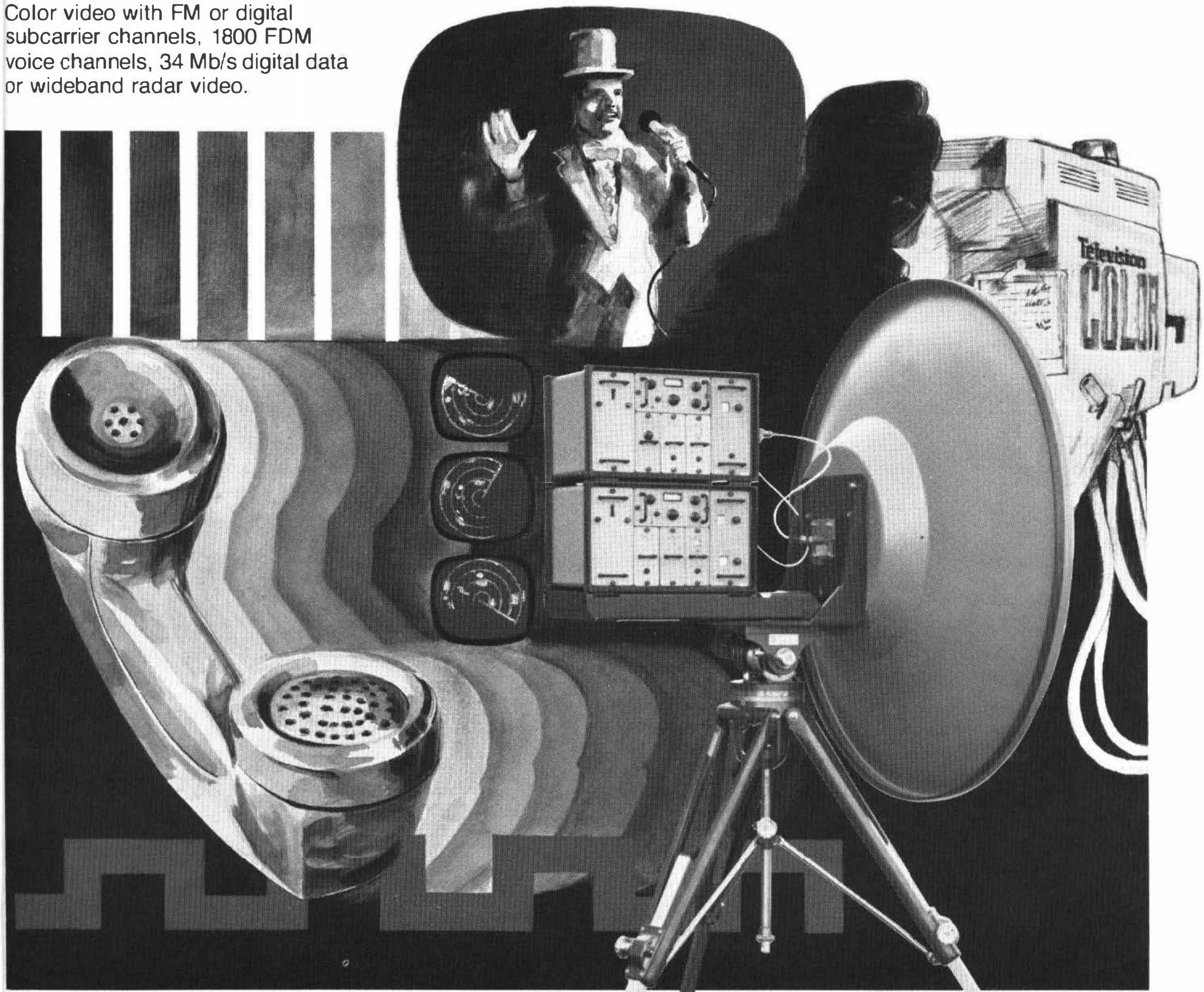

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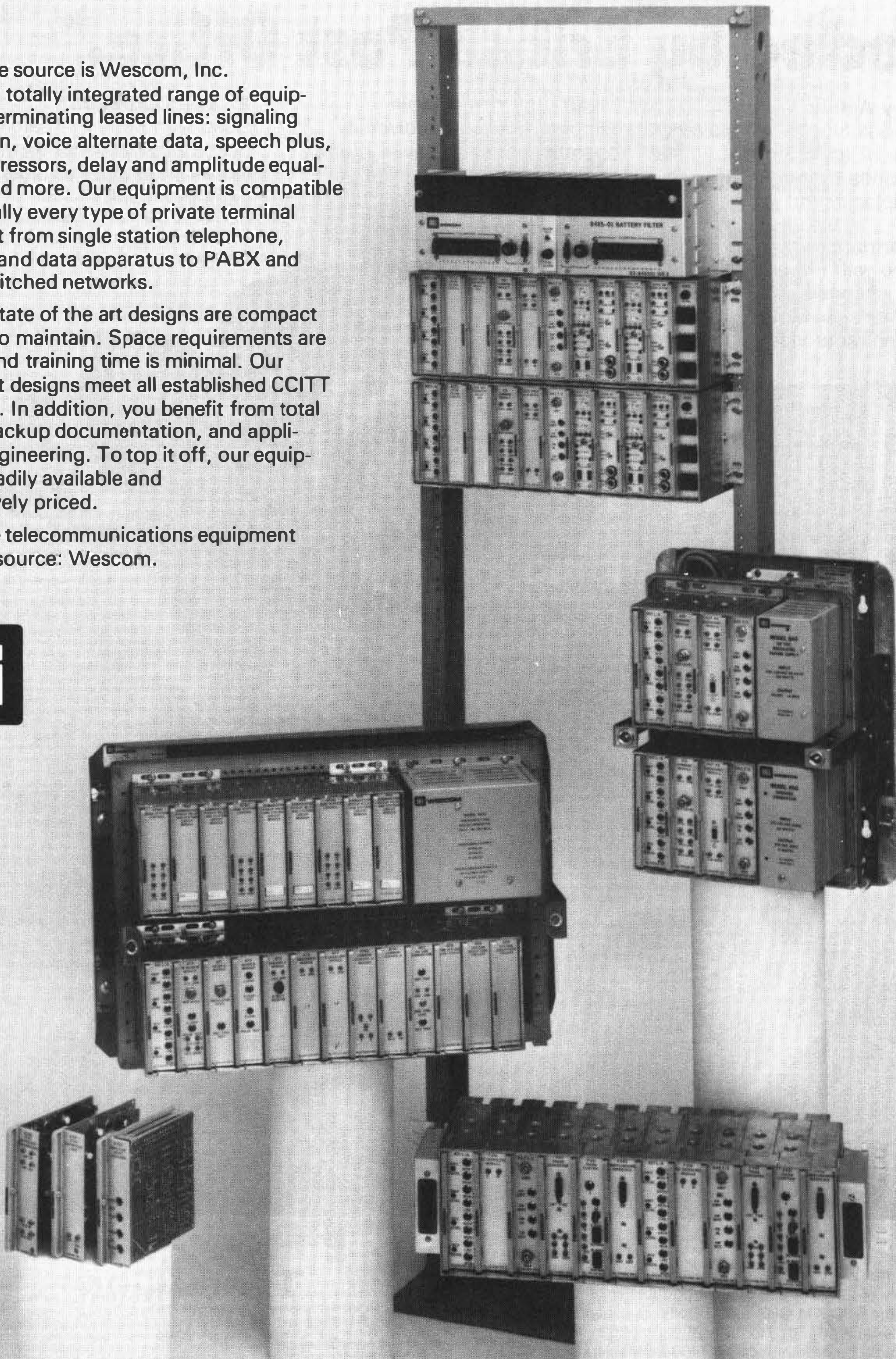

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