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The Post Office Electrical Engineers' Journal

EDITORIAL

In many areas in the field of telecommunications engineering, the benefits to be derived from observing *standards* in the specification and design of plant and systems are obvious: in many instances, the need is essential. International organizations (for example, the International Telegraph and Telephone Consultative Committee and the International Radio Consultative Committee) formulate recommendations that, among other matters, enable manufacturers and user administrations to retain a high degree of freedom in regard to equipment realization and operational use, while maintaining compatibility of interworking between systems of different manufacture.

An important aspect of such recommendations is that a manufacturer can produce an equipment design to meet the requirements of a major user and yet have the opportunity for further commercial exploitation of the product in other, even world-wide, markets.

In certain situations, if new systems designs were introduced without due regard to standardization of operational aspects, a user could be faced with a restricted choice of equipment to implement the system. In adopting a particular design, a user could be committed to that design to the exclusion of other manufacturers' products. The British Post Office (BPO) was confronted with just such a situation in respect of its radiopaging service and the choice of radio-signalling code for the proposed UK national radiopaging system.

The article on page 189 of this issue of the *Journal* describes how the BPO, UK manufacturers of radiopagers, the European Selective Paging Manufacturers Association, the Electronic Engineering Association and the UK Home Office Radio Regulatory Department met to agree on the format of a standard code for radiopaging; the format of the code is described.

The code has a large user capacity (2-million subscriber codes, each having 4 address functions). Also, because the code is new and there are no patent rights on the code, it may be freely used by any administration organization, or manufacturer.

Another example of the need and application of standard practices can be seen from the article on page 142, which describes the BPO policy and requirements related to the attachment of privately-provided-and-maintained equipment to the BPO network.

A new feature appears on page 211 of this issue, where forthcoming conferences of professional institutions are listed. It is hoped that this information may prove helpful to readers.

Attachment of Privately-Provided-and-Maintained Equipment to the British Post Office Network

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UDC 654:621.395

Customer demand is causing a continual increase in the number and complexity of private services provided by privately-supplied equipment attached to the British Post Office (BPO) network. This article defines briefly the status of attachments, indicates the steps taken by the BPO to prevent the attachments degrading its own services and describes the measures taken to provide design advice for attachment suppliers. Examples are given of the types of equipment marketed by suppliers for connexion to the main categories of BPO customer terminations and the appropriate technical requirements are outlined.

INTRODUCTION

With the increasing sophistication of modern life, customers are demanding a greater variety of communication facilities from the British Post Office (BPO) network. The demand has been stimulated by the rapid technological development progress of the last 2 decades, which has been reflected into the communications field and has enabled suppliers to bring more facilities within the economic reach of customers. The BPO provides a variety of services, but there is a growing fringe service area which, although not of prime service dimensions, presents a significant demand. For policy or economic reasons, the BPO may not wish to satisfy the demand, but there are manufacturers and suppliers who do. The BPO has no wish to inhibit progress in these fringe areas and allows private suppliers some latitude to meet the demand, provided that BPO services are not put at risk.

This article describes the steps taken by the BPO to minimize the chances of privately-provided-and-maintained equipment degrading the technical and operational performance of the network. However, before detailing these steps, the context in which the BPO permits the use of private devices on the network is briefly outlined.

CONTEXT IN WHICH ATTACHMENTS ARE PERMITTED

The BPO Obligation

Section 9 of the 1969 Post Office Act places upon the BPO the obligation to exercise its powers to meet the social, industrial and commercial telcommunication needs of the British Islands and, in particular, to provide telephone services to satisfy all reasonable demands for such services.

Monopoly

Section 24 of the 1969 Post Office Act gives the BPO the exclusive privilege to run systems throughout the British Islands, apart from statutory exemptions, for conveyance by electric, magnetic, electromagnetic, electrochemical or electromechanical energy of speech, music, visual, telegraph, data or control signals. This includes some areas that the BPO does not wish to enter, and the BPO is empowered to license the running of systems by private interests in appropriate circumstances. A specific licence may be issued to cover an individual case, or a general licence issued to apply to a particular class of systems. General licences are issued to licence the running of whole or part systems that the BPO considers do not need to be controlled individually; for example, radar or door-bell systems. A general licence has been issued to cover the connexion of private attachments to BPO installations when written consent to connect is given. Examples are telephone answering/recording machines, facsimile equipment and staff-location systems.

The BPO monopoly is not complete, as there are a few statutory exemptions. Examples of these are telecommunications systems confined to a single set of premises run by the occupier, and heliograph-type systems.

Private Attachments

Equipment that the BPO does not wish to provide for policy or business reasons, or is willing to accept competition for its provision, may be supplied by private business. Such equipment connected to the BPO network is classified as a private attachment, over which the BPO exercises control by the terms of the appropriate licence.

Attachments such as large commercial PABXs are privately provided, but maintained by the BPO; these are subjected to a rigorous type-approval examination and field trial of substantial duration before the BPO will allow their connexion to the public network and undertake maintenance responsibility. The comprehensive type-approval exercises are the subject of detailed Post Office Requirements and specifications. These are considered necessary when the BPO is accepting responsibility for the efficient working and reliability of the attachment. This type of attachment is not dealt with in this article.

Attachments that are privately provided and maintained are not assessed in terms of efficient operation, reliability or maintainability, because the BPO takes no responsibility for these aspects. The object is to ensure that these attachments do not adversely affect BPO plant or services and that they are not a source of danger to BPO staff. These devices are the subject of this article, and the steps taken to achieve this objective are outlined in succeeding paragraphs.

DISCIPLINE IMPOSED UPON ATTACHMENTS

The BPO has an obligation to ensure the efficient end-to-end operation of the public telephone and telegraph services and, to fulfil this obligation, the BPO network has been provided at vast capital cost. Inherent in this obligation is the responsi-

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† Formerly Service Department, but now Telecommunications Development Department, Telecommunications Headquarters

bility for the efficient operation and maintenance of the network, which necessitates control of the nature of services and signals on the network. Thus, the BPO has an obligation to all customers to take reasonable steps to ensure that privately-provided-and-maintained equipment connected to the network is:

(*a*) safe to connect to the system,
(*b*) not likely to interfere with BPO services,
(*c*) compatible with BPO systems to an extent dependent upon the function of the equipment, and
(*d*) not likely to impinge upon BPO maintenance liabilities and procedures.

These objectives are specified in terms of technical and operational requirements, which are contained in a series of *Technical Guides* available to prospective suppliers of attachments. The main requirements are indicated in subsequent paragraphs of this article.

When attachments have been technically and operationally assessed by Telecommunications Headquarters (THQ), and considered satisfactory for general permission for connexion to be granted, agreements are concluded with the suppliers; Telephone Area staff are then notified by appropriate entries in a *List of Permitted Attachments*, which is held in every Area. Where customers require unique configurations, an individual evaluation is effected and no entry is made in the list, but Area staff concerned are informed.

Safety

The BPO takes no responsibility for ensuring that private equipment is safe as far as a user or a private maintenance man is concerned. BPO policy aims to protect its personnel, other customers and equipment from exposure to danger from any hazardous conditions emanating from private equipment and transmitted through BPO equipment.

Alternating voltages in excess of 100 V RMS and direct voltages over 150 V are considered to be hazardous, and the standards applied to BPO customer apparatus designs and maintenance practices are based on this premise. The open-circuit voltage measured between any 2 terminals of an attachment intended to be connected to BPO plant, or between any such terminal and earth, must not exceed these limits; these voltage limits are, at present, under review and are liable to be changed. Further, alternating currents exceeding 10 mA RMS or direct currents greater than 50 mA, flowing through the body, are considered to be dangerous; these limits are based upon extensive research undertaken in several academic institutions into the effects of electrical contact with various organisms.

However, the onset of the phenomenon termed *ventricular fibrillation*† varies in individuals and with their bodily conditions at the time of the incident, and a number of generalizations have been made such as the assumption of an average 2000 Ω body at lower dangerous voltages. The limits quoted for current are also generalizations, which do not take into account variations in human reaction such as a known difference in reaction to the same current level flowing in male and female subjects. Nevertheless, some generally acceptable standards for application to all attachments have been identified.

An attachment is considered to be safe for connexion to BPO plant when: it does not generate dangerous voltages; it is not connected to sources of dangerous voltages; and, when connected to a 2000 Ω load, it does not cause dangerous load currents. Attachments that do not meet these requirements must isolate the sources of hazard by incorporating protective barrier devices.

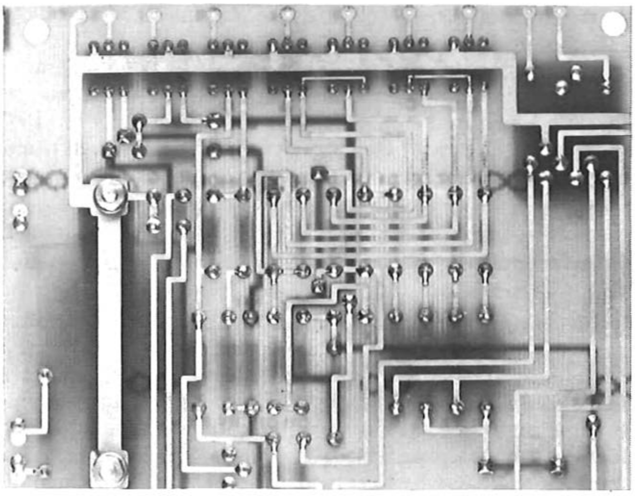

FIG. 1—Use of opto-electronic isolators illustrating the principles of physical protection. (Isolators are mounted on reverse side of top of board, across the earth track.)

Protection Devices

Protection against dangerous voltages can be provided at the power source for the attachment if secondary voltages are safe voltages, or by a barrier device at the interconnexion point. The choice depends upon the configuration of the equipment, including all other apparatus to which the attachment is connected. Certain items are acceptable as protection devices, provided that they meet proof-test voltage, insulation and physical design requirements; examples are transformers, relays, capacitors, opto-electronic devices and fuse disconnexion devices consisting of series fuses with earth shunt Zener diodes or gas-discharge tubes. The physical design requirements refer to separation and creepage distances between safe and unsafe parts, and precautions against accidental bridging between these parts. For example, a transformer intended to provide isolation against lower dangerous voltages, which incorporates an earthed metal screen between isolated and non-isolated windings, must withstand the application for 1 min of a 50 Hz or DC proof-test voltage of at least 2100 V. Immediately after this test, the insulation between the parts tested must be greater than 20 MΩ at 500 V DC. The construction of the transformer, and the protection unit in which it is mounted, must meet the physical requirements, and the effectiveness of earthing arrangements is assessed against earthing requirements specified.

Fig. 1 illustrates some principles of physical protection and shows a printed-wiring board incorporating a heavy-gauge earth track, which is straddled by opto-electronic isolators mounted on the reverse side of the board. All connexions to the safe side of the isolators are made on one side of the earth track, and all connexions to the unsafe side are made on the other side of the earth track.

Special Safety Precautions

Some attachments are designed to fulfil functions involving connexion to high voltages or connexion in areas of abnormal operation. In these cases, special requirements are applied, according to circumstances, which take the form of tests at higher proof-test voltages and more exacting physical requirements. For instance, a transformer incorporating an earthed metallic screen, required to provide a barrier for telemetry equipment connected to power-generating equipment not exceeding 33 kV, must withstand peak alternating proof-test voltages of 3750 V for 1 s and 1250 V for 2 min. Physical requirements commensurate with the higher voltage are applied and spark gaps must be fitted at the unsafe terminals

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† A nerve centre in the heart normally controls the muscular contractions by sending rhythmic electrical signals via nerve fibres to the muscles. Alien electric currents can destroy this rhythm and it is not restored by disconnexion of the alien current

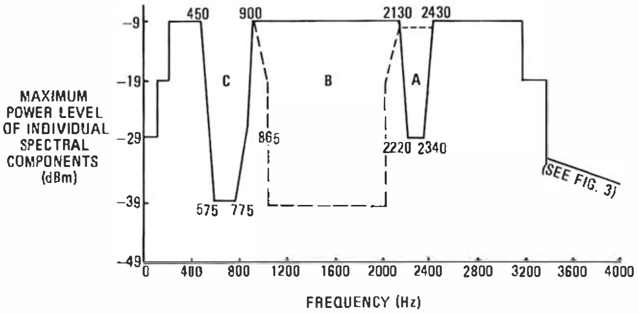
of the transformer, as well as at the terminals of the voltage-reducing device.

Special requirements also apply to attachments operating in areas having a high rise of earth potential. These requirements are met in a similar way to that adopted by the BPO for Central Electricity Generating Board areas of high rise of earth potential; that is, by using purpose-built line isolating units.

Interference

Standard BPO services are designed to operate within the technical and operational limitations imposed by the characteristics of the network. If these limitations are not observed, the quality of the services can be degraded through interference, with the ultimate possibility that the network could become unusable as a communications medium. Interference can be caused in several ways which, in technical terms, are mainly evident as transmission or signalling problems and, in operational terms, as network protocol problems.

Transmission interference can be caused by such factors as excessive transmission levels; this can cause amplifier overloading in the high-frequency (HF) network and, coupled with such factors as poor impedance matching or impedance unbalance-to-earth, unacceptable crosstalk levels in adjacent circuits. There are many other factors apparent when the frequency spectrum and transmission level are extended beyond the design limits of the part of the network involved. The transmission and signalling limitations are outlined below.



Notes: Signals are permitted in area A only if accompanied by signals in area B at a power level not lower than 12 dB below the power level of the signal in area A. Signals are permitted in area C provided that there is no false operation of trunk signalling equipment (SSAC 1)

FIG. 2—Maximum 1 min mean-power level of the output signal from apparatus connected to the PSTN

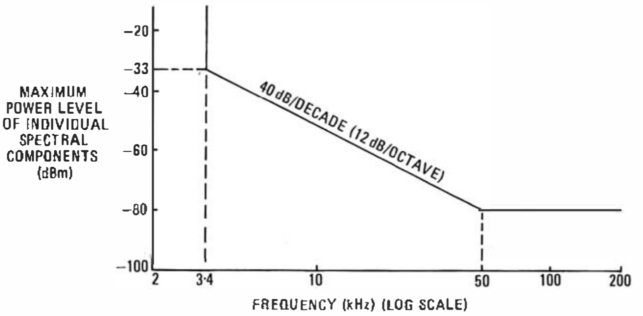


FIG. 3—Maximum power level above 3·4 kHz of the output signal from apparatus connected to voice-band circuits

Transmission Limitations

Limitations applied to individual spectral components from attachments to the public switched telephone network (PSTN) are indicated in Figs. 2 and 3. At present, the maximum level allowed at the 2-wire entry point to the HF network is −13 dBm† (1 min mean power). This figure is applied to attachments connected to private circuits because the HF network entry point may be very close to the attachment site. Attachments to the PSTN are allowed to transmit up to −9 dBm because there will always be at least a local exchange, and a length of line, between the attachment and the HF network, for which a 4 dB average allowance is made. Impedance matching is generally required to give at least 15 dB return loss for speech circuits, and the impedance unbalance-to-earth limit is quoted as a voltage ratio resulting from measurements using a combination of longitudinal and transverse signal sources.

The frequency spectral roll-off characteristic of Fig. 3 is dimensioned to: minimize crosstalk at higher frequencies; prevent troublesome intermodulation products in the HF network and overspill into adjacent channels; and prevent interference with some BPO services that now exploit the HF capabilities of the local network. The limitations below 200 Hz and above 3·2 kHz in Fig. 2 assist filtering in the HF network, and the limitations between 3·4 kHz and 8 kHz in Fig. 3 are applied to satisfy adjacent-channel requirements of channel translating equipment. There are other problems between 4 kHz and 20 kHz that arise from beat signals produced by derivations of 8 kHz sampling frequency of pulse-code-modulation systems and unwanted attachment transmissions in this range. Limitations between 18 kHz and 200 kHz are necessary to satisfy the crosstalk requirements of new HF customer terminations in the local network, and further limitations between 60 kHz and 108 kHz are to prevent direct breakthrough to the group band within channel translating equipment. These limitations, combined with other less important considerations, result in the characteristics portrayed in Figs. 2 and 3.

To illustrate practical cases, Figs. 4 and 5 depict unacceptable outputs: Fig. 4 is a sweep analysis of the output of an attachment powered by an HF switching power supply giving harmonic peaks; Fig. 5 is the sweep analysis of the tone output of an interrogator-type alarm system. Fig. 6 shows the spectrum of a 2·4 kbit/s modem after redesign to eliminate unacceptable signals, and Fig. 7 shows expanded detail of the peak at the lower end of the spectrum when scanned with a narrower bandwidth.

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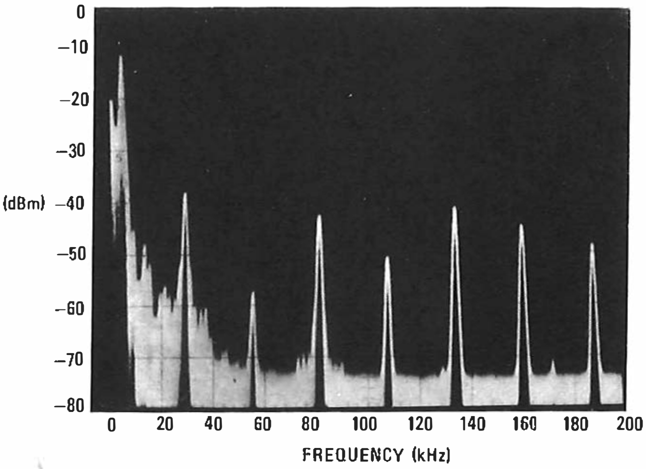
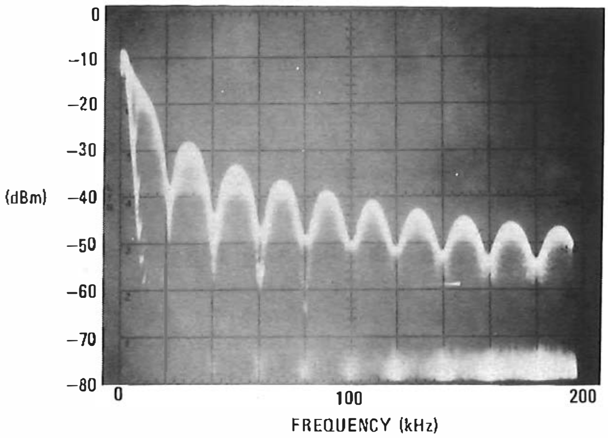
† dBm—decibels relative to 1 mW



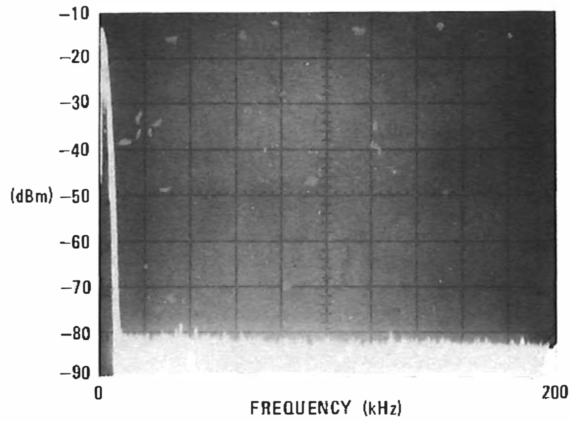
Scan bandwidth 1 kHz at 1 s/division

FIG. 4—Output from an attachment powered by an HF switching power supply



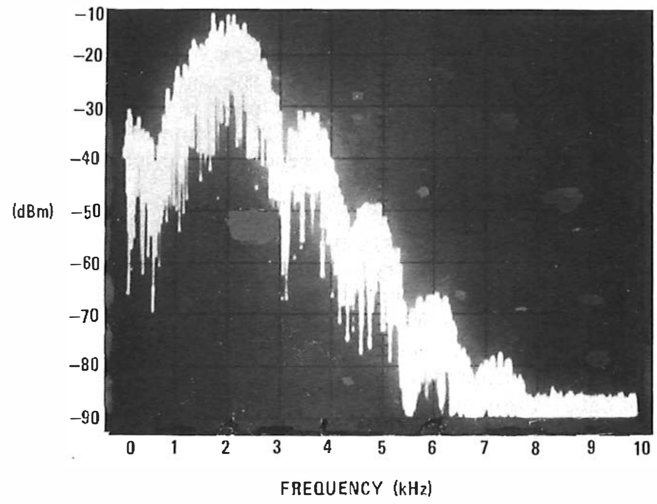
Scan bandwidth 1 kHz at 1 s/division

FIG. 5—Tone output spectrum from an interrogator-type alarm device



Scan bandwidth 1 kHz at 0·5 s/division

FIG. 6—Output from a 2·4 kbit/s modem after correction of unacceptable spectral components



Scan bandwidth 100 Hz at 0·5 s/division

FIG. 7—Expanded spectrum of peak at lower end of Fig. 6

Signalling Limitations

The 2 slots in the characteristic of Fig. 2 (A and C) indicate limitations to be observed in areas of the spectrum where main PSTN signalling systems operate, such as Signalling Systems (SS) AC1 and AC9. The characteristic for speech-band private circuits (not illustrated) shows similar slot limitations for circuits where BPO signalling such as SSAC13 and 500/20 Hz is provided.

There are other limitations applied to attachments used on international links to prevent interference with SSAC4 and SSAC8, and to prevent accidental disablement of certain echo-suppressors, which are designed to be disabled by a tone for duplex data transmission only.

Compatibility

The degree of compatibility with the BPO system that is required of an attachment depends on its nature and function. The BPO takes no responsibility for the efficient or reliable operation of attachments, but there are many attachment failings, that can reflect adversely on BPO services. Unsatisfactory attachment performance, particularly during a metered call for which the customer pays the BPO, has been the cause of considerable abortive maintenance effort and deterioration of BPO relations with some customers. As a result, the BPO has made some compatibility requirements mandatory, while others are simply advisory to assist designers of attachments.

Attachments to the PSTN are subject to many compatibility requirements because they can access, or be accessed by, any customer connected to the public system. The mandatory requirements concern the technical limits and operational processes for setting-up and answering calls, for satisfactory transmission and for terminating calls. Indeed, there are few compatibility requirements remaining that are the subject of purely advisory information.

Attachments to PBXs that have no access to the PSTN are subject to mandatory requirements pertinent to the type of PBX to which they are connected. Many of these attachments are connected directly to switching stages within the PBX, and are operationally partly integrated with the PBX. While it is important to ensure a large degree of compatibility with PBX operation, attachment failings are more containable than in the PSTN situation, with the possible exception of attachments operating in large private BPO-maintained networks.

Datel attachments are more closely integrated with BPO services; thus the interchange requirements between private data terminal equipment and BPO Datel equipment must be closely controlled by mandatory requirements. Otherwise, particular BPO Datel services could not be maintained without the danger of continuous responsibility disputes between the BPO, the attachment supplier and the customer.

Attachments to private circuits are subject to fewest mandatory requirements, because they are not normally accessible to users other than those renting the private circuit.

As far as the required degree of compatibility is concerned, telegraph attachments to the Telex network and to Tariff H or J private circuits are treated in a similar way to attachments to the PSTN and speech private circuits respectively.

Maintenance Demarcation

Charges to customers for BPO services contain an appropriate component for the likely maintenance cost during the life of the equipment involved, and BPO maintenance resources are planned and organized to provide adequate service. It is not BPO policy to allow its maintenance resources to be diverted, free of charge, to maintain private services provided by attachments. Therefore, methods of connexion and operation of attachments are decided and agreed at the time of assessment; these are designed to separate maintenance liability in the simplest practicable way.

Some attachments lend themselves to this objective by the adoption of simple means of connexion, but others do not allow a straightforward solution. For PSTN attachments, connecting attachments through a key or a plug and jack enables a customer to revert his installation to a completely BPO-maintained terminal when trouble with the attachment is suspected. Hence, it can easily be proved when the trouble lies with the attachment and when the supplier must be contacted for maintenance aid. A similar method is used for PSTN Datel terminals where a plug and jack connects the BPO modem to the private data terminal equipment. With the co-operation of the customer, this enables the remote BPO Datel maintenance centre to check that the BPO installation is basically satisfactory without a maintenance visit.

For some PBX and private-circuit attachments, the maintenance interface is not always so easily defined by customer action. However, some testing can be achieved at a Case No. 200 or distribution frame, depending upon the customer's equipment configuration and the availability of permitted private test equipment.

It is desirable that the customer should ensure that his attachment is fault free before invoking BPO maintenance aid. Unfortunately, it is difficult to ensure that the customer has taken this precaution before the BPO becomes involved. Sometimes, the customer has taken the correct action, but has received incorrect advice in the first instance from his maintenance source. There is certainly room for misunderstandings between the BPO, the customer, the supplier and the maintenance agency. But, in cases where there is identifiable abuse of BPO maintenance, the machinery exists to make an additional charge to the customer.

ATTACHMENTS TO THE PSTN

Attachments to the PSTN are required to simulate the performance of a telephone terminal, and to interact with the PSTN so that the network cannot differentiate between a telephone and an attachment in technical and operational terms. These devices fall broadly into 3 main categories: automatic-answering devices, automatic-calling devices (both with appropriate operational and transmission facilities) and transmission devices. There are also combinations and variations of the 3 categories, but all are subject to the same basic requirements.

Automatic-answering devices include terminal equipment such as answering/recording machines; these incorporate variable facilities, ranging from the simple answering and recording function, to an additional *TIM* recording-track and remotely-controlled message replay. Automatic-calling devices include intruder and fire alarms, which sometimes provide a programme of repetitive calling facilities and line-sensing circuits. Transmission devices consist of terminal equipment, such as facsimile, special modems, scramblers and slow-scan, low-definition television. The more complex telemetry systems, or remote-control-and-supervisory systems, are examples of combinations of the 3 main categories. Examples are control and supervisory systems for unattended television transmitting stations (providing perhaps 40 supervisory functions and 12 remote-control functions), systems for water or oil pumping and storage control, and systems for monitoring supply systems or customer television audience sampling techniques.

The technical requirements necessary to ensure that all these systems operate in the same way as telephone terminations are necessarily quite comprehensive. Impedance matching, impedance balance-to-earth, signal levels and frequency content, pulse speed and ratio, current-carrying capacity of the input circuitry and many other technical details are specified and tested during assessment. Many technical requirements are dictated by operational requirements, such as pay-tone detection and end-of-call detection, the latter necessitating machine recognition of end-of-call conditions on various TXS, TXK and TXE exchange lines.

Advice is given in the technical guide on the insertion loss and group-delay characteristics at spot frequencies that are likely to he exhibited by circuits routed in the PSTN.

ATTACHMENTS TO PRIVATE CIRCUITS

Private circuits are currently marketed as links offering a performance to certain basic limits within a tariff structure, and the customer theoretically orders his circuit to suit his particular needs. If the customer wishes to operate private equipment over a dedicated link, the equipment is required to meet technical limitations already outlined, but the operational aspects are primarily his concern. The specified performance of the links for speech-band needs are very basic and, in some instances, inadequate for some customers' uses. It is likely that newly specified circuit schedules will be introduced, which will more nearly meet customers' needs. More information will then be published, enabling the supplier and customer to choose the types of circuit for the particular terminal equipment and usage.

In all current audio tariff circumstances, attachments are required to satisfy basic impedance, impedance balance-to-earth, signal level and frequency spectrum limits and, where BPO signalling is provided, there are additional spectrum limitations to be observed to prevent interference with the signalling system.

Other circuits, such as wideband (group or supergroup) and 5 MHz closed-circuit television links, are provided and, for attachment use, further detailed level and spectrum limitations are applied.

Attachments to private circuits range from simple DC alarm systems, through speech-band and wideband modems and facsimile equipment, telemetry systems, private automatic exchanges, to private channel translating equipment.

ATTACHMENTS TO DATEL SERVICES

For Datel services, the BPO provides and maintains the appropriate data circuit terminating equipment, which may consist of a BPO modem with or without data control equipment. These ensure that transmission and network protocol are under BPO control. The interchange circuits for the transfer of binary data, control and timing between the BPO equipment and the private data terminal equipment must be specified, and the operational procedures agreed so that the customer can be given the Datel service facilities he requires.

In general, the BPO equipment conforms to CCITT† data recommendations, and the supplier is required to provide equipment designed to conform to the same recommendations. For example, for interchange circuits of the 100-series[2,3] or 200-series,[4] as defined in CCITT Recommendation V24, the electrical characteristics of generator and load, and the signalling polarities, must be in accordance with CCITT Recommendation V28.

BPO Datel services are specified for the various services offered, and it is necessary to ensure that the manner in which private data terminal equipment is intended to operate is compatible. The supplier agrees with the BPO the facilities that he intends to market and produces equipment accordingly. The customer must then provide the BPO with details of data transmission rates, signal timing arrangements, interchange-circuit delay times and transmission testing facilities; ultimately, agreement is reached with the customer on the particular operating procedures required.

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† CCITT—International Telegraph and Telephone Consultative Committee

Data terminal equipment attached to BPO modems includes computers, teletype printers, visual display units and data-type telemetry equipment.

TELEGRAPH ATTACHMENTS

Some customers wish to use private telegraph equipment on the Telex network, or on Tariff H or J private circuits.

Attachments can be connected to the Telex network for the Datel 100 service, provided that calls are either set up manually by BPO teleprinters and terminating units, or automatically by Data Control Equipment No. 3. When the call has been set up satisfactorily, the termination is switched to the private equipment and, in both instances, a BPO control unit and low-pass filter remain in circuit as the interface. Electrical requirements, which the private equipment must meet, are specified for: signalling-voltage polarities; power supplies; signalling-earth or common-return arrangement; sending-signal distortion limits; receive margin limits; maximum modulation error; input sensitivity and impedance limits. Where the Data Control Equipment No. 3 is used, there are additional interface signalling requirements for satisfactory interworking between the BPO equipment and the private terminating equipment.

Attachments to Tariff H and J private circuits do not have to be connected via BPO terminating equipment, although the BPO will provide a terminal relay unit. If the BPO terminating unit is not used, a low-pass filter must be provided as part of the attachment. The attachments are required to meet electrical standards similar to Telex network attachments, but this is varied according to the specified mode of operation.

Telegraph attachments are typically private teleprinters or low-voltage teletype machines and message switchers. Message switchers are becoming increasingly popular with large group businesses, operating nationally and internationally between business centres.

ATTACHMENTS TO PBXs

The current variety of PBXs and facilities determines the variety of attachments required by customers owning or renting the PBXs. There are 5 basic ways in which attachments can be connected to PBXs where the attachments are not required for accessing the PSTN. They can: terminate PBX speech circuits, with access being via either an extension line or a selector level; be connected in parallel with an extension telephone; be teed across speech or non-speech wires at a central point within the PBX; be connected to PBX audible-alarm circuits; or be connected to a non-speech interface designed for attachment use only. The attachments must meet all the basic transmission requirements, and must be compatible with the functions and signalling systems provided for the particular PABX or PMBX concerned.

The requirements are becoming increasingly varied as more proprictary types of PBX receive BPO type approval. Further, there are more facilities available on PBXs than on the PSTN, and some types of attachment may need to be sufficiently versatile in design to cater for variations such as signalling by loop-disconnect, SSMF4 and DC Code C dialling. The most recent trend in proprietary PBX designs involves computer control, and the attachments to these types of PBX are not only more varied, but include connexion of data-type attachments accessing the digital area of the PBX.

The majority of attachments are the types that terminate PBX speech circuits via either line circuits or a selector level. Examples are centralized dictation, staff-location, public-address and mobile-radio systems. A further category concerns private networks where PAXs, speech plus duplex, and channel translating equipment are required to be connected to PBXs, which form nodal points in the networks. Attachments, connected in parallel with an extension telephone, are often needed for use on both extension and exchange-line calls, and must meet both PBX and PSTN requirements. Examples are recording or answering/recording machines. The types of attachment teed across speech or non-speech wires are mainly call-information logging and traffic-analysis equipment; those connected to speech wires are subject to stringent crosstalk requirements to ensure that PBX and line characteristics are not degraded, and that BPO security policy requirements are observed. Attachments to PBX alarm circuits are extensions of the alarm systems and are specially designed to meet individual customer requirements. There are also non-speech interfaces designed for particular customer needs, such as 1-out-of-10 marking for staff-location systems.

FUTURE TRENDS

Many of the well-established and fairly standardized types of attachment currently show little signs of major change, and most changes concern design modernization and facility improvement. However, it is evident that evolution in some newer attachment areas indicates a likely closer integration of BPO services and some attachments in the future.

Development of the Experimental Packet Switched System,[5] which requires complex customer packet terminal equipment to generate address information and network control protocol, has necessitated a much greater BPO involvement in the compatibility of the private terminal equipment to minimize the risk of degrading the BPO service offered. This may indicate the approach the BPO would need to adopt for private terminal equipment attached to a future international packet switched system[6] using CCITT Recommendation X25 interface requirements, and also for private equipment attached to the future digital network. At present, for the packet terminals, the BPO uses a mini-processor-controlled tester, with test programs for assessing the customer's terminal equipment on site. A planned testing programme is applied, involving test of the rapport between terminal, packet-switching exchange and certain protocol stages in the system. The same test equipment can be used for analysis of trouble during service, to establish maintenance liability, because standard remote Datel testing procedures are inadequate. More complex computer-controlled testers may be needed for digital network terminals.

The imminent advent of the BPO Prestel service, where the customer's private terminal and information suppliers' terminal will have direct access to a BPO computer terminal, will also require a more detailed BPO involvement in the nature and capabilities of the private terminals. To a lesser degree, some private equipment on North Sea oil rigs, which has direct access to the inland telephone and Telex networks, requires a BPO interest more detailed than for ordinary attachments.

Hence, the introduction of new services and attachment capabilities, brought about mainly by technological advance, is likely to require a greater BPO involvement in the attachment performance, both initially and during the life of the attachment. This trend is likely to be a continuing process demanding the application of increasing BPO resources.

CONCLUSION

It is certain that attachments meet a wide range of customers' needs, across a broad spectrum of facilities. It is unlikely that the BPO could economically meet all these needs, and the private commercial sector can provide and maintain the comparatively small quantities of the many types of equipment usually involved.

Some customers, and many suppliers, have international interests and there is an emerging need for common international requirements to facilitate international marketing for attachments. Unfortunately, the various national networks and standards differ considerably, and harmonization of requirements is likely to take much time and effort to achieve, although some progress has already been made. Suppliers, customers and national telecommunications authorities could ultimately benefit from rationalized requirements.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of colleagues in the Service, Operational Programming and Telecommunications Development Departments of the BPO in the preparation of this article, and also the permission of Vanderhoff Communications of Nuneaton to photograph the subject of Fig. 1 for this article.

AUTHOR'S NOTE

While the attachment requirements outlined in this article were correct at the time of writing, they are continually under review and liable to alteration.

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Measurement and Analysis Centres: Measurement Techniques and Hardware Design

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A previous article[1] published in this Journal has described the organization and operational aspects of measurement and analysis centres (MACs), which provide facilities to measure automatically the quality of service given by the British Post Office public switched telephone network. The description of the MAC concept is continued in this article, which describes the techniques used to generate and monitor test calls and the hardware that has been developed to implement those techniques.

INTRODUCTION

An earlier article[1] has described the British Post Office's (BPO's) need for the measurement and analysis centre (MAC) system, the basic equipment employed and its use. This article describes the design features of the hub of the system—the software-controlled MAC.

The key features of a MAC are the ability to set up automatically telephone calls within the public switched telephone network (PSTN) and to monitor the behaviour of the network with all its diversity of operation. To accomplish these tasks, it was necessary to design the MAC system so that computer-based equipment and the PSTN can be inter-connected and information passed between them. In this article, a brief description is given of the MAC system configuration, the design of the interfacing hardware and the system requirements influencing that design. Techniques that the MAC system uses to establish and monitor test-calls and to ensure that the action of the PSTN is correctly recorded are also described.

SYSTEM CONFIGURATION

A complete MAC system consists of the MAC equipment, dedicated test-circuits that link a MAC to nominated telephone exchanges and the interfacing equipment at those exchanges. This interfacing equipment is known as *access equipment*. Where appropriate to the access arrangements, a *concentrator* is included as part of the test circuits. A concentrator enables a single outlet from a MAC to be connected to up to 5 exchanges. A block diagram showing the basic interconnexion arrangements of a MAC system is shown in Fig. 1.

To establish a test call, a MAC selects a path to the required inlet of the exchange unit to be measured. This is achieved by transmitting digits in the form of loop-disconnect pulses along the test circuit to switch the concentrator, if present, and the access equipment. Thereafter, further digits are transmitted by the MAC along this path and are used to set up a telephone call in a normal manner. A brief description of the functions performed by access equipment and concentrators is included in this article to indicate their role as sources of 3 key tones (with frequencies centred on 400 Hz, 1000 Hz and 2500 Hz) which are used for control and monitoring purposes.

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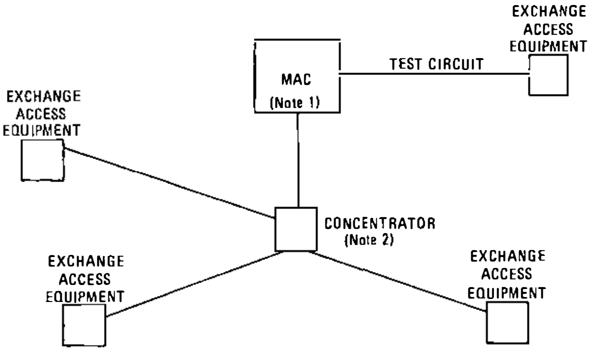


Note 1: The maximum number of test circuits connected to a MAC is 30
2: The maximum concentration ratio of exchanges served by a concentrator is 5 in non-director areas and 3 in director areas

FIG. 1—MAC system configuration

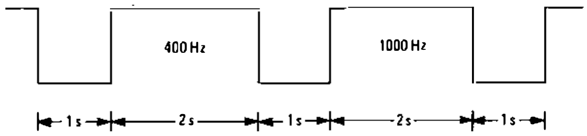


FIG. 2—MAC test tone cadence

Access Equipment

Access equipment, which was designed by BPO development engineers, provides the interface that allows the MAC system to access Strowger, crossbar and electronic exchange types, at local and tandem exchanges and at group switching centres. An access equipment enables a single test-line to be connected to approximately 100 access positions (for example, access to subscribers' line circuits, register-access relay-sets). The number of access positions in use depends on the size of the exchange to be measured; connexion paths are provided in the ratio of 1 access position to every 200 exchange inlets. Two digits must be received from a MAC to select a given access position. It is possible to gain access to both ordinary and coin-collecting-box inlets.

Access equipment is a source of all 3 key tones. One important use of these signals is to indicate that the correct switching action has been performed.

An access equipment also houses 'answer circuits', which are connected to exchange outlets and generate a special MAC tone. Connexions are made from this equipment in the ratio of 1 answer circuit to every 200 exchange outlets. A special MAC test tone cadence (see Fig. 2) based on frequencies of 400 Hz and 1000 Hz is generated and supplied to the exchange outlets. When a test call is routed successfully to a selected destination, the test tone is returned to a MAC via the PSTN and an associated test circuit for detection and identification. The 1000 Hz pulse, which forms part of the MAC test tone cadence, is used to measure the transmission loss through the PSTN. The 1000 Hz is generated at a known fixed level and the loss of the test circuit is built out to 20 dB. Therefore, any additional loss measured on the test connexion is directly attributable to the network. The access equipment also detects the presence of metering pulses at the exchange and converts them to pulses of 2500 Hz.

Concentrator

A concentrator is basically a 5-way switch, the path required being selected by the initial digit sent by a MAC at the outset of setting-up a test call. The concentrator is considered to be part of the test circuit linking a MAC and a nominated exchange, and is used to conserve line plant and minimize the use of interfacing hardware at a MAC.

MAC HARDWARE

The 3 principal components at a MAC are: proprietary or standard computer equipment; special interface hardware (SIH), which has been designed especially for MAC use; and the computer programs or software which control the system. In combination, these entities form a measurement device used to check on the behaviour of test calls generated by the MAC.

At a MAC, throughout the phases of establishing and monitoring each test call, the key parameters of voltage, frequency and time are measured accurately by a combination of hardware and software techniques. The results are used to decide whether correct or incorrect operation of the PSTN has occurred.

Hardware/Software Division

The division between the use of hardware and software to perform the basic measurement function has been chosen to make the best use of the features of a software-controlled central processor and of distributed hardware.

The ability of a processor/software combination to make very fast complex decisions makes it an ideal tool to measure and control time-dependent actions. The SIH acts as the electrical interface between the processor and the test lines, and extracts the required information which is passed to the processor.

The action of the PSTN in establishing and controlling switched connexions is a very complicated process and, in consequence, is difficult to define. The use of software lessened the problems of system modification necessary during the development of the MAC system. Important parameter settings, particularly those related to time, could be charged simply and at a small cost until the correct value was obtained. In the light of operational experience, it will be possible to further modify the system, if necessary, to ensure that the MAC reports the performance of the PSTN as accurately as possible. An earlier article[3] described how the complex task of tone recognition was solved by the use of a combined software/hardware technique.

Other benefits were obtained by employing centralized software, wherever suitable. Firstly, the complexity of hardware was reduced and therefore likely sources of errors in design that are costly to eradicate were also reduced. Secondly, because each test circuit is connected to a set of SIH boards, the reduced replication minimized the cost of the total system. Thirdly, the reliability of the total system was increased.

Besides the basic measurement operation, a MAC performs many other tasks; for example, input/output of data, recording test call failure information, processing of failure infornation, scheduling of test calls. This work is common to all test lines, and software techniques were used in all cases.

Standard Hardware

The functions of a MAC are based, primarily upon equipment supplied by GEC Computers Ltd. The central device is a miniprocessor, the GEC 2050, which has an associated internal core store of 48 kbytes. These 2 units are used to execute the programs, utilizing an external mass storage device in the form of a disc store which has a capacity of 4·8 Mbytes (approximately 5 million bytes) on both a fixed-disc and an exchangeable-disc pack. The MAC system is a real-time control system and, as is typical of such systems, its operation revolves around the information contained in this store.

The discs are used to hold information in a number of different formats. The first type is data, both in a basic format, as supplied by Telephone Area staff, and in a processed format suitable for direct use by the programs. Secondly, data pertaining to call failures is accumulated and a record is maintained describing all facets of these failures. Thirdly, because the size of the internal store is insufficient to hold all the MAC programs, the disc unit is also used to store programs that are not immediately or often required. When needed, these programs are transferred to a special 'overlay' area in the main store. The information stored on the fixed disc is transferred periodically to the exchangeable disc for security purposes.

Data is fed into, or copied from, the MAC system via 2 types of devices: the fast-transfer of bulk data is performed by a magnetic-cassette unit, and two 30 character/s Transtel keyboard/printers are available to enable the MAC staff to interact with the system.

The standard hardware devices identified above perform the normal computer activities of processing, storing information and transferring data in and out. However, it is the SIH which is required for the creation and monitoring of test calls that is the main subject of this article.

Special Interface-Hardware (SIH)

The majority of SIH equipment is housed in up to 4 units known as *crates*, which are housed in a single cabinet; each crate contains sufficient equipment to accommodate connexion to 8 test circuits. Two test circuits interface to a dual-channel assembly that consists of 3 boards:

(*a*) dual-line control board,
(*b*) telephone-line interface board, and
(*c*) tone-recognition board.

In addition to the 4 sets of boards in each crate, one crate, known as the *master crate* (see Fig. 3), contains 2 other boards:

(*a*) a clock board, and
(*b*) a multiplexer board.

A description of the functions of boards follows and the interconnexion arrangement between the SIH boards and the processor equipment is shown in Fig. 4. The individual boards are shown in Figs. 5–10.

Clock Board

The clock board provides a number of clock pulse trains necessary to drive the remainder of the SIH circuitry.

Multiplexer Board

The multiplexer board performs 2 functions: firstly, it broadcasts all commands, received from the processor via a processor interface board, along printed-wiring backplanes to the dual-line control boards; secondly, it scans all tone-recognition boards for indications of tone transitions (ON and OFF) and passes this information to the processor.

Dual-Line Control Board

The main function of the dual-line control board is to staticize the commands and the digits to be dialled as received from the multiplexer board. Dialling is controlled by this board, using relays on the telephone-line interface boards.

Telephone-Line Interface Board

The telephone-line interface board is connected to 2 test circuits via line-isolating transformers. Pulsing relays, housed on the board, are used to transmit the digits received from the dual-line control board. Other relays are used to short-circuit each line transformer during the operation, thus reducing line impedance and minimizing pulse distortion. The digits are transmitted at 10 pulses/s, using a 10 Hz pulse train derived from the clock board.

Also located on this board and an associated daughter-board, are 3 active filter circuits for each test circuit; these filters selectively detect the 3 key tones within defined bands centred on frequencies of 400 Hz, 1000 Hz and 2500 Hz. The sources and uses of these frequencies are explained later in this article.

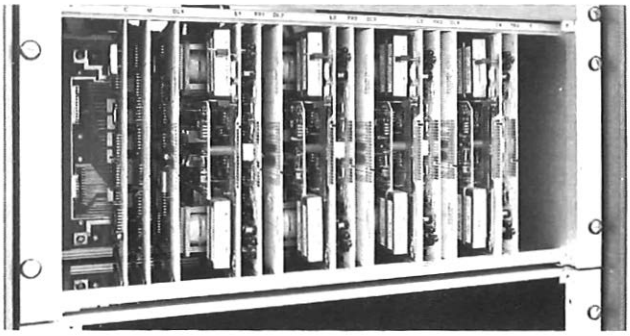


FIG. 3—Master crate

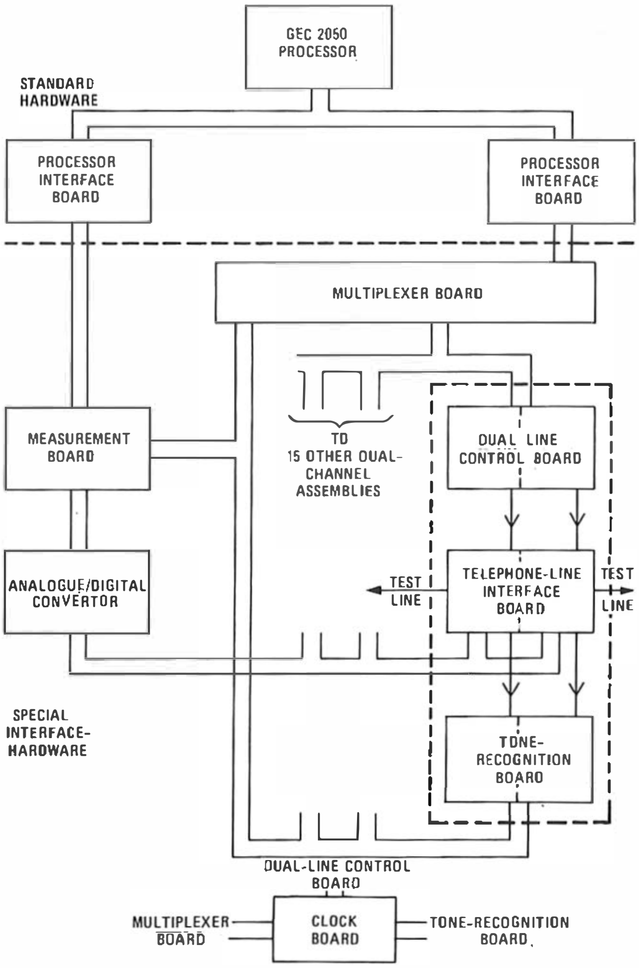


FIG. 4—MAC special interface-hardware

Tone Recognition Board

The tone-recognition board receives amplitude-limited signals from the telephone-line interface board and daughter-board combination. Frequency-dependent voltage amplitudes are produced by active filters, and these are used to determine the presence of each of the 3 key frequencies on the test circuits. It is essential that noise should not cause false operation of the tone receivers; therefore, protection is incorporated in the design by digitally filtering-out tone bursts of very short duration and ignoring very short breaks in continuity.

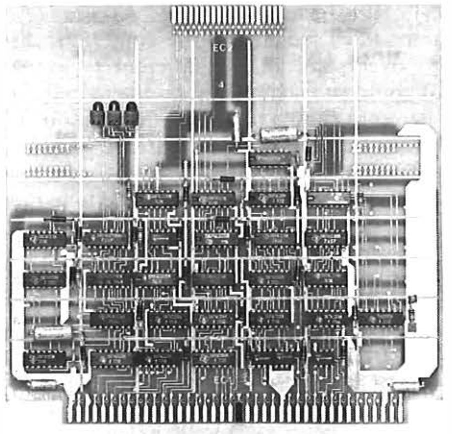


FIG. 5—Dual-line control board

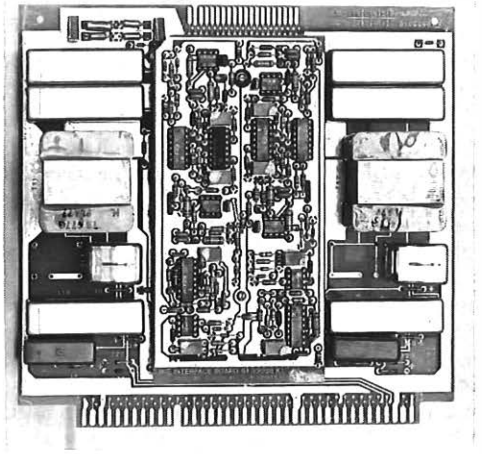


FIG. 6—Telephone-line interface board

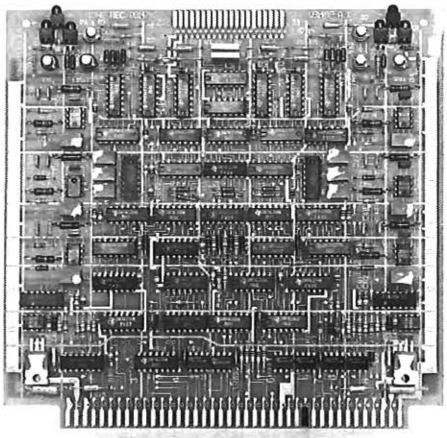


FIG. 7—Tone-recognition board

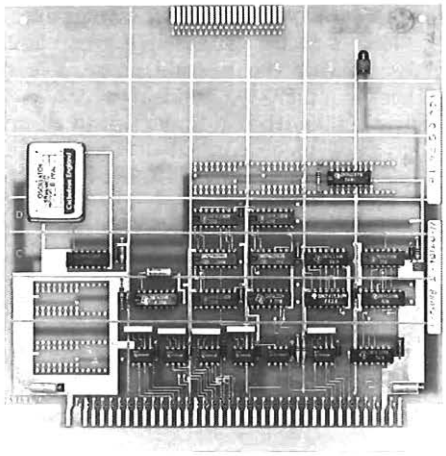


FIG. 8—Clock board

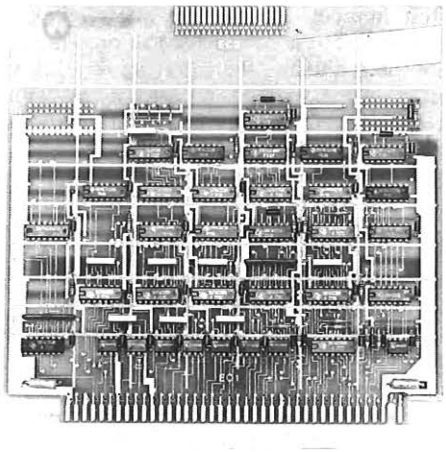


FIG. 9—Multiplexer board

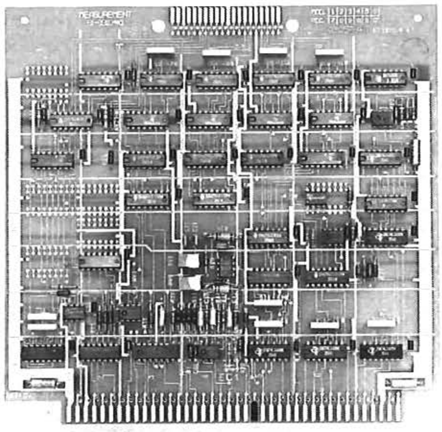


FIG. 10—Measurement board

Measurement Board

In addition to the boards described, one other board is incorporated in the MAC system. It is the *measurement board* and is housed in a special crate known as the *measurement assembly* which performs a transmission level test on a proportion of successful test calls and passes the information to the processor via a second processor interface board.

THE TEST CALL

The setting-up of a MAC test call is divided into 3 distinct phases: the steering phase, the sending phase and the post-sending phase. During the steering phase, a connexion is established between the MAC and an access position (the test-call originating point). It is important to ensure that this connexion has been made correctly before continuing with the setting-up of a call in the network because an undetected fault in the test circuit would cause the MAC to produce erroneous results. The MAC confirms that the test circuit has been correctly established by examining the tones that are returned from a concentrator and an access equipment in response to the steering digits generated by a MAC. The concentrator and access equipment return 400 Hz and 1000 Hz tones respectively to the MAC. Provided that these tones are received at the expected level and within the specified time limits, the MAC identifies the correct setting up of the test circuit.

At the beginning of the sending phase of a test call, the MAC determines if dial tone has been received at the access equipment. If an indication of dial tone is received, the MAC sends the digits to route the call through the network to a required test number. During the inter-digital pauses, the MAC examines the test circuit for the presence of standard supervisory tones and for the metering tone. A supervisory tone detected during sending indicates a call failure and, in this case, the call is terminated. Metering pulses detected during sending indicate a metering fault, and the MAC records this information and continues with the call to determine if it is routed to its required destination.

When all the test-call digits have been sent, the MAC is in the post-sending phase; it then determines the result of the call by identifying whatever supervisory tone appears on the test circuit and checking that a metering pulse is received during the correct period. On a limited number of calls, the MAC also checks that a second metering pulse is received during the correct period and performs the transmission test. During the post-sending phase of coin-collecting box calls the MAC also checks for the receipt of pay tone and simulates payment by sending a special digit to instruct the access equipment to generate a coin pulse.

A test call that passes through each of the above phases and during the latter phase receives test-number tone and metering tone at the expected time is recognized as a successful call. Any deviation from this sequence must also be identified by the MAC and the failure information recorded for later classification and processing.

SYSTEM REQUIREMENTS AFFECTING THE SIH

Tone Detection

The 2 basic functions of a MAC are to generate the required test-call digits and to identify any meaningful tones that are received from the PSTN during the setting-up of a test call. As previously indicated, the tone identification requirements are such that a MAC needs to detect tones in 3 discrete frequency bands centred on 400 Hz, 1000 Hz and 2500 Hz.

The 400 Hz band contains all the standard supervisory tones to be found on the PSTN. These tones include ringing tone, number-unobtainable tone, busy tone, equipment-engaged tone, test-number tone and pay tone. In addition, when a concentrator has been used, a 400 Hz tone is returned to the MAC to indicate that the concentrator has been seized correctly during the steering phase of the test call.

The 1000 Hz band is needed because of the 1000 Hz component in the MAC test-number tone. In addition, the access equipment returns a 1000 Hz tone to a MAC to indicate switching of a concentrator and the seizure and switching of an access equipment. The removal of 1000 Hz tone is used to indicate the return of dial tone from the PSTN.

The 2500 Hz band caters for the requirement to check that the test call is metered correctly. As it is not possible to send all unmodified metering pulse conditions directly back to a MAC over some of the different types of signalling system that could be encountered on the test circuit, a special tone was therefore chosen to convey the metering information from the access equipment to a MAC. An access equipment switches a 2500 Hz tone through to a MAC when the metering condition in the exchange is detected; the tone is transmitted for as long as the condition exists. The MAC recognizes as a metering pulse any burst of 2500 Hz tone greater than 100 ms.

In addition to the basic function of generating test calls, there is one other MAC facility which has an influence on the tone-detection requirements. This facility is termed *digits monitoring analysis* (DMA), which has been mentioned in a previous article[1]. During DMA, the routing digits of live calls on selected circuits are stored in the access equipment and signalled back to the MAC using a frequency-shift-keying technique. The tone frequencies used are 2500 Hz and 1000 Hz. The 2500 Hz is used initially to confirm that the MAC is connected to the DMA store and then alternate bursts of 2500 Hz and 1000 Hz tones are used to represent the *make* and *break* pulses of the digits stored.

In order to design the tone receivers in the SIH, it was necessary to specify the range of frequency and tone amplitude that were expected in the 3 frequency bands. The bandwidth of the 400 Hz receiver was dictated by the specifications of the different types of BPO ringing machine. The 1000 Hz and 2500 Hz tones that a MAC is required to detect are generated by crystal oscillators in the access equipment and, because of the accuracy of the crystal oscillators, the bandwidths of the 1000 Hz and 2500 Hz tone receivers were very narrow and determined largely by economic factors.

The tone amplitude ranges within which the 400 Hz and 1000 Hz receivers should operate were governed primarily by the ranges of levels that were expected from the network, taking into account the calculated transmission losses for the different types of test call. It was necessary to specify levels below which a 400 Hz tone or a 1000 Hz tone should be classified as *no tone*, bearing in mind that perfectly flat responses over the frequency band were not practical. In fixing the levels of these tones, due account had to be taken of the effects of noise on the network and of noise on the test circuits.

The level range to which the 2500 Hz tone receiver should operate was fixed mainly by the accuracy to which the circuit generating the tone could be set during manufacture and by the effects of the test circuit.

It was necessary to specify 4 sets of parameters for each of the tone receivers to define completely their frequency responses. These parameters are:

(*a*) the frequency range over which the receiver must operate, provided that the tone is received at the correct level,

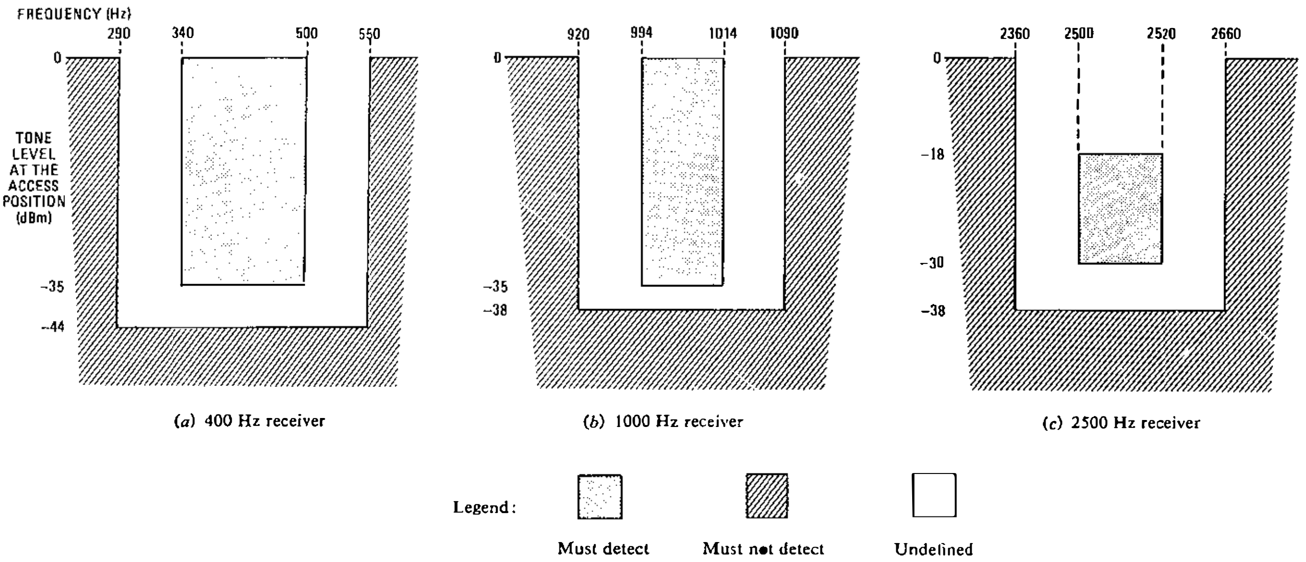
(*b*) the frequency ranges over which the receiver must not operate, irrespective of level,

(*c*) the range of levels over which the receiver must operate, provided that the tone is received within the correct frequency range, and

(*d*) the level below which the receiver must not operate, irrespective of frequency.

As explained, there is a fixed loss between a MAC and an access equipment, and this loss affects the range of levels over which the tone receivers must operate. The frequency response parameters for each of the tone receivers are given in Table 1, and shown in Fig. 11. The tone levels shown in Table 1 are the equivalent levels at an access position; that is, the test-call originating point.

To identify uniquely all the tones that a MAC can expect to receive, it is necessary for the SIH to have not only the frequency response shown in Table 1 but it must also report accurately the times of tone transitions. As explained in a



(*a*) 400 Hz receiver (*b*) 1000 Hz receiver (*c*) 2500 Hz receiver

FIG. 11—Frequency responses of MAC tone receivers as measured at an exchange access position

TABLE 1

Tone-Receiver Frequency Responses and Operating Margins

Frequency Range for Operation (Hz)	Frequency Range for Non-Operation (Hz)	(Hz)	Level Range for Operation (dBm)	Non-Operate Level (dBm)
340–500	<290	>550	0 to −35	−44
994–1014	<920	>1090	0 to −35	−38
2500–2520	<2360	>2660	−18 to −30	−38

previous article[2], the overall task of tone identification is performed by a combination of hardware and software. The role of the hardware is to inform the software when a tone transition occurs.

The required accuracy of these transition reports is dependent upon the frequency involved in the transition. Greater accuracy is required for the 400 Hz receiver than for the others because of the necessity to distinguish between several different 400 Hz supervisory tones with similar cadences. DMA tone dictates the accuracy required for the 2500 Hz receiver. The 1000 Hz receiver requires the least accuracy because the MAC test-number tone is significantly different from any other tone on the network.

The accuracies achieved by the SIH in reporting tone transitions are detailed in Table 2.

TABLE 2

Accuracy of Tone-Transition Identification

Frequency (Hz)	Accuracy (ms)
400	±10
1000	±25
2500	±10

Digit Sending

All digits transmitted by a MAC are in the form of loop-disconnect pulses. As previously indicated, a MAC generates digits to switch the concentrator, access equipment and the exchange equipment in the PSTN involved in the setting-up of a test call. In addition, a MAC can send digits to operate a remote printer connected to an outlet of the access equipment and also instruction digits to instruct the access equipment to perform a number of special operations.

To distinguish between instruction digits and the other digits sent by a MAC, it was necessary to devise a procedure whereby the MAC waits 4 s after sending a previous digit before sending an instruction digit. After 4 s, the access equipment will have switched itself into a state in which it interprets digits as instruction digits. If an inter-digital pause is extended beyond 4 s for the purpose of tone identification, the MAC can send an instruction digit called the *transition digit* to instruct the access equipment to revert to the state in which it interprets digits as test call digits. The most important instruction digits are the *pay* digit and the *hold* digit.

The *pay* digit instructs the access equipment to generate a *coin* pulse, which is sent by the MAC after receiving initial pay tone during a coin-collecting-box test call. The *hold* digit instructs the access equipment to hold the test call currently in progress to assist an engineer in the exchange in tracing the fault which affected the test call. The *hold* digit is sent for failed calls in analysis sequences 1 and 2[1], which are designed to explore failure conditions. Only equipment beyond the access position is held; therefore, the MAC can continue to send test calls along the test circuit to all other access equipments on the concentrator and to other access positions on the same access equipment.

IMPLEMENTATION OF TONE DETECTION

The MAC tone-detection circuitry was designed to meet the requirements outlined above in as flexible a manner as possible. Timescales dictated that the design be based on well-proven techniques, and a solution incorporating active filters appeared to meet this requirement and offered the greatest flexibility in design.

Each of the tone receivers was designed to be capable of detecting tones in one of the frequency and level ranges given in Table 1 and be unaffected by the presence of signals in the other 2 frequency bands. Although the initial requirement was for simultaneous detection of 400 Hz and 2500 Hz, and for 1000 Hz and 2500 Hz, the system was designed to allow simultaneous detection of 400 Hz and 1000 Hz to cater for possible future needs. The task was not only to ensure that each receiver did not detect high-level tones in the other bands, but also that such high-level tones did not inhibit the

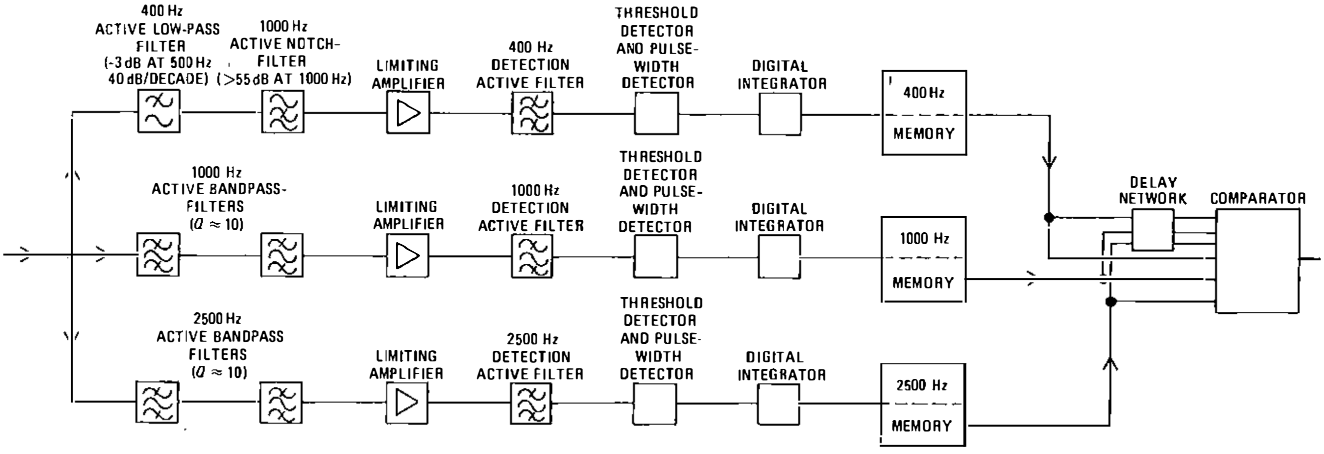


FIG. 12—SIH tone-detection subsystem

detection of low-level in-band tones. In the worst case, the unwanted signal could be 35 dB greater than the signal to be detected.

A block diagram of the tone detection subsystem is shown in Fig. 12. The subsystem contains 3 separate tone receivers, each consisting of a number of stages as described below.

Pre-filtering

For each of the tone receivers, the first 2 stages of filtering (the pre-filtering stages) are concerned with reducing the levels of signals in the other 2 bands to ensure non-interference with in-band signals.

The 1000 Hz and 2500 Hz receivers have bandwidth requirements that are narrow enough to allow the first 2 stages of filtering to be implemented using medium Q bandpass circuits. There was a constraint on the Q value owing to the need to restrict the persistence of the filters to a period that does not adversely affect the accuracy of transition reports. A Q of 10 was chosen for these filters. The bandwidth of the 400 Hz receiver was too large to enable simple bandpass circuits to be used for the first 2 stages. Therefore, a low-pass filter and a notch filter were used to provide the necessary rejection of 1000 Hz and 2500 Hz signals.

Limiting Amplifier and Detection Active Filter

After the pre-filtering, the signal is fed into a limiting amplifier which produces a constant amplitude signal for all signals with sufficient amplitude to require detection. After this stage, the frequency of the signal is the only parameter of interest. The square-wave output of the limiting amplifier is then passed into the detection active filter, which produces a sine wave output with an amplitude dependent upon the signal frequency. The characteristic of this filter determines the bandwidth of the receiver.

Threshold Detector and Pulse-Width Detector

The sine-wave output of the detection active-filter is fed into a threshold detector which looks for positive peaks and produces an output every time the input goes above a predefined threshold; thus, the threshold detector produces a pulse for every detected cycle of the sine wave. The pulse-train output produced by the threshold detector is then passed into a pulse-width detector (PWD). The PWD indicates that the signal is present as long as it is receiving pulses from the threshold detector. The time-constant of the PWD was designed such that one peak (that is, 1 cycle) can be missed without indicating that the signal is absent.

Digital Integrator and Comparator

The output of the threshold detector is passed to a digital integrator, which is an up/down counter. A tone must be present for at least 60 ms before the digital integrator will indicate the tone is present. Similarly, a tone must be absent for at least either 60 ms (1000 Hz and 2500 Hz) or 16 ms (400 Hz) before the digital integrator indicates that the tone is absent. This stage of digital filtering was incorporated to reject any short ON or OFF periods of tone which might be produced by noise. The OFF-rejection is shorter for the 400 Hz to allow the correct detection of ringing tone. The output of the digital integrator is staticized in a bistable for later interrogation by the multiplexer board. The output of the bistable, together with a delayed version, is passed to a comparator. The comparator is then able to determine when a transition has occurred by identifying a difference between the current bistable output and the delayed bistable output. When the multiplexer scans the tone recognition board it is able to determine if there has been a tone transition by examining the comparator output.

SUMMARY

The monitoring of the quality of service provided by the BPO telephone network will be undertaken in the future by MAC systems installed in each of the 61 Telephone Areas in the UK. This article has concentrated on how a MAC establishes a test call within the network, the criteria by which the success or failure of a test call is measured, and the special hardware which plays an important part in this activity.

Having detailed the setting-up and monitoring of single test calls, a further article to be published in this *Journal* will discuss many of the design features of the MAC software. The article will include descriptions of each software module, the use of core and disc storage, input/output and the factors affecting the performance and capacity of a MAC.

ACKNOWLEDGEMENT

The MAC was developed by GEC Computers Limited in close cooperation with the BPO. The success of the development is a tribute to the expertise of GEC Computers Limited and the authors wish to acknowledge the valuable work of their development team.

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A Review of the Development of the INTELSAT System

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This article reviews the development of the INTELSAT system from the early experiments in satellite communications through to the planned introduction of INTELSAT V operation in 1979.

INTRODUCTION

As far back as 1945, the British science-fiction writer and prophet of much science fact, Arthur C. Clarke, was proposing a global communications satellite system[1] that was remarkably similar to the INTELSAT system we know today. However, even though Clarke's proposals were based on sound technical factors as were known at that time and which have since been so unquestionably confirmed, it was not until some 15 years later that the first tests were initiated involving satellite communications that were to lead directly to the establishment of the INTELSAT system.

The early satellites had rather distinctive names: Score, Courier, Echo, Telstar, Relay, Syncom and Early Bird. The very first active satellites, such as Score (launched by the Americans in December 1958) and Courier (launched in 1959), had very limited capabilities and were entirely experimental. The first passive satellite, Echo I, which consisted simply of a large reflecting metallized-balloon of 30 m diameter, was launched in 1960 into an orbit about 1600 km above the earth. This system required high-power transmitters on the ground to compensate for the losses due to both the scattering of the reflected energy and the propagation path losses.

These early tests established the feasibility of providing long-distance communications by use of artificial earth satellites. The tests also indicated that active satellites (that is, satellites equipped with amplifiers to boost the received signal before retransmission to compensate for path losses, and an aerial system to direct the retransmission towards the earth to eliminate losses due to scattering) offered better potential for efficient operation. Thus was conceived the now historically-famous Telstar I satellite, which was launched in 1962.

By 1962, the British Post Office (BPO) and the French Ministry of Posts and Telecommunications had agreed to build earth stations (at Goonhilly in Cornwall and Pleumeur Bodou in Brittany respectively) to work with the American Telegraph and Telephone (ATT) Company earth station at Andover, USA. In 1962, all 3 administrations participated in the first experiments in transatlantic satellite communications via the Telstar I satellite.

THE EARLY SATELLITES

Low-Orbiting Satellites

Telstar I was an active satellite using a single wideband transponder that received signals in a 50 MHz band centred on 6390 MHz; the signals were frequency converted, amplified and retransmitted in a 50 MHz band centred on 4170 MHz. The satellite had a prime power source of 14 W and the frequency-converted signal was retransmitted with a power of about 2 W through an aerial system that resulted in an effective isotropic radiated power (EIRP) of about 3-4 dBW* being transmitted towards the earth[2, 3]; the traffic capacity of Telstar I was about 12 circuits.

The Telstar I satellite, shown in Fig. 1, was a relatively small satellite; it was approximately 0·9 m in diameter and weighed 77 kg at launch. It was launched into a low elliptical orbit with an apogee of 6200 km and a perigee of 950 km; the inclination of plane of orbit relative to the equator was 44·8° and the orbital period was 157·8 min. This orbit provided periods of mutual visibility of the satellite from the American and European earth stations of about 30-40 min duration, 3 or 4 times a day. Although a system based on such satellites would not be particularly suitable for full time operational purposes, the tests that were carried out clearly established the feasibility of providing, via orbiting active satellites, high-quality wideband telephony and other com-

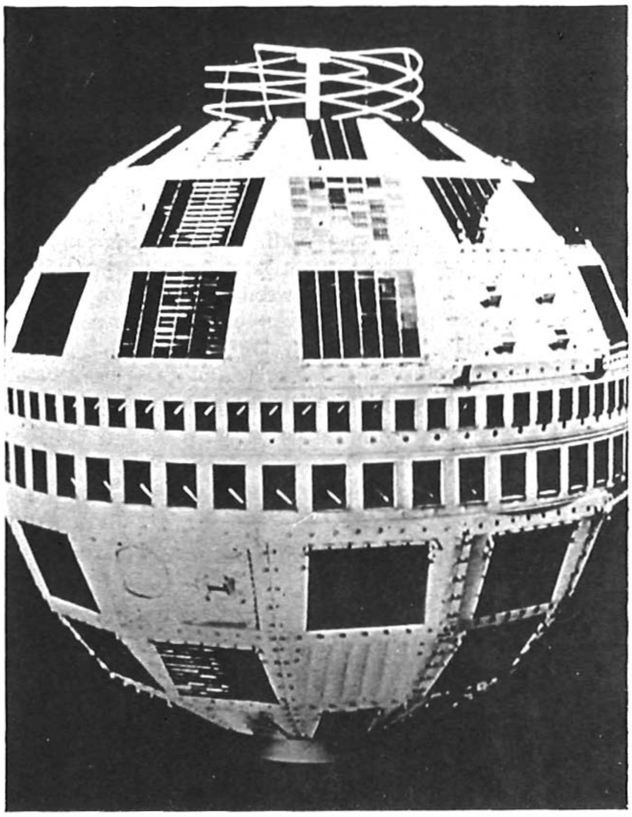

FIG. 1—The Telstar satellite

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† Radio Engineering Services Division, External Telecommunications Executive

* dBW—decibels relative to 1 W

munications services, including monochrome and colour television transmissions.

The success of Telstar I was followed by further tests using the Telstar II and Relay I satellites in 1963, and the Relay II satellite in 1964. The Relay satellites were active devices similar to the Telstar satellites but they received from the earth station in the 2 GHz band instead of the 6 GHz band as used by Telstar satellites. The Relay satellites required about twice the earth-station transmit power compared to that used for Telstar, but the transmitted EIRP from the satellite was also about double, being of the order of 6–8 dBW. In addition, in 1964, some further testing was carried out on a second passive device, Echo II, but the high losses involved (about 100 dB in each direction of transmission) made this form of operation unattractive.

Geosynchronous Satellites

Following the tests with low-orbiting satellites, the Americans, in conjunction with the Japanese, also carried out tests in the Pacific region using satellites positioned in a geosynchronous orbit 35 800 km above the equator. The first of the geosynchronous satellites to be successfully launched was SYNCOM II; this satellite was placed over the Pacific Ocean in 1963. A second one (SYNCOM III) was launched in 1964.[4] These satellites had 2 transponders each. However, the transponders were of very narrow bandwidth; SYNCOM II had one transponder of 5 MHz and one of 1 MHz (providing two 500 kHz channels) and SYNCOM III had one transponder of 5 MHz and one of 10 MHz. The SYNCOM satellites had a transmit power of 2 W, the same as the Telstar satellites but, because of their higher-gain aerial systems (the transmit aerial had a gain of about 6 dB and the receive aerial 3 dB), the satellite EIRP of about 6–8 dBW was much the same as that from the higher-power Relay satellites. Further, in contrast to Telstar and Relay, both of which transmitted in the 4 GHz band, SYNCOM transmitted in the 2 GHz band and received in the 7 GHz band.

The total prime power supply in these early satellites was measured in terms of only a few tens of watts. The SYNCOM satellites for example had a prime power source of 29 W, which was about double that of Telstar, derived from some 3850 solar cells located around its cylindrical surface.

Because a satellite in geosynchronous orbit is stationary relative to a given point on the earth's surface and is therefore available for 24 h/d, it is far more suitable for permanent communications purposes than a satellite in low orbit. However, the long propagation path involved (over 35 800 km for both the up and the down paths) results in approximately a 250 ms one-way delay which, in a 2 way conversation, results in about 0·5 s delay between an initial statement or question and the response. Nevertheless, it was considered that the advantages of the geosynchronous satellite far outweighed this potential disadvantage and that users would generally have no difficulty in accepting this degree of transmission delay.

THE CREATION OF INTELSAT

The International Telecommunications Satellite Consortium

Following the success of the first 3 years of experimental work on satellite communications, it was recognized that the future development and exploitation of space communications could be efficiently and effectively conducted only on an international basis. Hence, on 20 August 1964, in Washington DC, USA, INTELSAT was born[5]. There were 11 founding members—Australia, Canada, Denmark, France, Italy, Japan, the Netherlands, Spain, the UK, the USA and the Vatican City. The administrative and executive arrangements under which the INTELSAT consortium operated throughout the period of the interim agreement from August 1964 until February 1973, is shown in Fig. 2. From its conception in 1964, the membership of INTELSAT increased from 11 to 83 nations. Of particular interest is the fact that the responsibility for all international satellite communications in the USA had been taken over from the ATT Company in 1963 by the Communications Satellite Corporation (COMSAT), which had been formed under a mandate from the USA Congress under the Communications Satellite Act of 1962. COMSAT provided the USA representation on the Interim Communications Satellite Committee (ICSC), which governed the consortium; COMSAT had a 52% voting share and also acted as Manager for INTELSAT. The UK, represented by the External Telecommunications Executive of the BPO and representing also the interests of the Cable and Wireless Company and the Republic of Ireland Department of Posts and Telegraphs, had the second largest voting share at 7·5%. All other members shares ranged from 5% down to as little as 0·01%. However, the voting procedures did not allow the USA to pass any propositions on a straight one member majority vote. Any motion supported by the USA had also to be supported by 3 other members with a voting strength between them of 12½%. The USA were, however, in a position unilaterally to block any proposals with which they did not agree.

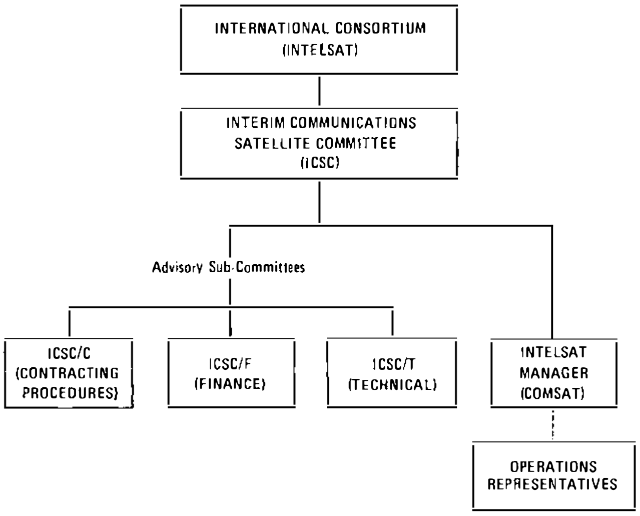

FIG. 2—INTELSAT organization: interim arrangements (20 Aug. 1964 to 11 Feb. 1973)

The International Telecommunications Satellite Organization

Under the INTELSAT definitive arrangements[6], which resulted in the consortium being reorganized as an International Organization in February 1973, voting rights are more closely aligned to utilization of the system and, hence, the current USA share was reduced to approximately 25% while the combined UK/Eire share was increased to about 11%. The new 4-tier administrative and executive structure which came into being at that time is shown in Fig. 3. The old ICSC then became the Board of Governors and the role of COMSAT as Manager for INTELSAT was limited to that of operational and technical management under a management services contract. All other management functions, including finance, legal matters, traffic forecasting, International Telecommunications Union (ITU) liaison, and consideration of requests to access the INTELSAT system, became the responsibility of a newly established Executive headed by a Secretary General.

In addition to the permanent INTELSAT management organization, there are also 3 groups of operations representatives. These groups are formed from users of the satellite

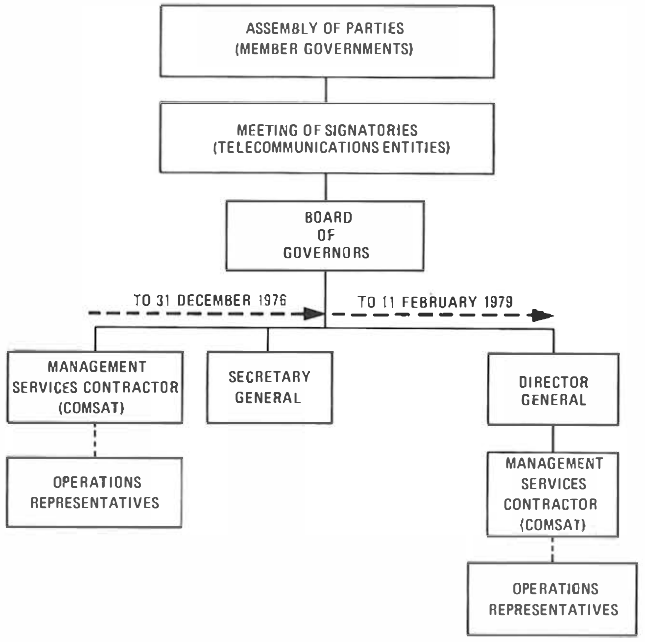

FIG. 3—INTELSAT organization: definitive arrangements (12 Feb. 1973 to 11 Feb. 1979)

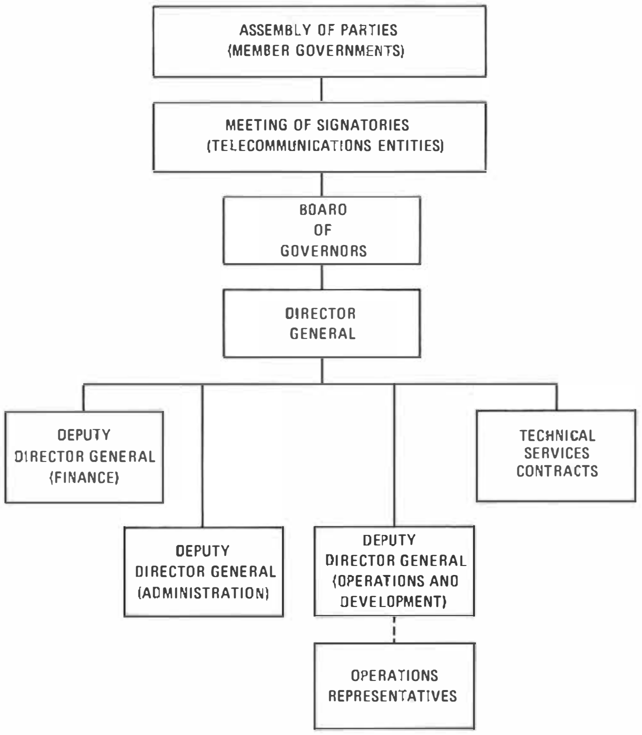

FIG 4—INTELSAT organization: permanent arrangements (from 12 Feb. 1979)

system, and they meet periodically to co-ordinate operational matters in the Atlantic, Indian and Pacific Ocean regions, and keep INTELSAT informed of projected service requirements.

The first management services contract will run until February 1979, at which time permanent management arrangements for INTELSAT will be adopted. However, in January 1977, the Secretary General was replaced by a Director General, who is directly responsible to the Board of Governors for the performance of all management functions. The management services contractor (COMSAT) is therefore now responsible to the Board of Governors through the Director General. The permanent management structure approved for INTELSAT (see Fig. 4) provides for the appointment of 3 Deputy Directors General who will handle finance, administration, and operations and development. The management structure also provides for 2 technical contracts, to be awarded by the Director General with the approval of the Board of Governors as a follow-on to the present management services contract after it expires in 1979. One of the contracts will be for 6 years and the other for 4 years. Both contracts are to be awarded to the same contractor and will commence in February 1979. The 6-year technical services contract provides for continued contractor operational and technical support with respect to the INTELSAT V and prior series of satellites. The 4-year technical services contract is primarily concerned with the INTELSAT V follow-on satellite series.

PAST AND PRESENT INTELSAT SATELLITES

A chronology and general description of the INTELSAT satellites to date is given in Table 1.

The INTELSAT I Satellite

The first satellite launched under the aegis of the new international body was INTELSAT I; this satellite was based on the earlier SYNCOM satellites and was more popularly known as Early Bird, see Fig. 5. (The official designation given by the manufacturer for the Early Bird satellite was HS 303[4,7].) Early Bird had 2 transponders, each having about 30 MHz bandwidth, and a transmit power of about 4 W; its aerial system had 3 dB more gain than its SYNCOM predecessors and illuminated only the North Atlantic region with an EIRP of about 12–14 dBW. The total prime power source, provided by some 6000 solar cells around the satellite's cylindrical surface, was 45 W. The Early Bird operating frequencies conformed with the new ITU allocations for fixed satellite services, receiving from the up-link in the 6 GHz band and transmitting the down-link in the 4 GHz band. INTELSAT I, although not spherical, was about the same size and weight as Telstar, being 0·7 m in diameter and 0·6 m high and weighing 68 kg at launch, and was placed into a geosynchronous orbit 35 800 km above the equator over

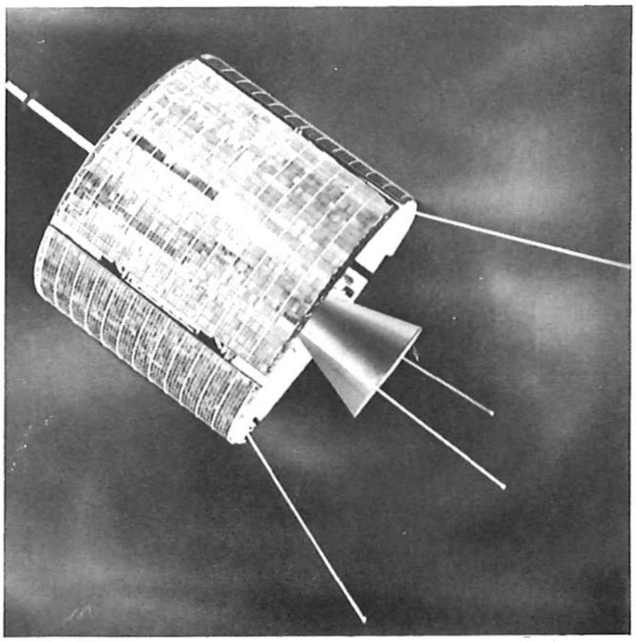

FIG. 5—The INTELSAT I (Early Bird) satellite

TABLE 1
Satellite Chronology

Launch Date	Operational Date	Status
INTELSAT I (Early Bird) 6 Apr. 1965	28 June 1965	Placed in service over Atlantic at Long. 25°W. Retired reserve 20 Jan. 1969; reactivated 29 June 1969. Retired 21 Aug. 1969. No longer in service
INTELSAT II (F-1) 26 Oct. 1966		Failed to achieve synchronous orbit due to malfunction of apogee motor
INTELSAT II (F-2) 11 Jan. 1967	27 Jan. 1967	Placed in service over Pacific at Long. 172°E. No longer in service
INTELSAT II (F-3) 22 Mar. 1967	7 Apr. 1967	Placed in service over Atlantic at Long. 6°W. No longer in service
INTELSAT II (F-4) 27 Sept. 1967	4 Nov. 1967	Placed in service over Pacific at Long. 176°E. No longer in service
INTELSAT III (F-1) 18 Sept. 1968		Failed to achieve proper transfer orbit due to launch vehicle malfunction
INTELSAT III (F-2) 18 Dec. 1968	24 Dec. 1968	Placed in service over the Atlantic at Long. 30°W. Ceased operation 29 June 1969. Resumed operation 1 Aug. 1969. No longer in service
INTELSAT III (F-3) 5 Feb. 1969	16 Feb. 1969	Placed in service over the Pacific at Long. 174°E. Repositioned over Indian Ocean at Long. 62·5°E and began service there 1 July 1969. No longer in service
INTELSAT III (F-4) 21 May 1969	31 May 1969	Placed in service over the Pacific at Long. 174°E. No longer in service
INTELSAT III (F-5) 25 July 1969		Failed to achieve proper transfer orbit due to launch vehicle malfunction
INTELSAT III (F-6) 14 Jan. 1970	1 Feb. 1970	Placed in service over Atlantic at Long. 24°W. No longer in service
INTELSAT III (F-7) 22 Apr. 1970	8 May 1970	Placed in service over Atlantic at Long. 19°W. Failed in synchronous orbit March 1972
INTELSAT III (F-8) 23 July 1970		Failed to achieve synchronous orbit due to malfunction during apogee-motor firing
INTELSAT IV (F-1) 22 May 1975	13 July 1975	In service over the Indian Ocean at Long. 63°E.
INTELSAT IV (F-2) 25 Jan. 1971	26 Mar. 1971	Placed in service over the Atlantic at Long. 335·5°E. Now in reserve
INTELSAT IV (F-3) 19 Dec. 1971	19 Feb. 1972	Placed in service over the Atlantic at Long. 340·5°E. Now in service carrying major path and leased transponder traffic
INTELSAT IV (F-4) 22 Jan. 1972	14 Feb. 1972	Placed in service over the Pacific Ocean at Long. 174°E. Now in reserve at Long. 179°E.
INTELSAT IV (F-5) 13 June 1972	30 July 1972	Placed in service over the Indian Ocean at Long. 61·4°E. Now in reserve at Long. 60°E.
INTELSAT IV (F-6) 20 Feb. 1975		Failed to achieve proper transfer orbit due to launch vehicle malfunction
INTELSAT IV (F-7) 23 Aug. 1973	21 Nov. 1973	Placed in service over the Atlantic Ocean at Long. 330°E. Now in service over Atlantic Ocean at Long. 359°E, carrying leased transponder traffic
INTELSAT IV (F-8) 21 Nov. 1974	15 Dec. 1974	In service over the Pacific Ocean at Long. 174°E.
INTELSAT IV-A (F-1) 25 Sept. 1975	1 Feb. 1976	In service as the primary satellite over the Atlantic Ocean at Long. 335·5°E.
INTELSAT IV-A (F-2) 29 Jan. 1976	1 Apr. 1976	In reserve as spare satellite over the Atlantic Ocean at Long. 330·5°E.
INTELSAT IV-A (F-4) 26 May 1977	11 Aug. 1977	In service as a major path satellite over the Atlantic Ocean at Long. 325·5°E.
INTELSAT IV-A (F-5) 29 Sept. 1977		Failed to achieve proper transfer orbit due to launch vehicle malfunction
INTELSAT IV-A (F-3) 7 Jan. 1978	Sept. 1978	Planned for service over the Indian Ocean at Long. 60° E.
INTELSAT IV-A (F-6) 31 Mar. 1978	Sept. 1978	Planned for service over the Indian Ocean at Long. 63°E.

the Atlantic Ocean in April 1965. After many weeks of testing it went into operational service in June of that year, providing initially about 60 circuits between Europe and North America.

By 1965, in addition to the earth stations in the UK and France, 2 more earth stations had been built in Europe, one at Raisting in West Germany and one at Fucino in Italy. However, the characteristics of Early Bird were such that only 2 earth stations could access (that is, transmit to) the satellite simultaneously (one through each transponder), therefore it was only possible to establish one point-to-point trunk between Europe and the USA. To enable all the European earth stations to participate in this venture, a 3 week rota was established between the German, French and UK earth stations, so that one station would be operational for a week, a second was on standby and the third was free for maintenance purposes. This rota was effective for 5 days a week, leaving the Italian earth station to provide the service over weekends with one of the others acting as standby.

On this basis, operations grew over the next 2 years from about 60 circuits for 12 h/d for 5 days a week, to about 240 circuits for 24 h/d. In addition, during that time, a second earth station in North America became operational at Mill Village, Nova Scotia, Canada, and shared operations with the Andover earth station in the USA. As an alternative to the telephony service, a good-quality television transmission could be provided. Although initially expected to have a lifetime of 1·5–2 years, Early Bird provided regular service for over 3 years, and was still operational, although not then in use, 5 years after its launch.

The INTELSAT II Satellite

The first INTELSAT II satellite to be launched successfully into a geosynchronous orbit was positioned over the Pacific Ocean in January 1967. Initially, this satellite provided service between the Brewster Flats earth station in Washington on the West coast of the USA and an earth station at Paumalu on the Island of Oahu in the Hawaian group. The characteristics of the INTELSAT II satellite permitted multiple access by several earth stations over its 120 MHz of transponder bandwidth, and earth stations in Japan and Australia soon joined with the 2 USA earth stations in the Pacific region to establish, in early 1967, the first multiple access satellite system.

Basically, the INTELSAT II satellite (see Fig. 6) was a development of the INTELSAT I (HS 303) satellite, and in fact was designated by the manufacturers as HS 303A and was designed with a life expectancy of 3 years. It was approximately the same height as INTELSAT I but was twice the diameter and double the weight. In contrast to the transponders in INTELSAT I, the 120 MHz bandwidth transponder of INTELSAT II possessed no limiting characteristics and this factor permitted the multiple-access operation already mentioned. Having a prime power-source of 75 W (including a battery to provide power during eclipse periods) the output power of INTELSAT II was higher than its predecessor. But, with a wider beamwidth aerial system to facilitate coverage of both the southern and northern areas of a region, the transmitted EIRP was about the same at 12–14 dBW. The maximum circuit capacity, in terms of 4 kHz channels provided between INTELSAT standard earth stations, was also the same as INTELSAT I, being of the order of 240 circuits in both cases. However, because of the INTELSAT II's multiple access capability, it was possible to provide a television transmission and telephony service simultaneously; in fact, about 50% of the telephony capacity could be retained during a television transmission.

In April 1967, an INTELSAT II satellite was launched above the Atlantic region, thereby establishing the first 2-satellite system and enabling all the then existing earth stations in the region (7 at that time) to operate continuously, rather than on a rota basis. A third INTELSAT II satellite was launched in November 1967 for service in the Pacific region. Therefore, by early 1968, by which time there were 6 earth stations in the Pacific region, both regions had a 2-satellite complement.

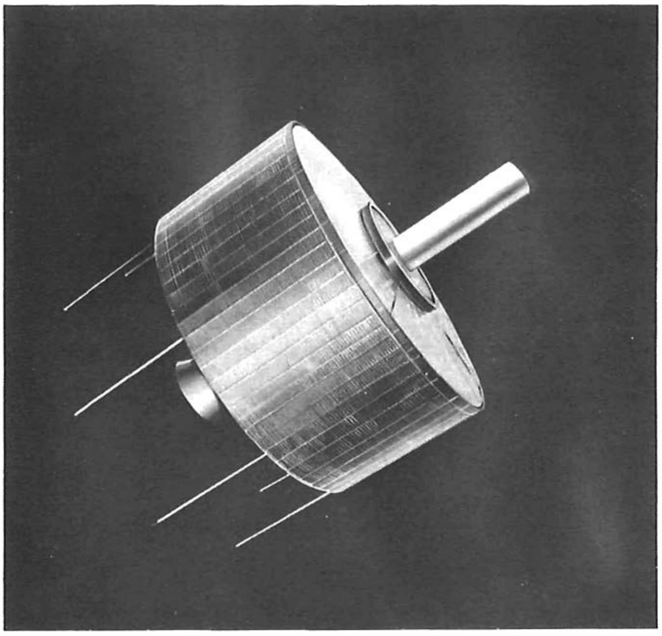

FIG. 6—INTELSAT II satellite

The INTELSAT III Satellite

The first INTELSAT III to be launched successfully was placed in service in the Atlantic region in December 1968 and, less than 2 months later, a second satellite was launched and brought into service in the Pacific region. Within 3 months, the third INTELSAT III to be launched was also placed in the Pacific region, and the original Pacific region INTELSAT III was then transferred to the Indian Ocean region. Hence, by 1 July 1969, some 6 months after the first INTELSAT III went into service in the Atlantic region, a truly global system had been established with INTELSAT III satellites in all 3 regions.

The INTELSAT III satellites (see Fig. 7) were 1·4 m in diameter and 1 m high, they had a prime power source of 120 W (including a battery) and weighed nearly 300 kg at launch. The satellites utilized the two 500 MHz bands allocated for fixed-service satellite communications in the 4 GHz and 6 GHz frequency spectrum, with 2 transponders of 225 MHz each for the communications services. The satellites received in the 6 GHz band (5932–6418 MHz) and retransmitted in the 4 GHz band (3707–4193 MHz) through an aerial system that provided global earth coverage, that is, coverage over the whole of the earth's surface as visible from the satellite with an EIRP of 22 dBW. The capacity of an INTELSAT III satellite was approximately 1200 circuits, plus one television channel.

Because of the increase in the number of earth stations and the growth of traffic in the Atlantic region, a 2-satellite system was necessary in that region. However, one satellite was sufficient to meet the requirements in each of the other 2 regions. The assignment of earth stations between the 2 satellites in the Atlantic region was done on a community of interest basis, hence, one provided service between the USA, Canada, France, UK and the countries of the Middle East and Africa, while the other provided service between the USA, Germany, Italy, Spain and the countries of South America.

By the end of 1970, just 2 years from the start of the INTELSAT III era, there were 20 earth stations operating in

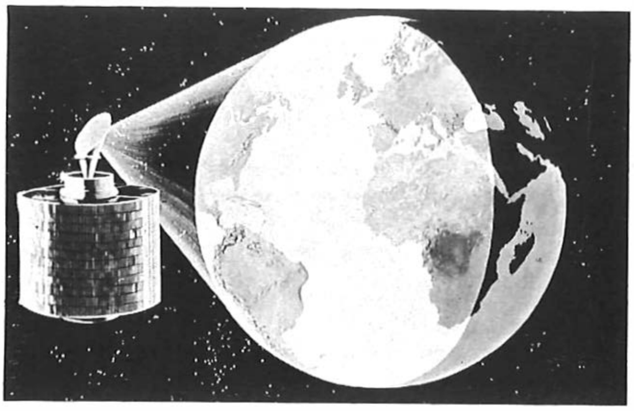

FIG. 7—INTELSAT III satellite

the Atlantic region, 14 in the Pacific region and 12 in the Indian Ocean region, which represented an increase of about 30 earth stations in 2 years.

The INTELSAT III satellite programme was not however endowed with great success. Of 8 attempted launches, 3 were abortive. Out of the 5 that were successfully launched, 2 had serious aerial de-spin problems, which resulted in their early retirement from service. Two others had communications equipment problems, which resulted in their traffic-carrying capacity being considerably reduced; one later developed the same aerial de-spin problems as the earlier satellites and was also prematurely retired from service. The remaining satellite also produced the same symptoms with respect to the aerial de-spin problems, but survived until a replacement satellite was provided.

Although the INTELSAT IIIs were designed and built to have a 5-year life, the time from launch of the first one to the replacement in service of the last one, was barely three and a half years. In fact, the period during which there was an INTELSAT III system in existence in all 3 regions was less than 2 years. Even then, back-up facilities for each region was provided by the obsolete INTELSAT II satellites.

Despite these difficulties, the INTELSAT III satellites will always have an honourable place in the history of satellite communications as the series of satellites by which, in 1969, the first truly global international satellite communications system was established.

The INTELSAT IV Satellite

The first INTELSAT IV was launched for service in the Atlantic region in January 1971 and commenced operations in March of that year. In contrast to the very rapid initial launch sequence of the INTELSAT III satellites (3 satellites were launched in the space of the first 6 months), it was nearly a year later before the second INTELSAT IV was launched for service in the Atlantic region. This was followed one month later, in January 1972, by the launch of the third INTELSAT IV for service in the Pacific region; 5 months later, in June 1972, the fourth INTELSAT IV was launched for service in the Indian Ocean region. Therefore, a global system using INTELSAT IV satellites had been established within 18 months from the first launch. It was some 14 months later, in August 1973, before the fifth INTELSAT IV satellite was launched and positioned in the Atlantic region, to give that region a full complement of 3 INTELSAT IV satellites. The seventh INTELSAT IV to be launched was the only INTELSAT IV that failed to achieve operational status. However, the sixth and eighth INTELSAT IV satellites were successfully put into orbit in November 1974 and May 1975 respectively. The successful launching of 7 out of 8 INTELSAT IV satellites contrasted with the rather disastrous INTELSAT III launch programme and in-orbit failures, although problems are being experienced due to degradation in the performance of some of the INTELSAT IV receivers.

FIG. 8—INTELSAT IV satellite

The INTELSAT IV satellites (see Fig. 8) are approximately 2·4 m in diameter and 2·8 m high, extending to 5·3 m to the top of the aerial structure[8, 9]. They use the same 500 MHz bands for transmit (4 GHz) and receive (6 GHz) signals as the INTELSAT III. However, using 12 separate transponders, the spectrum is divided into bands of 36 MHz, one of which is used for single-channel-per-carrier digital transmissions in designated satellites[10, 11]. The prime power supply, developed from some 42 000 solar cells, is approximately 550 W at 24 V and includes two 15 Ah batteries to ensure continuity of operations during eclipse periods. All 12 transponders receive from the earth stations via a global-coverage aerial system similar to the earlier INTELSAT II and III satellites. However, in addition to the global-coverage transmit aerial system, which has a beamwidth of 17°, the INTELSAT IV's have 2 narrow-beam, or spot-beam, transmit aerials of 4·5° beamwidth, which can be steered from the ground to illuminate 2 specific areas of the earth's surface. Of the 12 transponders, 4 can be switched to the global-beam or one of the spot-beam aerials, another 4 to the global-beam or the other spot-beam aerial and the remaining 4 are connected permanently to the global beam aerial system. The 2 spot-beam aerials are normally deployed one each towards the east and west of the region, and hence the associated transponders are referred to respectively as the *east spot-beam* and *west spot-beam* transponders. The INTELSAT IV global-beam transmissions are similar to the INTELSAT IIIs at 22 dBW EIRP, and the spot beams have an EIRP of 33·7 dBW. The object of the spot-beam transmissions is to provide more efficiently for the heavy east–west traffic requirements in each region, the spot-beam carriers having approximately double the capacity of similar-sized global-beam carriers. The capacity of the INTELSAT IV satellites is variable and dependent on the extent to which the spot beams can be utilized and the degree of multiple access employed. Although an INTELSAT IV satellite has a theoretical maximum traffic capacity of about 9000 circuits, in practice, when configured to meet actual traffic requirements, the maximum capacity provided is of the order of 3500 circuits plus 2 television channels, which is about 3 times the capacity of an INTELSAT III.

As during the INTELSAT III operational period, the Atlantic region traffic requirements have necessitated the use of 2 satellites in that region. However, during the INTELSAT IV era, the assignment of earth stations between the 2 satellites has been based on a very different concept. Instead of the 2 operational satellites working as regional satellites on a community of interest basis, one of them is designated as the *primary* satellite and the other as the *major-path* satellite. Basically, all earth stations access the primary satellite, while only those earth stations with dual-aerial installations, whether co-located or separated, access the major-path satellite. In addition, some special categories of single-aerial earth stations may also access the major-path satellite rather than the primary satellite. At present there are 9 dual-aerial and approximately 11 single-aerial earth stations working via the major-path satellite in addition to the 40 or so working via the primary satellite. Owing to the high level of traffic carried by each working satellite, it is normal practice to locate a spare satellite in each region. If a failure occurs to a working satellite, services can then be restored by simultaneously pointing-over all the aerials accessing the failed satellite to the spare satellite.

The INTELSAT IV-A Satellite

The first of a new series of satellites, the INTELSAT IV-A satellite, was launched from Cape Canaveral, Florida, USA in September 1975 and replaced the primary INTELSAT IV satellite in the Atlantic Ocean region. Subsequently, a further 2 INTELSAT IV-A satellites were launched successfully and are now functioning as the Atlantic region major-path and spare-in-orbit satellites. A launch vehicle malfunction resulted in the loss of the fourth INTELSAT IV-A satellite to be launched. However, the remaining 2 INTELSAT IV-A satellites have been successfully placed in orbit and will enter operational service in the Indian Ocean region during 1978.

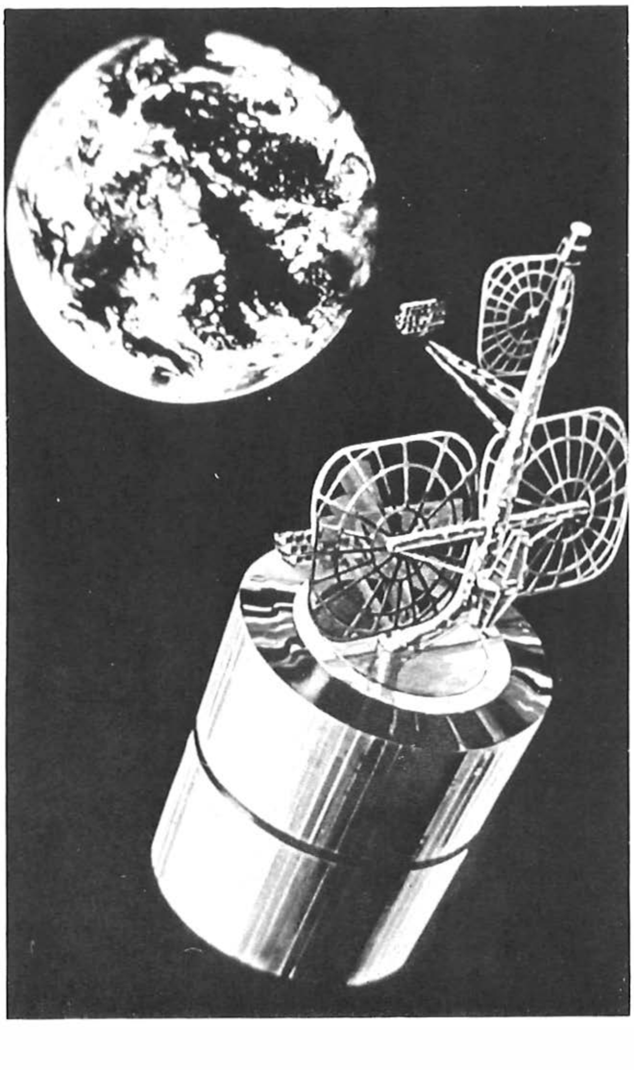

FIG. 9—INTELSAT IV-A satellite

An INTELSAT IV-A satellite (see Fig. 9) has an overall height including the aerial structure of about 7 m and a diameter of 2·4 m. The height of the solar panel surrounding the main body of the satellite is 2·8 m. Launch weight is approximately 1515 kg, with the in-orbit weight after apogee motor firing reducing to 825 kg.

An INTELSAT IV-A has many features that are derived from the INTELSAT IV design. However, the nominal capacity is increased by more than 50%, to about 6000 telephone circuits plus 2 television channels, by increasing the number of operating transponders from 12 to 20 and using an improved aerial system that makes available a greater effective bandwidth through frequency re-use by beam separation. Hence, for Atlantic service, the east beam will cover Europe and Africa with a 320 MHz bandwidth capability. The same 320 MHz bandwidth will be re-used in the west beam, covering North and South America. Furthermore, an INTELSAT IV-A has the ability to focus spot beams on 4 selected areas of the earth's surface. Alternatively, the 2 spot beams in the eastern or western sectors may be combined to form hemispheric coverage beams. In addition to the 8 east-beam and 8 west-beam transponders, 4 transponders are used to provide global-beam coverage, and there is the further facility that 2 of the east-beam and 2 of the west-beam transponders may be switched to provide 2 additional global-beam transponders. This facility is of particular importance in the Indian Ocean region, where global beam capacity is at a premium.

The INTELSAT IV-A satellite is spin stabilized similar to the earlier INTELSAT satellites and the aerial system is despun, as in the INTELSAT III and IV series. The spacecraft has 2 main elements, which can be seen in Fig. 10. One is the rotating section, which contains most of the satellite "house-keeping" functions, including the power subsystem, the

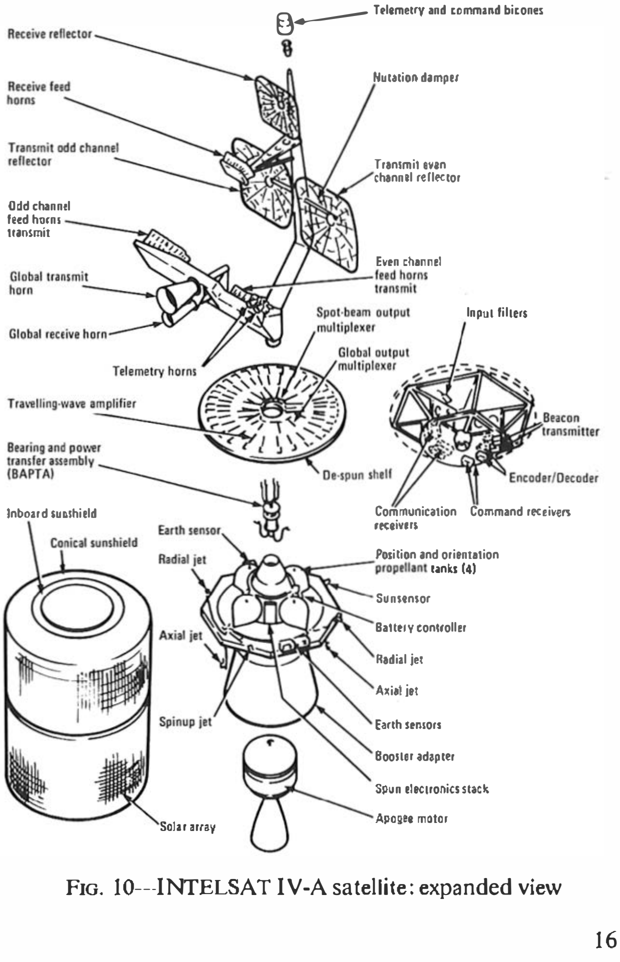

FIG. 10—INTELSAT IV-A satellite: expanded view

positioning and orientation subsystem, the apogee motor, and the despin control subsystem. The second element is the despun earth-oriented platform, which contains the communications repeater, aerials and associated elements of the telemetry and command subsystem.

The mechanical interface between the spun and despun elements is a ball-bearing joint which is clamped during launch. The corresponding rotating electrical interface between aerial and spacecraft body is provided by slip rings for power and a rotary transformer for signal circuits. All the spacecraft aerial reflectors are supported by a single tubular mast. The 1·35 m transmit and 0·89 m receive quasi-square reflectors are constructed of a metallic mesh on an open web frame to minimize solar torque. The feed-horn arrays and the global horns are cantilevered from the base of the mast and the telemetry and command omnidirectional bicone aerial is mounted at the mast tip. The earth pointing orientation of the despun section is maintained by the despin control subsystem. Rotor-mounted sun or earth sensors (3 earth and 2 sun sensors) provide an inertial reference.

The power subsystem includes a cylindrical solar array as the prime source and 2 nickel-cadmium batteries to provide continuous service during eclipse periods. The 17 000 solar cells initially provide approximately 700 W, decreasing to 600 W at the end of the satellite's seventh year.

The positioning and orientation subsystem maintains the spacecraft's orbit and attitude. Propulsive thrust is generated by anhydrous hydrazine, with 2 jets providing spin speed control, while 2 axial and 2 radial jets provide attitude and orbit control. The 4 associated propellant tanks have a maximum storage capability of 157·9 kg of hydrazine. The 709·4 kg solid-fuel apogee motor is supported from the aft end of the spacecraft. This motor provides the required impulse to nearly circularize the highly elliptical transfer orbit at synchronous altitude.

The INTELSAT IV-A global-beam transmissions are similar to those of the INTELSAT III and INTELSAT IV satellites at 22 dBW EIRP, while the hemispheric and spot-beams have an EIRP of 26 dBW and 29 dBW respectively. The minimum isolation between the same frequencies when used in both the east and west beams is 27 dB.

UK EARTH STATION EVOLUTION

Whereas INTELSAT is responsible for the provision and management of the space segment, it is the responsibility of participant telecommunications administrations in individual countries to provide and operate the earth stations within their own country. In the UK, the site chosen for the first UK earth station was on Goonhilly Downs in Cornwall.

The first aerial at Goonhilly was completed in 1962 to take part in the tests with Telstar, probably the best known of the early experimental satellites. The Goonhilly 1 aerial (see Fig. 11) has a dish diameter of about 26 m and a total moving weight of 1120 t. After the Telstar tests, the Goonhilly aerial was used primarily in conjunction with the Early Bird satellite operating in the Atlantic Ocean region[12]. A second aerial, Goonhilly 2 (see Fig. 12) was built in 1968 for operation to the Atlantic satellite while Goonhilly 1 was taken out of service and re-equipped to operate to a satellite in the Indian Ocean region from 1969. The Goonhilly 2 aerial has a diameter of 27·4 m, which is slightly larger than Goonhilly 1; however, its moving weight is somewhat less at 965 t. The third aerial, Goonhilly 3 (see Fig. 13), became operational in 1972 and was used to work to a second operational Atlantic satellite. This aerial has a dish diameter of 29·6 m, but its moving weight is only 345 t. These 3 aerials currently give the UK access to about 80 countries and handle some 2500 circuits.

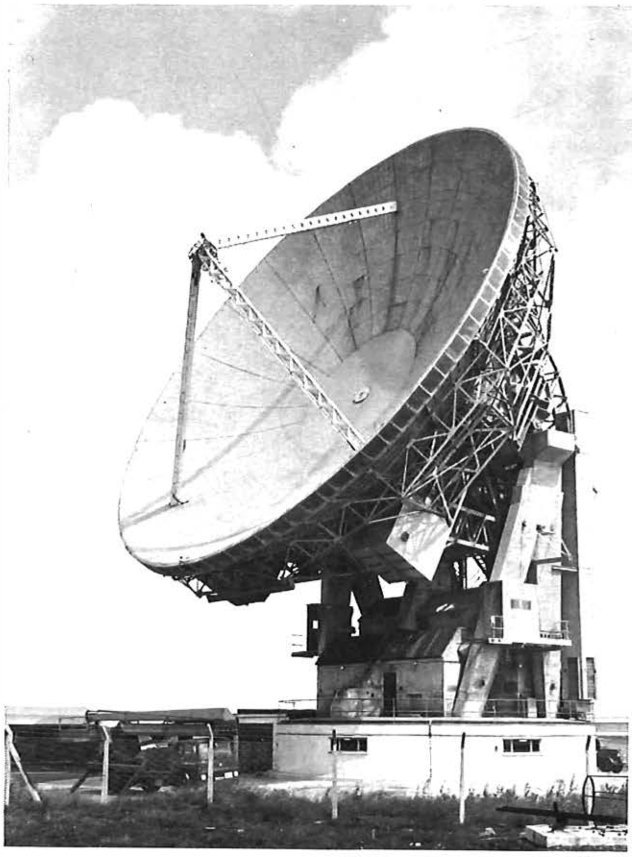

FIG. 11—The Goonhilly 1 aerial

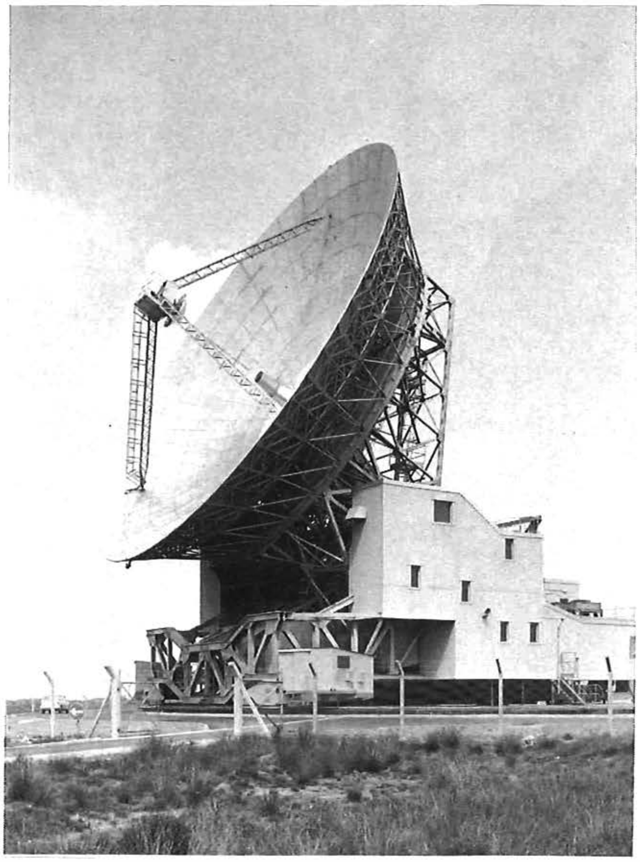

FIG. 12—The Goonhilly 2 aerial

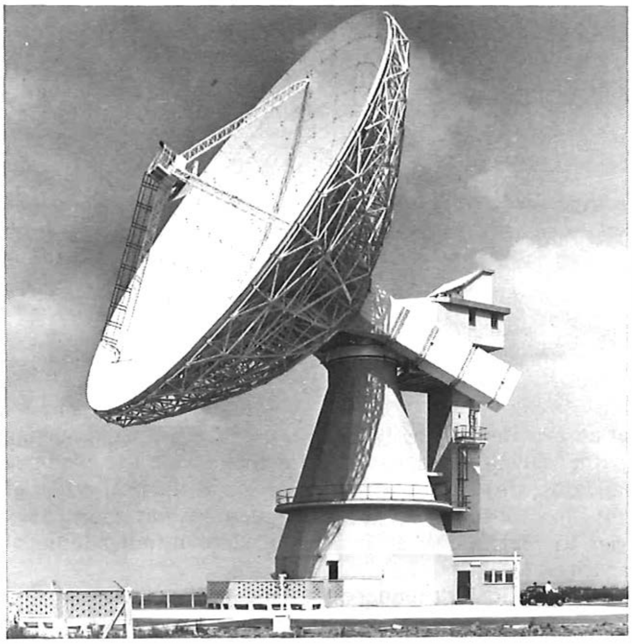

FIG. 13—The Goonhilly 3 aerial

SYSTEM DEVELOPMENT

Ever since the inception of INTELSAT, there has been a problem in expanding the capacity of the system at a rate sufficient to meet the increasing traffic demand. The volume of intercontinental telephone calls is increasing at an annual rate of about 20%, which means that the size of the system has to be doubled about every 4 years if this growth is to be contained. Hence the dramatic increase from the 240 circuit capacity of the INTELSAT I satellite to the 6000 circuit capacity of the INTELSAT IV-A in a period of some 12 years. To meet this continued growth in traffic, a further series of satellites has been procured that have an even larger capacity than the INTELSAT IV-A series. The new satellite, known as the *INTELSAT V* (see Fig. 14) is scheduled for operational service in 1979 and each satellite will have a capacity of about 11 000 telephone circuits. They will use a number of technologies new to the INTELSAT system, including 3-axis stabilization, 14/11 GHz operation and frequency re-use in the 6/4 GHz band by means of dual-polarization techniques[13, 14].

Growth of the earth segment has kept pace with the development of the space segment. Since INTELSAT was formed in 1964 the number of aerials operational in the system has risen to more than 200. Additionally, the development of earth-station facilities has proceeded concurrently with the expansion of the space segment to meet the growth in demand for satellite communications. The introduction of INTELSAT V operation requires the further expansion and modification of earth-station facilities. Some countries, including the UK, will need to procure 14/11 GHz terminals and the majority of existing 6/4 GHz earth stations will require an increased carrier capability. Many countries will also have to modify their existing 6/4 GHz terminals for dual-polarization operation and most of the remaining countries will need to improve the polarization isolation of their terminals to mitigate unwanted interference with transmissions in the opposite polarization[15]. Furthermore, earth stations which transmit carriers to the frequency re-use transponders will, in general, require more up-link EIRP than for INTELSAT IV or IV-A operation.

To keep pace with the rapid growth in satellite communications, it is necessary that additional earth terminals (aerials and associated equipments) be provided within the UK. Some of these terminals will be situated on a second earth-station site located at Madley in Herefordshire. The fourth UK aerial for use in the INTELSAT system is currently under construction at Madley and will be known as *Madley 1*; a second Madley aerial is planned for 1979.

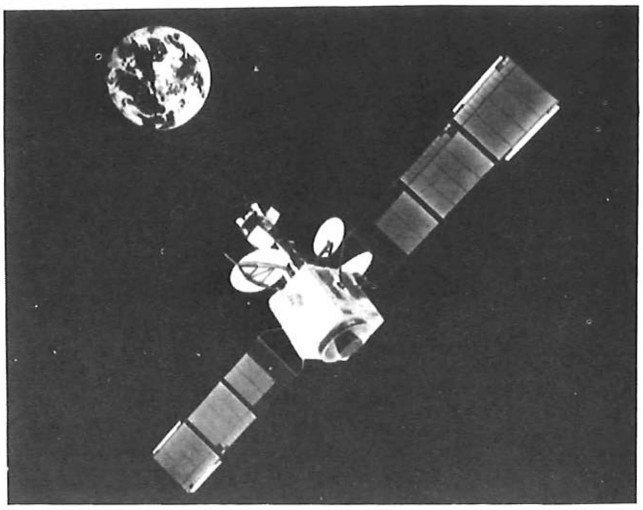

FIG. 14—The INTELSAT V satellite

CONCLUSIONS

This article has reviewed the principal features in the development of the INTELSAT system and briefly examined the likely impact of INTELSAT V operation. The INTELSAT system, together with the associated earth station facilities, now form an integral, vital and expanding part of the world-wide telecommunications network. If the past success of the telecommunications satellite system is any guide to the future, then the INTELSAT system (and the UK as second largest shareholder) will assume an increasingly important role in the international telecommunications network.

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Automation of Traffic-Data Collection

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UDC 621.395.31—52

This article considers the automation of the traffic-data collection process, which provides information essential to the efficient operation and future planning of switched telephone networks.

INTRODUCTION

The major basic information used to run and plan the British Post Office's (BPO's) telephone network is the telephone traffic being carried by the system and the expected future demand in terms of telephone connexions and traffic offered to the network. Because of the random nature of the call-making behaviour of customers, there are problems in identifying what can be regarded as the true underlying level of present and past demand. This, in turn, has repercussions on the expected accuracy of forecasts of future demand because the historic level of measured demand is one of the main inputs used to produce forecasts.

As a direct consequence of the difficulty in establishing the real demands placed on the telephone network, it is not easy to measure the performance as seen by the customer, either of parts of the network or of the whole. The variability, that is, the inherent inaccuracy, of traffic information concerning current demand can be reduced by taking more measurements in terms of volume or frequency. However, this implies increased costs, particularly when the process is labour intensive.

This article considers, in general terms, the types of traffic data and call information required, the accuracy that might be needed, possible costs and benefits involved, and the implications of these requirements in terms of the automation of traffic-data collection.

TYPES OF TRAFFIC DATA AND CALL INFORMATION REQUIRED

The level of demand placed on the network varies throughout the day, week, month and year. A common traffic pattern has busy periods in the morning, afternoon and evening, with some days being consistently busier than others. At the exchange level, it is usual for exchanges with a large proportion of business customers to have morning and afternoon busy-periods, while those having mainly residential customers normally experience an evening busy-period. For the individual routes between exchanges, the busy-hour pattern may be different to those of the parent exchanges.

It is common practice throughout the world to use some kind of *busy-hour* as the period in which to measure traffic levels, and for these to be used as the demand against which to provide capacity in the network. Each link or stage in the network is treated as a provisioning unit, while the plant-congestion performance, as seen by the customers, is an aggregate of the performances of various combinations of some of these parts.

The day-to-day performances of the elements of the network are assessed by the busy-hour measurement and information on overloads; that is, data on the number of occasions the capacity was inadequate to meet demand. This information enables telephone exchange maintenance staff to get an overview of the performance of the elements making up the network and to compare them with the planning standards; these are normally expressed as the proportion of calls expected to be lost due to plant congestion immediately prior to the time when it is planned to install additional capacity.

An indication of overall performance is given by the quality of service as measured by direct human observation. This assessment covers various aspects of the system performance, such as congestion due to plant shortages, throughout the working day. Relating the overall quality of service and busy-hour performance for the individual links is not a simple task and will not be considered in this article.

Increased system capacity can be required in various forms. For example, additional circuits may be required to supplement a route carrying an unexpectedly high demand between 2 exchanges, or additional common-control capacity may be required in an exchange. The control capacity is usually decided by the number of calls handled; the need for additional capacity could originate from an increase in traffic levels or from a change in customer calling behaviour, leading to shorter call durations. In the latter case, it may be that only additional control capacity is needed because adequate traffic-carrying capacity is already available. Such trends in customer calling patterns can be expected to be slow to develop, but changes may result from the increased use of computers, and other devices such as repertory diallers, to originate calls.

For planning purposes, it is usual to base forecasts on historic demands. Thus, any inherent errors in the measurement of demand are likely to be magnified by the forecasting process and result in planning for the wrong demand. Another range of information required for planning purposes which is, as yet, not adequately quantified is customers' behaviour with regard to human factors, such as dialling rates and response to tones.

Customers' calling behaviour is obviously influenced by the charges made for calls. For example, where local calls are free, or paid for in the standing charges, not only are more calls per telephone made but, on average, the calls are shorter. As we have seen, this can be significant for the planning of the common-control capacity for exchanges.

If a new range of charges is introduced, customers respond by changing their calling pattern—even if only in the short term. Such changes can result in the profile of call demands across the day being significantly altered, which can, in turn, lead to call-revenue incomes different to those that would have been expected with the old profile. There can also be changes to the performance of the network in terms of the dimensioning criteria. For example, if there is a movement of traffic away from the previously determined busy-hour because of, say, an increase in charges for that period, this may result in excess capacity with, possibly, the provision of even more equipment already planned.

Therefore, when considering possible tariff packages it is necessary to have some idea of how customers may behave,

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and, in order to do this confidently, both traffic and call information is required. It is usual for such information to be in the form of customer calling rates for different classes of customer; typical classifications being business and residential.

Lastly, there is a need for information that is necessary to carry out research and development activities, such as basic theoretical studies into the mathematical description of telephone traffic and the performance of various elements of the switched network.

DATA COLLECTION

By far the greatest proportion of traffic information gathered has been that obtained by using exchange automatic traffic-recorders; this data is usually known in the BPO as the *A854 record*, named after the code reference of the form used to record the information. This method has required a considerable amount of manpower, not least to read the meters on which the traffic counts are recorded. However, this information, which is used both for the day-to-day running of the network and its planning, is increasingly the subject of processing by computer. Typically, there are 2 transcription stages involved in the passage of the information into a computer data-base: from meter to paper, and then from paper to punched paper-tape for reading into the computer store. In addition to the manpower costs involved, there is the ever present possibility of errors being introduced.

There is the prospect of overcoming these problems if the output from the traffic recorder is machine readable. Examples of such output are punched paper-tape and magnetic cartridges, but usually these involve manual handling and the possibility of machine errors. Thus, if economic considerations are favourable, the direct transmission of traffic records into a computer is an attractive possibility.

Another desirable feature of not requiring the direct use of manpower in collecting information is the avoidance of a conflict of priorities between this traffic-collecting activity and some other maintenance work, which may well appear to have a more direct bearing on the service experienced by the customer.

Naturally enough, even the direct input of data into a computer has its problems: as with most machine-readable forms of information transfer, the human eye cannot be used directly to check the data for features such as possible errors. However, the machine can be programmed to vet the data automatically and to detect many of the errors, but, in spite of programming ingenuity, human judgement is still required in many cases—and even this combination does not eliminate all the errors.

The ability of computers to accept information and to output results is well known. In considering the traffic and call information to be collected, a degree of caution is necessary to ensure that not only is the required information gathered but also that no unnecessary data is obtained.

The collection of any other traffic information, such as that required for tariff studies, is normally a special measurement exercise and is only carried out for a limited period. As with most special studies, gathering the information can be expensive; there is, therefore, good reason to keep the sample size small, but this, unfortunately, frequently conflicts with the need for accuracy.

Some of the forces, such as the requirement for more information and the reduction of demands on manpower, that are pushing the collection of traffic and call information towards automation have been discussed. However, this will not solve all the problems and, indeed, would doubtless create some new ones. With proper management, benefits could result and the present trend towards the greater use of machines in the collection and processing of data can be expected to continue.

DATA FLOW

The volume and frequency of measurements required to monitor the system performance vary, from those required at the local level to maintain grades of service, through to those needed for longer-term planning and forecasting. In addition, there are the special measurements, which also have a wide range of requirements.

For a typical medium-sized local exchange, with 5000 subscribers, a year's standard busy-hour traffic level information from a sample of 12 weeks consists of some 20 000 characters of information. If a special record of the traffic levels and the number of calls made on outgoing routes from such an exchange was made, more information is involved. Covering the period 0800–2300 hours, with hourly records, for one working week alone (Monday to Friday, inclusive) would also produce about 20 000 characters of information.

The volume of data and its accumulation influences the choice of recording media that can be used. The capacities and operational speed of typical storage media are given in Table 1, and, to give some feel for the amount of data involved, it is estimated that an average Volume (4 issues) of this *Journal* has about a million characters in it.

TABLE 1

Typical Data Storage Capability for Various Recording Media

Characteristic	Medium		
	Paper Tape	Magnetic Cartridge	13 mm (½ inch) Magnetic Tape
Length (approximate)	300 m	90 m	730 m
Capacity (characters)	120 000	2·4 million	20 million
Maximum data-transfer rate	60 characters/s	1000 characters/s	36 000 characters/s
When used for monitoring traffic level and numbers of calls	One week's record (Monday to Friday) at 30 min intervals from 0800–1800 hours on 120 trunks or inputs	As for paper tape but accommodating 2400 trunks	One week's record at 15 min intervals each 24 h on 4000 trunks
When used for monitoring call details (number dialled, duration of call, etc.)	One week's record (Monday to Friday, 24 h/d) on 5 typical trunks	As for paper tape but on 100 trunks	As for paper tape but on 800 trunks

The reliability or level of confidence required of the data collected varies, depending upon the intended use of the information. If the data is being gathered to verify or consolidate an existing method of controlling traffic-flow in the network, then it may be necessary to collect data from as many different situations as possible. In such cases, however, the only requirement is that the manual method of collecting data be automated; usually it is necessary to ensure only that exactly the same results are achieved by the automatic method as were attained by the original manual method. In other cases, a combination of requirements may occur and, in this instance, while automating a manual system, the opportunity to improve or increase the amount or accuracy of collected data is taken.

The data-flow demand, the maintenance effort needed to achieve the required level of accuracy, and the processing power to analyse the collected data must all be carefully planned and costed. For some studies, data is to be collected once only and, while for various reasons it can be imperative that this data is obtained without regard to cost, even in these instances expenditure must be minimized.

With data flows of the order recorded in Table I, there is the need to be alert to any errors or faults leading to false records being obtained. Thus, with a human reading at only, say, 200 words/min and averaging about 15 characters/s, there is a need to exploit machine checks to the maximum. Thus, when large volumes of data are collected it is usually possible to process it only by the use of computers, with considerable reliance being placed on automated data-checking as well as the subsequent data handling and analysis.

COSTS AND PROSPECTS

At present, the collection and processing of bulk data is a costly procedure. For example, it is estimated that to measure and analyse the traffic flow in a 20 000-line telephone exchange for 5 years, 5 days a week, 15 hours a day, would cost something in excess of £500 000. This expenditure includes the purchasing and installation of the special measuring and data-collection equipment and the subsequent processing on a main-frame computer.

The introduction of mini-computers or processors which are self-contained in the measuring equipment (normally referred to as *microprocessors*), could reduce costs appreciably, and even a small amount of processing or data assembly during collection could reduce the subsequent processing cost on a main-frame computer. These types of installations are already being tested and put on trial by both the BPO and various equipment manufacturers. In the future, it is expected that much more information could be collected and processed at a fraction of present-day costs but, with the continually increasing demand for additional information, the expenditure on its collection can be expected to increase over the years.

With the use of software-controlled exchanges (such as those being planned for the BPO *System X* family of exchanges) there are many decisions to be made on the automation of traffic recording. There is the basic question of whether the control and collection should be carried out by the main processor of the exchange or perhaps delegated to a small processor; the latter is independent of certain problems, such as system overloads, which are likely to be encountered by the main processor. This independence would guarantee, to some extent, the availability of traffic information which may well indicate why the main processor got into difficulties and, thus, provide basic information to allow the introduction of procedures to minimize the probability of the situation occurring again.

It is certainly imperative that, whatever form the traffic-measurement sub-system takes, it should be properly integrated with the whole system and not be an adjunct. In many of the present switching systems, a significant price is now being paid for the traffic-measuring features having been the prime subject of cost-reduction treatment in the past.

COST-BENEFIT ANALYSIS

It can be argued that, for much of the traffic information required, the need-to-know aspect is so strong that the disadvantage of not having it leaves the cost as the only subject for consideration. Judgement, however, is also of considerable importance in evaluating expenditure; if, for example, for one purpose there was the probability of errors in the collected information of, say, 1 in 10^3 characters, it may be felt that this is quite acceptable: for some other purpose, it may be decided that an increase in cost of 100% which would decrease the errors by a factor of 10 (1 in 10^4), would be good value for money.

There is a similar situation when considering complete loss of records due to failure in the logging equipment. If the information is being recorded on punched paper-tape, the failure rate of paper-tape punches could be considered to be at such a level that a second punch in parallel, to give a duplicate output, is completely justified.

In justifying the collection of information, it is quite usual to accept as a basis for argument the existence of the present planning and decision-making procedures. However, to evaluate properly the justification of the cost of fully automating or modernizing traffic-data collection, a reassessment may be necessary of the whole planning process, of which the data collection is a part.

CONCLUSIONS

The general trend is towards more complicated switching systems in which the traffic-carrying capacity of a system is exploited to the full. Similarly, the BPO public switched telephone network (PSTN) is designed to provide the maximum traffic-carrying capacity, in terms such as calls or erlangs carried, consistent with the grade-of-service standards. One of the results of this trend is that the spare capacity in the network is at a minimum; thus, if calling patterns are not those used in the planning and design stages, the efficiency hoped for may not be achieved.

To be able to deal with this problem, early warning of possible difficulties is needed. Automation of the traffic-data collection process, as well as its analysis and interpretation, offers a possible solution. In particular, the facility to interrogate the network, in real time, about the traffic flows could lead to very effective network management in dealing with such unexpected events. However, it is important to ensure that the volume of information does not result in the system's operating and design functions being completely overwhelmed by data and unable to establish a clear picture of the situation.

In addition to the efficiency problem, many new services can be expected to use the PSTN and to place on it demands whose characteristics cannot be fully anticipated. Once again, automation of record collection and its proper analysis would help to provide information at an early opportunity.

Summarizing, various forces, such as the need to minimize the direct use of manpower, the requirement for larger volumes of data, a more readily, perhaps even instant, availability of information, and improvements in the reliability and accuracy of information, have been seen to make the automation of traffic-data collection an attractive prospect. The increase in the cost-effectiveness of the technologies that can be used in such activities leads to the conclusion that increasing exploitation of automation can be confidently expected.

High-Frequency Characteristics and Measurement Techniques for Wideband Coaxial Cables

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The structural uniformity of coaxial cables assumes a greater significance in determining the acceptability of such cables for the provision of high bit-rate digital line transmission systems. This article reviews the significant characteristics of coaxial cables in relation to analogue and digital transmission; the inadequacy of existing test methods and associated test equipment for assessment of cable performance for high bit-rate digital transmission systems is highlighted. Also described is the work in hand by the British Post Office towards the establishment of new system-oriented testing techniques and the realization of test equipment that is more appropriate to the needs of digital transmission.

INTRODUCTION

The increasing bandwidth requirements of successive generations of coaxial transmission systems have introduced many new cable-testing problems and placed progressively more onerous requirements on the associated test equipment. This article considers the significant cable characteristics for analogue and digital transmission on main network coaxial cables, and outlines the existing test methods used by the British Post Office (BPO). Present trends in coaxial cable testing are discussed, with emphasis placed upon the need for the development of test methods more appropriate to the needs of digital transmission.

SIGNIFICANT TRANSMISSION CHARACTERISTICS

In assessing the feasibility of operation and the subsequent design of new types of analogue and digital systems, the principal transmission characteristics required are attenuation, phase delay, impedance and crosstalk. The mean values, associated tolerances, and the way in which these characteristics vary with frequency and temperature must be accurately determined. Also of fundamental importance is the consistency of the characteristics along the length of the cable, a factor that becomes increasingly significant as system bandwidths increase. Finally, the long-term stability of the electrical parameters must be investigated, and possible detrimental effects due to installation practices and ageing assessed.

Attenuation

The attenuation/frequency characteristic is the prime factor in determining the maximum length of individual repeater sections, and extensive evaluation of this parameter is essential in the feasibility and design stages of analogue and digital transmission systems. In the subsequent cable manufacturing and installation stages there is usually no need for further routine measurements of attenuation for inland-cable applications.

Phase and Group Delay

Since the phase characteristic is almost entirely dependent upon the effective permittivity, it follows that, for air-spaced coaxial cables, this parameter is extremely consistent and is essentially linear with frequency. Apart from the need to measure the exact values of phase delay during the feasibility and design stages, there is little need for further measurement during the subsequent manufacturing, installation and maintenance stages. The corresponding group-delay characteristics are almost constant with frequency, and measurements are normally restricted to overall system testing on the energized repeater sections.

Crosstalk

The crosstalk performance of modern coaxial cables is extremely good and no measurable crosstalk has been detected in the frequency range 1–500 MHz on the main network coaxial cables used by the BPO. The occurrence of crosstalk within an installed system is normally attributable to fault conditions at cable joints, flexible cable tails or points of damage, rather than inherent crosstalk within the cable. Consequently, crosstalk testing is not required in the cable factory and is normally limited to type-approval and system tests of installed repeater-section cable lengths, usually on a restricted scale.

Possible exceptions to this rule may occur however in the upgrading of existing installed cables for wider band operation; for example, as required for digital transmission. Experience has shown that crosstalk testing is a very sensitive method for detecting incipient faults which can occur due to imperfect outer conductor jointing, i.e., dry joints. Unfortunately, while the conductor surfaces are clean, such joints are virtually undetectable by normal test methods and they do not usually give trouble until significant oxidation/corrosion has occurred.

In the case of analogue systems, the non-linear contact resistance variations that may occur at dry joints give rise to noise bursts with small associated level variations which, while troublesome, are not usually too serious. However, the consequent effects on a digital system may be more significant and, in severe cases, framing alignment may be lost during the period of contact resistance variation.

To safeguard this situation, development is in hand of a quick method for the location of dry joints; current investigations based on crosstalk tests are yielding greater sensitivity than the more traditional dry-joint test methods employing harmonic and intermodulation techniques.

Impedance and Impedance Uniformity

A knowledge of the impedance/frequency characteristics is obviously important to the system designer, but it is the uniformity of this characteristic that becomes an increasingly critical factor as system bandwidths increase. All practical

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cables contain numerous small imperfections distributed throughout their length and these give rise to both return and forward echoes. The resultant signal-to-echo-noise ratio, unlike signal-to-thermal-noise ratio, is independent of signal level. Some of these irregularities occur randomly, but others, due to the repetitive nature of manufacturing processes, are distributed periodically. In practice, the magnitudes of the random irregularities do not constitute a significant problem and are adequately controlled by present cable specifications.

The periodically distributed irregularities can be more serious because they give rise to coherent forward-echo components in the time-domain and sharp resonant peaks in the frequency-domain characteristics. These effects normally occur at frequencies in excess of those used in analogue systems and only become significant for very high bit-rate digital transmission. The BPO cable specifications for digital systems seek to ensure that forward-echo distortion is controlled within acceptable limits by imposing bounds on the permissible values of impedance irregularities.

Impedance and impedance-uniformity tests of one form or another are normally required in the feasibility, design, manufacturing, installation and maintenance stages of coaxial cable systems, and it is in this area that most of the recent development of cable test methods has occurred.

CABLE TEST METHODS USED BY THE BPO

Measurement of Attenuation

Indirect substitution techniques[1] are normally used for precise high-frequency attenuation measurements. In this method, the attenuation of the unit under test (UUT) at the test frequency is compared (after appropriate frequency translation) with that of a reference attenuator operating at a fixed frequency.

Unfortunately, indirect substitution techniques do not lend themselves readily to large numbers of repetitive measurements in the field. For this reason, the BPO has developed a loss-and-gain measuring set[2] which uses, predominantly, direct substitution techniques; in this, the UUT is compared with a variable attenuator directly at the test frequency. A series-substitution comparison technique (see Fig. 1) is generally used as this permits the use of optimized and fixed signal levels at critical points in the circuit, thus minimizing errors due to interaction effects. In this method, the test signal is divided, by means of a precision resistive splitting network, between a fixed pre-set REFERENCE arm and a MEASURE arm, and the UUT is connected in series with the measuring attenuator. The MEASURE attenuator is adjusted to balance the outputs of the 2 arms, which are compared using a coaxial change-over switch, and the difference in level is displayed to the appropriate degree of resolution by a precision, high-gain, selective detector. In the commercial versions of the BPO loss-and-gain measuring set, an operational frequency range 0–1 GHz and a resolution of 0·001 dB have been achieved. A block diagram of the BPO loss-and-gain measuring set is shown in Fig. 2.

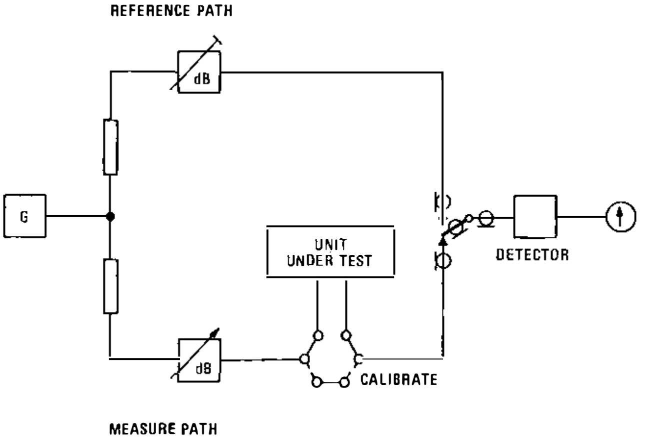


FIG. 1—Direct series-substitution comparison technique

Measurement of Phase Delay and Group Delay

Phase and group-delay measurements are normally made using the Meyer method[3], in which the phase and group-delay characteristics are derived by measuring the precise frequencies at which the $(2n - 1)\pi$ points occur. The BPO loss-and-gain set can be used for this purpose by combining the outputs of the MEASURE and REFERENCE arms in a suitable resistive network. A high degree of resolution and precision can be achieved (typically of the order of 1 ps and 3 parts in 10^6 respectively) for phase-delay measurements; greater accuracy can be achieved if steps are taken to correct for phase variations in the measuring path. Although the method is somewhat laborious, the high degree of consistency of this parameter obviates the need to make frequent measurements, and development of a more rapid test method has not been necessary.

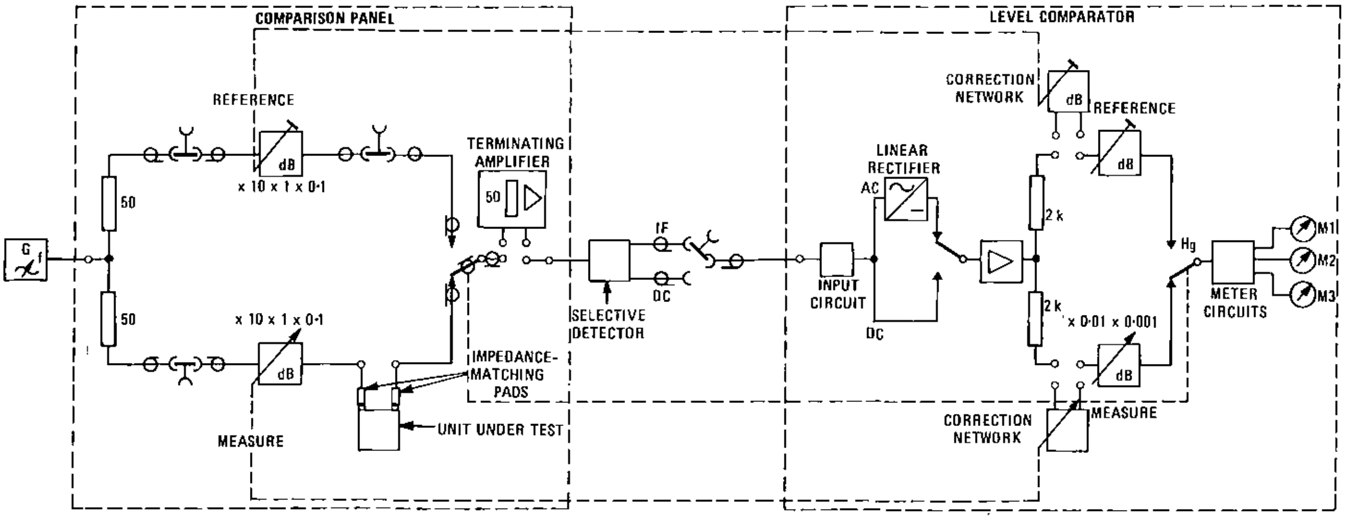


FIG. 2—Block diagram of BPO loss-and-gain measuring set

Measurement of Crosstalk

Traditionally frequency-domain techniques have almost invariably been used for the measurement of crosstalk on coaxial cables. For BPO cable specifications, a measuring sensitivity of 160 dB is required and this can be achieved using signal output powers of a few watts in conjunction with low noise narrow-band selective detectors. The BPO loss-and-gain set can be used for this purpose in conjunction with external equipment, or a special-purpose high-loss comparison panel can be used. A measurement uncertainty of the order of 1 dB is adequate. As in the case of delay measurements the method is somewhat laborious but, due to the excellent screening of modern main network coaxial cables, significant amounts of crosstalk testing are seldom required, and until recently there has been little need to develop more sophisticated test methods. However, the need to assess installed coaxial cables for digital transmission has necessitated development of more-rapid crosstalk measuring techniques; recent BPO development work on crosstalk measurement using time domain techniques is discussed later in this article.

Measurement of Impedance and Impedance Irregularities

For system-design purposes, there are 3 main aspects of the impedance characteristic to be determined:

(*a*) the nominal value of the characteristic impedance,

(*b*) the magnitudes of the large discrete and randomly-distributed irregularities, and

(*c*) the magnitude and spacing of the periodically-distributed irregularities.

Reflection-type tests are normally used for impedance measurements and typical circuit arrangements are shown, in a generalized form, in Fig. 3.

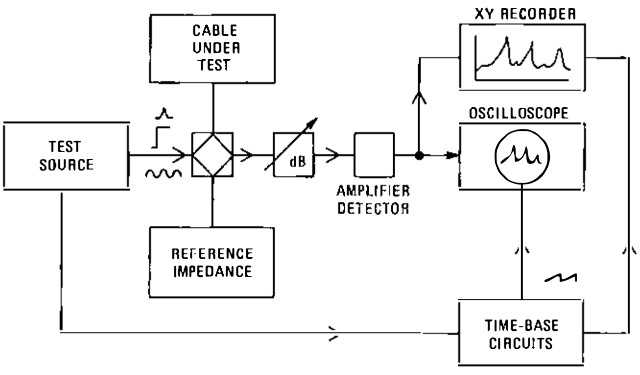
Pulse-Echo Test

The most commonly used method for assessing impedance and impedance uniformity is the pulse-echo test[4, 5]. In this test (see tests A and C of Fig. 3), the impedance value, commonly termed the *end impedance*, is measured by means of a calibrated variable simulating-network, and the impedance uniformity is assessed by displaying the reflections from impedance irregularities on a time basis, see Fig. 4. Sine-squared pulses, having bandwidths appropriate to the system requirement, are normally used. Due to the rapidity with which pulse tests can be made, the method is widely used for such purposes as

(*a*) impedance measurement and matching,

(*b*) quality control and acceptance testing, and

(*c*) location of faults.



	Type of Test	Test Signal	Reference Impedance
A	End impedance 1	Pulse	Calibrated variable simulating-network
B	End impedance 2	Unit step	Resistor
C	Pulse echo	Pulse	Calibrated variable simulating-network
D	Regularity return loss	Swept sine-wave	Resistor or simulator

FIG. 3—Arrangement of test equipment for reflection-type tests

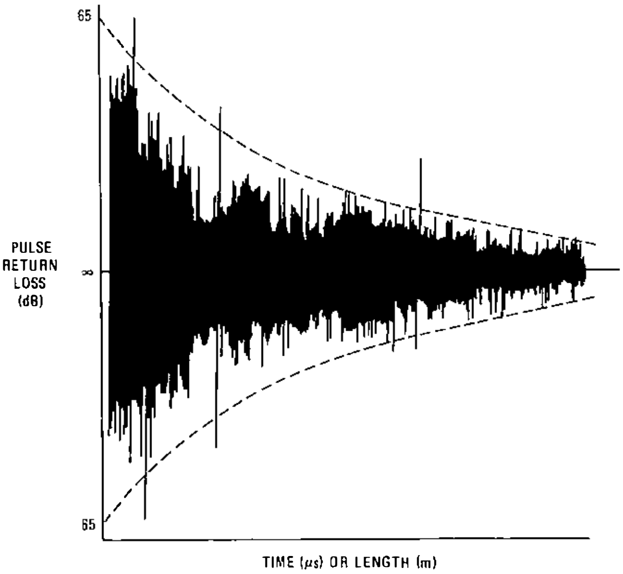


FIG. 4—Pulse return echo response

Commercial pulse-echo sets have maximum sensitivities of the order 70–90 dB for pulse return-loss measurement with typical resolutions of 1 dB. For end-impedance measurement, a resolution of the order of 0·05 Ω can be achieved, but it is difficult to comment on the absolute accuracy because the results are somewhat arbitrary and largely depend on the characteristics of the simulating network. A number of pulse-echo sets provide automatic correction for cable attenuation and a smaller number also offer automatic correction for phase distortion.

Pulse-echo methods have also been used to provide a quick test for locating dry joints in the outer conductors of coaxial cables. A technique recently developed[6] is to launch high-level pulses directly onto a pair of outer conductors of a multi-pair coaxial cable and to check for induced crosstalk on each coaxial pair in turn. Where contact resistance faults are present in the outer conductor, the resultant longitudinal coupling produces a crosstalk path and the fault can be located in the normal way by measurement of the delay between the transmitted and returned pulses.

The method has significant advantages over the normal crosstalk test because:

(*a*) very much greater sensitivity is obtained due to the direct injection of the test signal onto the outer conductors,

(*b*) fewer tests are necessary (for example, for an 18-pair coaxial cable, only 18 tests are required using the outer injection technique while 153 tests are required to check all the pair-to-pair combinations using the normal method), and

(*c*) when one coaxial pair only is faulty, this cannot be detected by normal crosstalk tests since both send and receive pairs must be faulty before significant coupling is obtained; the new method suffers no such limitation.

The basic method of direct injection onto the outer conductors may also be used in conjunction with sweep-frequency equipment. In this case, fault location is more difficult but it should be possible to increase the range of the test by choice of appropriate frequency ranges.

Unit-Step Impedance Test

Although the pulse-echo end-impedance test is ideal for production testing, it is less suitable for tests of an investigative nature, or for comparisons between different equipments. These limitations arise due to the arbitrary nature of the test and the short length of cable involved in the impedance measurement.

To overcome these problems, an alternative technique has been developed by the BPO[7], which uses a unit-step pulse to refer the cable impedance to a resistive standard via a hybrid bridge (test B of Fig. 3). From a knowledge of the transfer characteristic of the bridge and the response of ideal structurally-uniform cables of the type to be measured, it is possible to prepare impedance/time (distance) calibration lines for different nominal impedance values. The impedance response of the cable under test can be read-off directly from a scaled graticule, as shown in Fig. 5. A resolution of 0·05 Ω can be achieved with a measurement uncertainty of the order of 0·1 Ω. This method has the advantages that

(*a*) a definitive impedance/distance display of the cable response is obtained for distances up to 100 m,

(*b*) the cable impedance can be displayed in a form suitable for evaluation in terms of the appropriate theoretical laws or manufacturing specifications such as quoted by CCITT[8]† and

(*c*) the impedance can be referred to resistive standards that can be calibrated at DC.

Regularity Return-Loss Test Methods

The first method to come into general use for the assessment of periodic irregularities, was the conventional sweep-frequency sine-wave return-loss test, in which the cable impedance is referred to that of a suitable standard using a hybrid-bridge technique (test D of Fig. 3). The resultant cable characteristic, which is referred to as *regularity return loss* (RRL), displays all types of irregularities, but significant periodic irregularities are readily distinguished because they produce sharp spikes at the resonant frequencies.

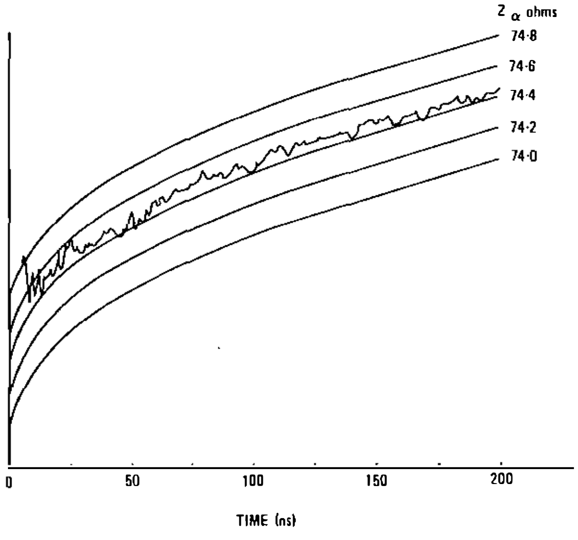
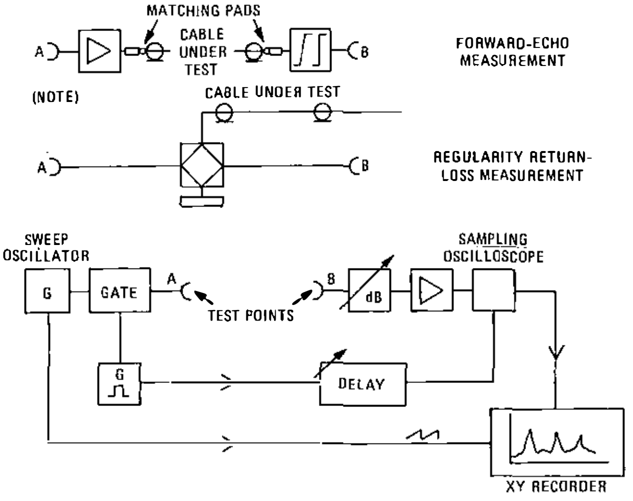


FIG. 5—Typical time-domain impedance characteristic of 2·6/9·5 mm coaxial cable



Note: The circuit elements for forward-echo and regularity return-loss measurements are connected as appropriate to test points A and B.

FIG. 6—Arrangement of test equipment for CW-burst measurements

For measuring the relatively high values of return loss required for system applications, the conventional sweep-frequency sine-wave test suffers from the following limitations:

(*a*) Errors are produced due to test equipment imperfections, such as unwanted reflections from test leads, connectors, terminations and inaccuracy of reference impedance and hybrid unbalance.

(*b*) When measuring installed cables that have large impedance irregularities, such as sealing ends, joints and cable tails, severe masking effects occur.

To overcome these problems, the BPO introduced the sweep-frequency carrier-wave (CW) burst technique,[9] in which bursts of test signal are generated by means of a gate under the control of a pulse generator; a block diagram of the test equipment arrangement is included in Fig. 6. The length of the burst signal is adjusted to suit the length of cable to be tested, and sampling techniques are used to detect the returned signal. By correct choice of burst length and sampling point, it is possible to eliminate spurious signals caused by inadequate balance and matching within the test equipment. In addition, any desired portion of a cable may be tested so that, if required, reflections due to discrete irregularities can be eliminated. This is illustrated by the RRL characteristics shown in Figs. 7(*a*), 7(*b*) and 7(*c*), which were measured on an installed repeater-section length of cable. In Fig. 7(*a*), RRL tests were made by the conventional method before the tail cables were connected; the gradual upward drift of the characteristic was due to test equipment imbalance. Fig. 7(*b*) records the results of the same test after the connexion of tail cables; the masking effect of the tail cable and gas-block joint can be seen to obliterate the main cable characteristic. The test arrangement for the results recorded in Fig. 7(*c*) was similar to that of Fig. 7(*b*) except that the CW-burst method was used, and the burst length and sampling point were adjusted so that the RRL characteristic of the main cable only was displayed.

Although the above examples show the advantages of the CW-burst method, it would be wrong to imply that this test is the more suitable for all RRL applications; the additional cost and complexity of the test method is probably justified only for measurements on high-quality cables. For measurements on lower-quality cables, such as certain braided types, the conventional method is normally to be preferred because this allows variations of absolute mean impedance along the length of the cable (sometimes exhibited by such cables) to be more readily assessed.

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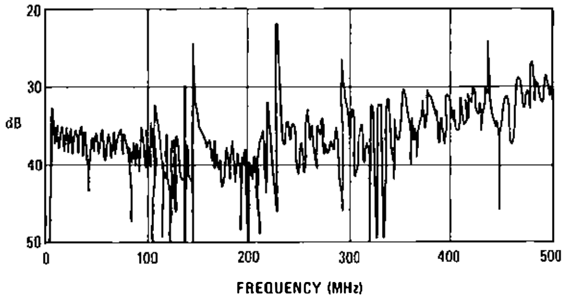
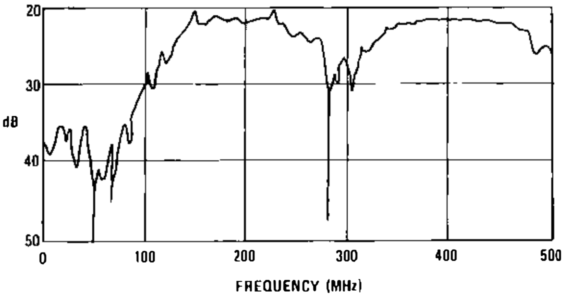
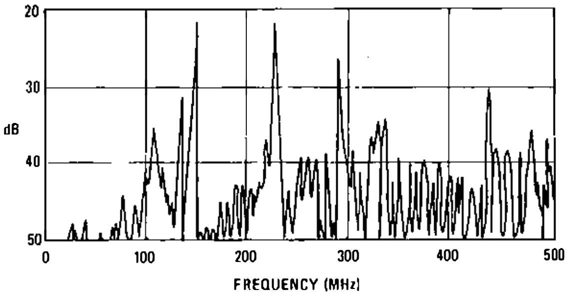
† CCITT—International Telegraph and Telephone Consultative Committee



(*a*) Conventional test method



(*b*) Tested through tail cables



(*c*) CW-burst test method (cable as in 7(*b*) above)

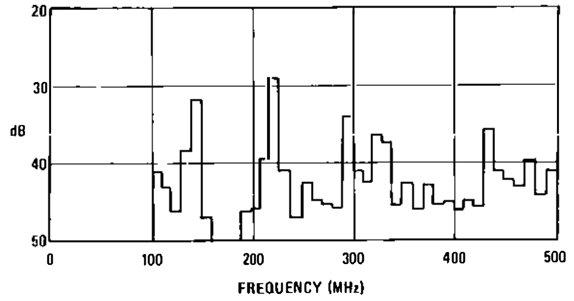
FIG. 7—Typical frequency-domain impedance-irregularity characteristics of 1·2/4·4 mm coaxial cable as determined by regularity return-loss tests

Power-in-Band Test

Due to the complexity of the RRL characteristic, it is difficult adequately to define the RRL requirements of a cable in simple specification terms, hence only the heights of the spikes are specified. To control the width and/or numbers of the spikes, some BPO cable specifications also include *returned-power-in-band* requirements, which place upper limits on the permissible reflected power in discrete 10 MHz bandwidths over the required frequency range. In the power-in-band test[3,7], additional circuitry (or software) is added to the RRL test equipment to square the reflected signal and integrate it in 10 MHz bands (see Fig. 8).

Limitations of Return-Loss Test Methods

Although a significant improvement in measurement accuracy was achieved in progressing from conventional return-loss testing to the CW-burst method, the uncertainty of measurement is still greater than desired. A comparatively wide spread of results is obtained due to error sources such as sampling jitter, drift of burst length and sampling point, side-band components due to gating of the test frequency, attenuator errors, spectral purity and differences in standardizing procedure, most of which are associated with the analogue test equipment normally used. Recent investigations using a number of CW-burst RRL measuring sets in the range 15–40 dB at frequencies of 30–500 MHz, showed that, while the mean values of RRL agreed within 1 dB, the 3 standard deviation limits for measurement uncertainty were 4 dB. Although these errors are significant, a more serious drawback is that, due to the masking effect of cable attenuation, the RRL test is heavily biased towards the testing end and will fail to detect major irregularities that are electrically remote.



Note: CW-burst test method used

FIG. 8—Typical frequency-domain impedance-irregularity characteristic of 1·2/4·4 mm coaxial cable as determined by a returned power-in-band test

Forward-echo can be calculated from return-loss values[9] provided it is assumed that the magnitude and spacing of the periodic irregularities are uniform throughout the length of the cable. Unfortunately, this assumption is not necessarily valid for practical cables, particularly for installed repeater-section lengths which are made up of a number of separate cable lengths. Tests on installed cables have revealed discrepancies (due to non-uniform distribution) of ±20 dB between forward-echo values determined by direct measurement and those derived from return-loss tests. At best, therefore, the RRL test can be regarded as a method of sampling the periodic irregularities; if enough pairs are measured, an overall estimate of probable forward-echo levels can be obtained. A better assessment of forward echo using the CW-burst return-loss test can be achieved by adjusting the burst length and sampling points to test progressively along the cable in a number of discrete steps, correcting each successive step by the attenuation of the test path. However, this method, referred to as the *distributed return-loss* method, is laborious and the range is limited by the cable attenuation. Therefore, for a true assessment of forward echo, a through-test method is necessary, and this is of particular importance for assessing installed repeater-section cable lengths.

FORWARD-ECHO TEST METHODS

The first method to be adopted for the direct measurement of forward echo was a CW-burst test, which enables frequency-domain measurements of forward echo to be made.[9] The basic CW-burst return-loss test set can be used to perform through CW-burst measurements (the test arrangement is included in Fig. 6), the sampling point being selected so that the forward-echo signal following the main burst is detected. A typical forward-echo/frequency trace is shown in Fig. 9.

The main disadvantage of the CW-burst method for forward-echo measurement is lack of sensitivity, which makes the test method unsuitable for tests on full-length repeater sections. Its principal application to date has been for exploratory investigations on electrically-short lengths (drum lengths) of cable. Unlike the CW-burst return-loss test, errors due to impedance mismatch cannot be fully eliminated and, as in the case of the other forward-echo test methods to be described, careful attention must be given to this aspect.

Excess-Attenuation Tests

In practice, periodic impedance irregularities in coaxial cables are invariably of a capacitive nature, therefore the reflected component of the signal at each irregularity is in quadrature with the main signal. The forward-echo signal, resulting from double reflections, is therefore 180° out-of-phase with the main signal and, consequently, sharp spikes are obtained in the attenuation characteristic at the resonant frequencies of the irregularities.

Automatic test equipment designed for the measurement of excess-attenuation spikes has been developed by the BPO[10] for the evaluation of forward-echo distortion in the BPO trunk coaxial-cable network. Tests can be made on full-length repeater sections by using a spare pair in the cable for synchronizing the test equipment at each end. The necessary sensitivity is obtained by using a relatively high-power input signal to the cable (approximately +30 dBm) and narrow-band selective detection.

The evaluation of forward echo is derived directly from the height of the excess-attenuation peak[10] on the assumption that the irregularities are capacitive. This assumption has been substantiated in practice since good correlation has been obtained between excess-attenuation and other forward-echo test methods.

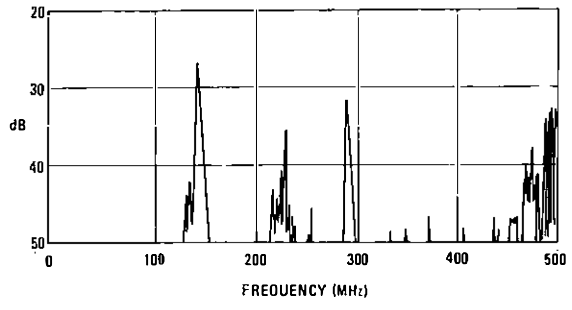
Through-Pulse Test

Unlike the 2 previous methods described, the through-pulse test[11, 12] is a system-oriented test method, which provides a direct measurement of forward echo in the time domain by closely simulating the operation of the actual digital transmission system. In this test, see Fig. 10, the transmission path is equalized in a manner similar to the proposed digital transmission system.

High-amplitude (50 V) pulses are transmitted at repetition rates of the order of 50 kHz; these values are low enough to ensure that successive pulses do not give rise to echo enhancement and the effects of near-end crosstalk are avoided. The resultant transient response of the cable, containing the received pulse and the forward-echo components, is detected and displayed on an XY recorder. Cross-correlation and signal-averaging techniques are used to obtain high measuring sensitivity, and the method is suitable for evaluation of full-length repeater sections. Tests can be made on a 'near-end' basis by looping the cable back at the distant end or on a 'far-end' basis by using a spare coaxial pair and an associated regenerator at the far end to provide the test pulse.

A significant advantage of this technique is that it is possible to identify separately the effects of both discrete and periodic echoes, see Fig. 11. The overall attenuation and distortion of the received pulse can also be assessed.

Further advantages of the basic techniques used are that the high resultant sensitivity enables the test equipment to



Note: CW-burst test method used

FIG. 9—Typical frequency-domain forward-echo characteristic of 1·2/4·4 mm coaxial cable

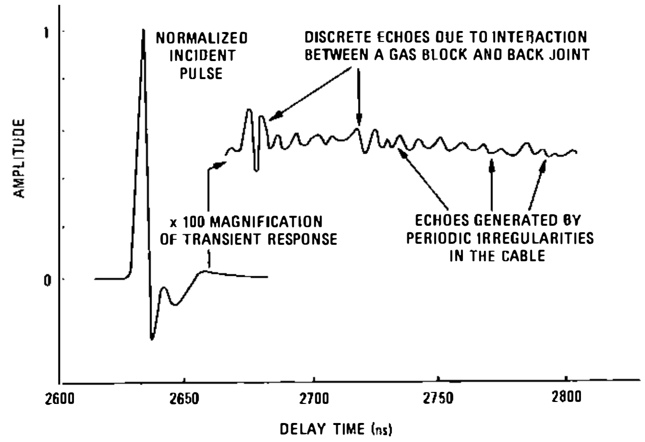


FIG. 11—Through-pulse-echo response

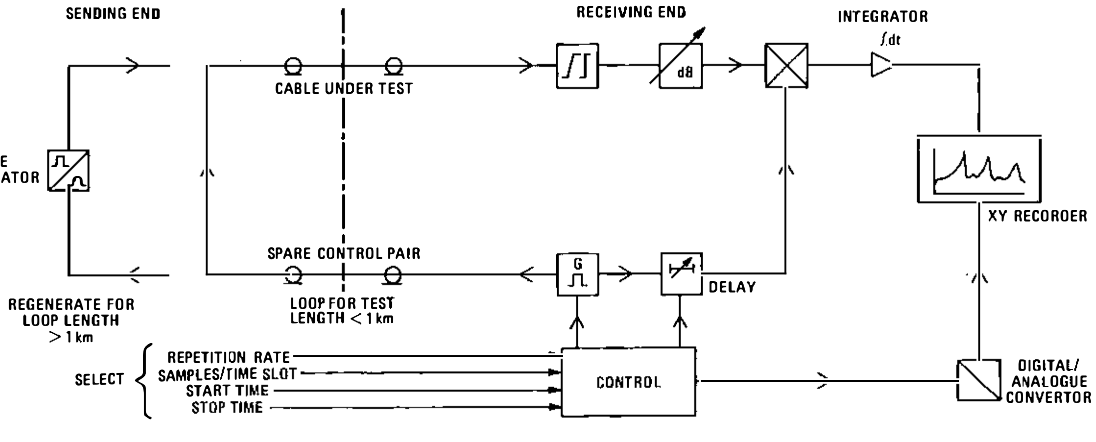


FIG. 10—Arrangement of test equipment for through-pulse-echo test

be reconfigured to make high sensitivity, equalized, return-pulse-echo tests and crosstalk measurements. Prototype through-pulse-test equipment has recently come into use by the BPO for evaluation of its coaxial-cable network and arrangements for the production of commercial versions of the equipment are being considered.

PRESENT TRENDS IN COAXIAL CABLE TESTING

Testing policies for analogue systems have been well established for many years and most of the recent development of coaxial cable test equipment has been associated with the introduction of high bit-rate digital transmission. Initial emphasis in the BPO is on the introduction of systems operating at 120 Mbit/s and, later, at the CCITT standardized rate of 140 Mbit/s. Preliminary technical and economic studies are also in hand on the use of higher bit-rates.

Before considering overall testing policies, it is first necessary to identify the purposes for which each test is required. In this connexion, the CCITT has recently drawn up the following preferred classification for the different categories of test equipment[13].

Category A

Advanced test equipment, required for such purposes as,

(*a*) carrying out feasibility studies and exploratory investigations,

(*b*) establishing system design parameters and cable specification values, and

(*c*) type approval.

Category B

Field test equipment for assessing the suitability of existing installed cables for digital transmission.

Category C

Field test equipment for locating portions of cables not meeting the requirements of digital systems.

Category D

Factory test equipment for acceptance testing drum-lengths of new cable.

Category E

Field test equipment for acceptance-testing newly-installed repeater-section lengths of cable.

Category F

Test equipment for maintenance purposes.

Test Equipment for Exploratory and Design Applications (CCITT Category A)

It is difficult to discuss exploratory testing in a general manner since much depends on the objectives of the investigations and the resources available. However, recent trends in BPO work have been towards increasing automation of the test equipment and the use of computer simulation techniques to assist in the development of optimized test methods.

A centralized cable test facility[14] has been established at the BPO Research Centre which enables a wide range of frequency and time-domain tests to be undertaken, many under computer-controlled conditions.

Increasing importance is also being given to the use of microprocessors, both in the role of front-end processors for complex test installations and for overall control of portable test equipments.

Tests in the Cable Factory (CCITT Category D)

When considering tests associated with cable manufacture, the commercial aspects become more significant. As the amount of testing required depends on the margin between the actual cable quality and the specification/system requirements, it is convenient to consider the test requirements in 2 categories: for use up to 140 Mbit/s, and for use above 140 Mbit/s. Fortuitously, these classifications are convenient when the cable characteristics are considered since, in most main network coaxial cables, the first major periodic impedance-irregularities occur in the frequency range 150–200 MHz, due to the periodicity of the stranding lay. For digital systems up to 140 Mbit/s, using ternary line-coding, a bandwidth of 100 MHz is adequate and, consequently, significant problems due to periodic impedance irregularities are not anticipated. This is not the case for higher bit-rate systems, and, in such applications, additional testing will almost certainly be required. It is important, therefore, that the cable specification is limited to the requirements of a particular system.

In the case of the factory testing of cables for use up to 140 Mbit/s, the quality control procedures used in the UK for selection and processing of materials adequately control the consistency of the attenuation, phase delay and crosstalk, and these parameters need be checked only at the type-approval stage. In addition, the spread of attenuation and phase characteristics has been reduced by specifying the required values for impedance and delay which, for a given outer diameter, effectively fixes the diameter of the inner conductor and the effective permittivity; that is, the cross-sectional geometry of the cable has been standardized. Thus, the minimum routine transmission tests necessary for control and acceptance purposes are considered to be impedance and impedance uniformity. Such tests are already undertaken on a 100% basis for analogue systems.

Although periodic impedance-irregularities are not normally significant below 100 MHz, there is always the possibility that a malfunction on the production lines may introduce a periodic irregularity below this frequency, and it is necessary to ensure that this has not occurred. Previous practice for checking periodic impedance irregularities has been to use sweep-frequency RRL and power-in-band tests on a 100% basis, but this involves considerable testing time and relatively expensive test equipment. In an effort to guard against unacceptable periodic irregularity levels, while at the same time minimizing the testing requirements, consideration has been given to exploiting the results from the standard (return) pulse-echo test more fully, since pulse-echo tests are already performed on a 100% basis for both quality control and acceptance purposes. Although it is not usually possible to differentiate between periodic and random irregularities on the pulse-echo trace due to their complexity (see Fig. 4), it is obvious that the individual reflections from periodic irregularities cannot exceed the *grass-level* of the trace (the *grass level* is defined as the general level of the peaks of the pulse-echo trace excluding the larger discrete spikes). If hypothetical worst-case assumptions are made that the grass-level reflections are periodic, and occur at the most critical frequency, then it is possible to calculate upper levels for these reflections for any required signal-to-echo-noise ratio. Assuming that the cable has been tested with a pulse having an appropriate frequency spectrum then, in cases where the grass-level reflections are of lower magnitude than the calculated worst-case levels, it is apparent that the cable does not contain unacceptable levels of periodic irregularity.

Based on an assessment of a large number of coaxial cable pairs installed in the BPO telephone network, it has been found that, up to 100 MHz, the cable quality is sufficiently uniform to enable a simple grass-level pulse-echo requirement to be implemented and that the time-consuming RRL and power-in-band tests can therefore be eliminated. For cables required for 140 Mbit/s systems, a 10 ns sine-squared pulse has been specified and separate requirements have been placed on the maximum permissible height of the individual spikes and of the general grass-level (50 dB and 60 dB respectively), thereby controlling both the discrete and periodic irregularities. For lengths up to 500 m (of 1·2/4·4 mm cable), correction for cable attenuation can be satisfactorily achieved using an envelope having simple linear-decay laws and the standard, non-equalized pulse-echo sets in common factory use are therefore satisfactory for this test. Thus, using the procedure outlined for acceptance tests in the factory, it has been possible to progress from a 12 MHz (analogue) to a 140 Mbit/s (digital) specification with minimal changes in test requirements or equipment.

In the case of cables required for operation above 140 Mbit/s (for example, 565 Mbit/s), the feasibility studies show that although the cable quality is satisfactory the margin between system requirements and cable performance is much smaller than in the 140 Mbit/s case. It is probable therefore that additional testing will be required, but this aspect is still under study.

Tests in the Field (CCITT Categories B, C, E and F)

In addition to providing digital systems on newly-installed cables, attention is being given in the BPO to the conversion of cables installed for existing analogue systems to digital transmission. The testing requirements for these 2 situations are rather different. In the former case, the cable would have been manufactured to a specification appropriate to the system requirements and the main purpose of the acceptance tests is to ensure that the cable has been installed without significant degradation of the characteristics. For existing cables, however, the cable has probably been installed to a much lower bandwidth specification and, without considerable extra testing, it cannot be guaranteed that the cable characteristics will be satisfactory over the digital bandwidth, or that unacceptable reflections will not be produced by joints and tail cables[3]. In addition, it is important to check that no intermittent faults (dry joints) exist as these are likely to have more serious effects in the case of digital transmission. To reduce the amount of extra testing, system-oriented field test equipment is required for rapid overall checks on installed repeater-section lengths. At first sight, it might be considered that a simulated system test using measurements such as error rate or eye closure would be the most appropriate. However, at the very low orders of error rate involved, it is not possible to obtain meaningful error-rate measurements in a realistic time scale and eye closure measurements are insufficiently sensitive. Another disadvantage of measurements of this type is that no information is available on the reasons for failure if the test requirements are not met.

To meet the needs of overall evaluation for digital transmission, a field test set based on the equipment shown in Fig. 10 and using microprocessor control, is under development. This test set should be suitable for the following purposes:

(*a*) Performing equalized through-pulse-echo tests to determine the magnitude of the received pulse and forward echoes. This enables an overall assessment to be made of signal-to-thermal-noise power and signal-to-forward-echo power and, hence, of system error-rate.

(*b*) Performing high-sensitivity equalized return-pulse-echo tests. (The use of signal averaging techniques gives an increase in sensitivity of up to 100 dB compared with that of a conventional pulse-echo test set.) The high sensitivity and use of equalization enables echoes due to faults, poor joints and excessive periodic irregularities to be precisely located anywhere within the repeater section.

(*c*) Performing crosstalk measurements (the use of signal averaging techniques enables crosstalk attenuation measurements of up to 180 dB to be achieved).

(*d*) Performing overall delay measurements. This will also provide an accurate measurement of repeater-section length.

The design objective for the preferred test equipment is that the equipment shall provide a rapid assessment of cables for digital transmission and for location of faults on cables that fail to meet the digital requirements.

CONCLUSIONS

The introduction of high bit-rate digital transmission has highlighted the limitations of much of the existing, analogue based, cable test equipment. Apart from the extra time required to test the wider bandwidths, the results do not always provide adequate assurance that the cable is satisfactory for digital transmission. These limitations are increasingly serious at the higher bit-rates under consideration since, for the first time, the basic impedance irregularity structure of the cable becomes a significant factor in the ultimate performance of the system. Recent work in the BPO to develop more effective, system-oriented, test methods and to optimize test programmes to meet the needs of digital transmission have been described. Although the new techniques have only recently been introduced and further refinement will be necessary, preliminary indications are encouraging and it is thought they should do much to facilitate the smooth and efficient transition to high bit-rate digital transmission in the BPO network.

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A Through-Pulse-Echo Measurement Technique

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UDC 621.315.212: 621.374: 621.317.34

This article describes a through-pulse-echo measurement technique that has been devised to detect the presence of signal-echo mechanisms in coaxial cables. The prime cause of signal-echo generation is the non-uniformity of coaxial-cable structure, which assumes greater importance in regard to transmission efficiency when coaxial cables are used to route high bit-rate digital transmission systems. Using the results of the measuring technique described in this article enables the calculation of digital system error-rate probability due to echo mechanisms. A prototype test equipment is also described.

INTRODUCTION

Recent studies by the British Post Office (BPO) concerning the operation and performance of high bit-rate digital transmission systems, have prompted the development of system-oriented cable testing techniques. Test equipment, incorporating the devised techniques, is required for both system installation and maintenance purposes. The prime function of the test equipment is to quantify the echo mechanisms present on installed sections of coaxial cable.

This article briefly considers the non-uniform nature of coaxial cables in the context of their use as bearers of high bit-rate digital transmission systems. A mathematical analysis of the transmission problem is presented and followed by a description of the measurement techniques that have evolved. Based on evidence provided by recent 565 Mbit/s digital transmission feasibility studies, the design targets of a prototype test equipment have been defined and are outlined in this article. A description of a prototype equipment realization and its operation is also given, together with examples of measurement results produced under both field and laboratory conditions.

Finally, an indication is given of how the measurement results can be applied directly to digital system calculations to achieve an estimate of the error probability degradation.

STRUCTURAL NON-UNIFORMITY OF COAXIAL CABLES

It is well known that coaxial cables do not, in general provide a smooth transmission profile[1]. Their lack of structural uniformity results in the generation of echoes that propagate both forward and backward from reflection points[2]. From a system performance aspect, forward echoes can result in a significant transmission impairment[3], which becomes more critical as the bandwidth is increased. Broadly speaking, the lack of structural uniformity in a coaxial cable is a function of the cable manufacturing process and the subsequent handling and installation practices. The 3 principal mechanisms of transmission performance impairment due to cable non-uniformity are:

(*a*) discrete impedance irregularities (introduced by joints, gas blocks and other mechanical/electrical deformations),

(*b*) random impedance irregularities (caused by distributed mechanical/electrical deformations), and

(*c*) periodic impedance irregularities (created by systematic variations in the impedance profile with cable length).

Systems designers have had to be mindful of discrete and random impedance irregularities for many years; it is only recently that their attention has been focused upon the phenomenon of periodic impedance irregularities.

Many authors, from Brillouin[4] onwards, have considered the implications of structural periodicity on coaxial cables. However, this has become a significant problem only with the advent of modern wideband transmission systems. For example, the 1·2/4·4 mm and 2·6/9·5 mm coaxial cables used in the BPO telecommunications network appear, in the main, to have noticeable and detectable attenuation resonances, due to structural periodicity, at frequencies of about 100 MHz or above. Therefore, the 1, 3, 4, 12 and 60 MHz frequency-division-multiplex (FDM) and 120/140 Mbit/s time-division-multiplex (TDM) systems are largely immune from such effects, as their spectral energy is concentrated below 100 MHz. This is not so, however, in the case of possible 565 Mbit/s systems, which have a significant spectral occupancy in excess of 100 MHz. It is therefore necessary to consider ways of assessing this phenomenon in order that the transmission capability of the main network can be fully exploited.

EXISTING MEASUREMENT TECHNIQUES

The need to accurately characterize the structural periodicity effects has resulted in the development of several measurement techniques termed *excess attenuation*[5], *swept CW-burst return loss*[6] and *CW-burst forward echo*[7,8]. Such measurement methods have, so far, played an important part in assessing the structural phenomena in the case of "on-drum" and installed coaxial cables. Unfortunately, the methods suffer from practical shortcomings that make an alternative technique desirable. The problems associated with each of the present measurement techniques are as follows:

(*a*) *CW-burst return loss.* This method gives only near-end information, and has been demonstrated[9] to give a poor estimate of the forward-echo properties over installed sections of cable.

(*b*) *CW-burst forward echo.* Insufficient measurement sensitivity prevents this technique being used on long section lengths of cable. Moreover, if the cable ends are not co-located, as in the case of field measurements, then the test equipment becomes very complex and the technique is difficult to implement.

(*c*) *Excess attenuation.* This method has proved to give highly accurate results, but the physical realization of the test equipment tends to be very complex and the test results give no indication of the position of any echo source detected.

Further complications also exist in the application of the measurement data gained by the above measurement techniques. The derivation of a digital line system performance impairment figure can be quite involved, as none of the

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methods are directly related to the digital system. This is an important aspect of the problem, which is pursued in the following sections of this article.

THEORETICAL MODEL

In general, the analysis of structural periodicity on transmission lines has resulted in frequency-domain descriptions of the phenomenon. In particular, Rosman[10] derived a fairly succinct second-order solution for a truly periodic case that gives a generally adequate description. The approach he adopted is indicated by the line model shown in Fig. 1 and the relationship given in equation (1).

The second-order forward-echo components (which, in practice, are predominant) are given by:

$$F(f) = \frac{\rho(f)^2 e^{-2\gamma(f)x_0}}{1 - e^{-2\gamma(f)x_0}} \left\{ N - \frac{1 - e^{-2\gamma(f)Nx_0}}{1 - e^{-2\gamma(f)x_0}} \right\} \quad \ldots\ldots (1)$$

where, N = the number of periodic discontinuities,

x_0 = the distance between discontinuities,

$\gamma(f)$ = the transmission coefficient $= \alpha(f) + j\beta(f)$,

$\rho(f)$ = the discontinuity reflection coefficient at each periodic irregularity, and

f = the frequency of operation.

This result can be expressed in a transmission system context by applying wideband equalization to the transmission path, as indicated in Fig. 2.

Now, $$H(f) = H_0(f) \cdot E(f) \cdot (1 + F(f)) \quad \ldots\ldots (2)$$

where, $H(f)$ = the overall frequency response of the section,

$H_0(f)$ = the unequalized frequency response of the cable without echo components,

$E(f)$ = the equalizer frequency response, and

$F(f)$ = the forward-echo component as defined in equation (1).

In a digital transmission system, the equalized frequency response of a regenerator section is likely to be of a raised-cosine[11] or 75% raised-cosine shape.

Thus, $$H(f) = R(f)\{1 + F(f)\} \quad \ldots\ldots (3)$$

where, $$R(f) = H_0(f)E(f) \approx 0{\cdot}5\left\{1 + \cos\frac{\pi f}{f_m}\right\} \quad \ldots\ldots (4)$$

and f_m is the data-stream bit-rate.

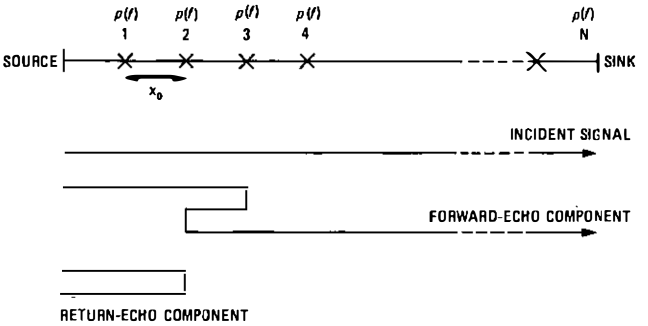


FIG. 1—Forward echo due to structural periodicity

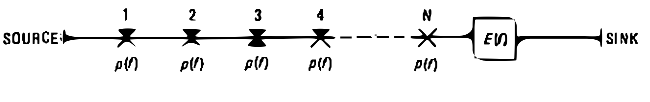


FIG. 2—Equalized cable-section

From a consideration of the impulse response of a transmission path containing a single forward-echo resonance and applying a Fourier transform, the following expressions apply:

$$\mathscr{F}^{-1}R(f) = r(t) \approx \frac{\sin 2\pi f_m t}{2\pi t\{1 - (2f_m t)^2\}} \quad \ldots\ldots (5)$$

$$\mathscr{F}^{-1}R(f)F(f) = r(t)_* f(t) \quad \ldots\ldots (6)$$

$$e(t) \approx |R(f_0)| \frac{\rho^2 V_p}{x_0}(N - f_0 t)e^{-\alpha V_p t} \cos 2\pi f_0 t \quad \ldots\ldots (7)$$

A derivation of the above expression for the echo component may be found elsewhere[12]. The component parts of this equation not previously defined are

f_0 = the resonant frequency of the forward-echo component,

$\alpha = \alpha(f_0)$ = the attenuation coefficient at the resonant frequency,

$\rho = \rho(f_0)$ = the reflection coefficient at the resonant frequency,

$V_p = V_p(f_0)$ = the phase velocity at the resonant frequency, and

$|R(f_0)|$ = an amplitude weighting governed by the equalized frequency-response at the resonant frequency.

The form of this echo component is shown in Fig. 3 and is an exponentially-decaying sinusoid that exists for time

$$0 \leqslant t \leqslant \frac{N}{f_0} \quad \ldots\ldots (8)$$

In the high bit-rate digital line systems at present being considered, it is likely that data scramblers will be used to ensure that the bit-stream is randomized. Hence, the forward-echo components can be expected to add on a power basis, as they form a series of random variables. The derived transient response results are obviously pertinent for a single element transmitted, but the relationship to a coded data-stream is not quite so obvious. A qualitative description of the relationship is given in Fig. 4.

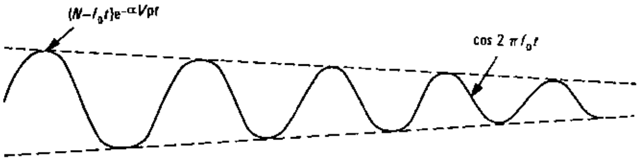
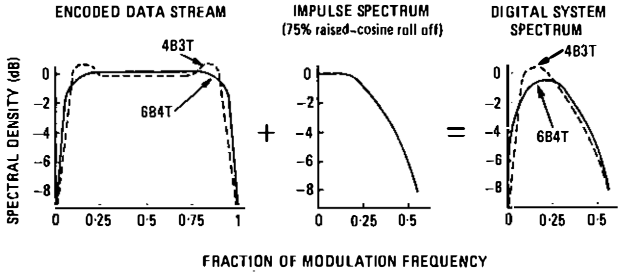


FIG. 3—The equalized forward-echo response of a coaxial cable with a single resonant structure



Note: The terms *4B3T* and *6B4T* relate to the line codes of digital transmission systems and indicate a reduction in the symbol rate. For example, in the 4B3T case, the symbol rate is reduced by translating 4 bit binary words into 3-symbol ternary words

FIG. 4—The spectral density of an encoded data-stream and impulse response of an equalized coaxial-cable

Clearly, there is a difference in assuming that the impulse response totally defines the characteristic of a channel. The line code employed would generally modify the low frequency response, but the disagreement is small and, in fact, the impulse response provides a slightly pessimistic result.

To apply the results to digital line system error-probability calculations, it is necessary to determine the energy contained in the forward-echo response. This is obtained by forming the integral

$$E = \int_0^{N/f_0} A^2(N - f_0 t)^2 e^{-2\alpha f_0 t} \cos^2 2\pi f_0 t \, dt \quad \ldots\ldots \text{(9)}$$

which follows directly from equation (7) with

$$R(f_0)\rho^2 \frac{V_p}{x_0} = A \quad \ldots\ldots \text{(10)}$$

A solution to equation (9) is given elsewhere[12] and yields the approximate relationship

$$E \approx \frac{(AN)^2}{4\alpha V_p}. \quad \ldots\ldots \text{(11)}$$

The forward-echo response exists for a period

$$T = \frac{N}{f_0}, \quad \ldots\ldots \text{(12)}$$

during which the number of bits transmitted is

$$n = \frac{N}{f_0} f_m. \quad \ldots\ldots \text{(13)}$$

Hence, for a random bit stream, the echo components form the sum of n independent variables, and the total degradation components is

$$\sigma_E{}^2 = k \cdot \frac{nE}{T}, \quad \ldots\ldots \text{(14)}$$

where k is a factor related to the number of signal levels in the transmission code.

Therefore, $$\sigma_E{}^2 = k \cdot \frac{(AN)^2}{4\alpha V_p} \cdot f_m \quad \ldots\ldots \text{(15)}$$

This additional component may be combined with the system noise power to give an overall signal-to-noise ratio of the form:

$$\text{Signal-to-noise ratio} = \frac{\hat{V}^2}{\sigma_N{}^2 + \sigma_E{}^2}. \quad \ldots\ldots \text{(16)}$$

On the basis of these results, it would appear that the relationship of echo response to digital line system performance is quite a simple one. From a practical standpoint, realization of compatible results might be more difficult to achieve when the measurement technique is applied to installed coaxial cables. However, this theoretical treatment has served to indicate the general approach to the measurement problem; further theoretical considerations will be included in a later section of this article.

TEST EQUIPMENT DESIGN CONSIDERATIONS

The fundamental measurement approach described in the previous section is known as *a through-pulse-echo technique*[13]. Using the same equalized transmission path as the digital line system being considered ensures that the echo response is directly indicative of the system error-rate performance. In the case of a 565 Mbit/s system operating over a 1·2/4·4 mm coaxial cable and using a 6B4T line code, the following conditions apply:

(*a*) total section length = 1 km,
(*b*) total equalized section loss ≈ 80 dB,
(*c*) thermal noise level ≈ −90 dBm, and
(*d*) received signal-to-forward-echo ratio ≈ 60 dB.

Thus, for a transmitted signal level of 0 dBm, the forward-echo-to-thermal-noise ratio would be −50 dB. ...... (17)

To overcome the resultant negative signal-to-noise ratio, it was decided to use a combination of a high amplitude impulse (of duration < 1 ns) in conjunction with signal averaging at the receiving end. The degree of averaging necessary may be calculated from the following data:

(*a*) amplitude of transmitted impulse (S) ≈ 50 V,
(*b*) amplitude of received pulse (S_0) ≈ 5 mV,
(*c*) amplitude of thermal noise (N_0) ≈ 8 μV(RMS), and
(*d*) amplitude of forward echo (E_0) ≈ 5 μV.

Assuming that a forward-echo-to-thermal-noise ratio of 40 dB is needed, then the number of averaged samples (n) required may be calculated from the expression

$$\frac{E}{N} \approx \frac{E_0}{N_0}\sqrt{n}, \quad \ldots\ldots \text{(18)}$$

from which n was found to be ≈ 2·56 × 10^4.

Practical realization dictates, that a higher number of samples be taken to overcome such effects as the additional noise contribution of amplifiers, the inability to perform jitter-free sampling, and the presence of non-random noise contributions.

EQUIPMENT REALIZATION AND OPERATION

The equipment configuration needed to perform through-pulse-echo measurements on installed coaxial cables is shown in Fig. 5. An avalanche impulse-generator is used to inject a 50 V signal pulse (⩽ 1 ns duration at the half amplitude point) at a repetition rate of less than 100 kHz into a coaxial pair that is used as a control and test pair to extend the test circuit to the distant end of the cable under test. At the far-end of the control pair the signal is regenerated and launched back into the cable under test.

The received test signal is passed through an equalizer and amplified prior to sampling. At each sampling position selected by the digital delay generator, n samples of the received signal are taken for a given time. These successive samples are then integrated to obtain the average signal value for the period and the result is recorded. This process is repeated in 1 ns intervals over a preselected time-window. In this manner, a complete characteristic of the received signal response is recorded.

By adjusting the position of the time window, it is possible to exclude the test impulse, thus enabling the echo train to be magnified and displayed in greater detail. A combination of increased amplification and signal averaging can be used to achieve the desired magnification whilst retaining an adequate display signal-to-noise ratio.

At the outset of the design exercise it was considered that crosstalk between the coaxial pairs and any interaction between successive echo tails could pose a serious problem to the signal recovery process. To obviate this possibility, a low repetition rate for the described process was selected. For example, a cable of length 1 km has a transmission delay of about 3·6 μs and the echo components decay significantly after a further 1 μs. Thus, even for a round trip of 2 km (7·2 μs), a pulse-repetition rate of 100 kHz allows an adequate margin for the decay of any crosstalk components. The possibilities of reflections occurring at the send and receive ends has been minimized by the use of masking attenuators that ensure a good impedance match between the cable and test equipment.

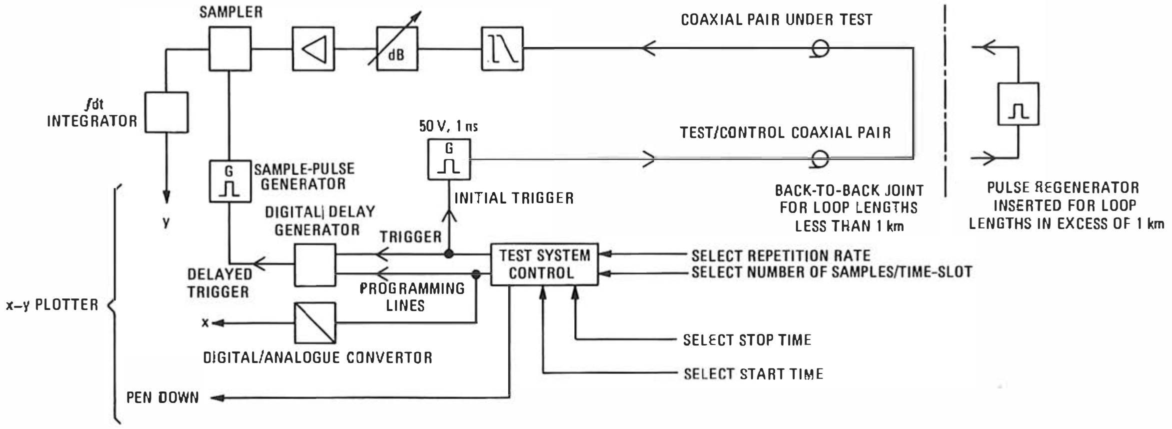


FIG. 5—Block diagram of through-pulse-echo test equipment

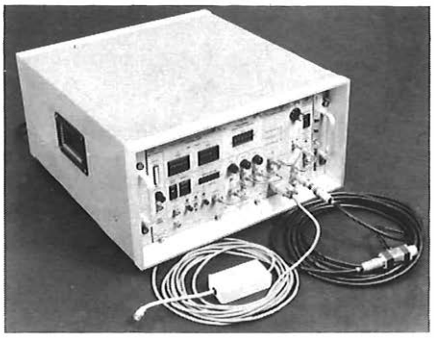


FIG. 6—The prototype through-pulse-echo cable tester

THROUGH-PULSE-ECHO MEASUREMENT RESULTS

The prototype equipment illustrated in Fig. 6 has a working range equivalent to approximately 180 dB of attenuation. Crosstalk present within the equipment is of the order of 220 dB; this provides an adequate margin for satisfactory field operation.

Two representative measurement characteristics are given in Figs. 7 and 8. The measurement result shown in Fig. 7 was produced under laboratory conditions and exhibits the sinusoidal echo pattern predicted by the simplified theoretical description. It can be seen from Fig. 8, which records a measurement on an installed cable, that additional components are also evident; these were generated by interaction between discrete discontinuities at cable joints.

In all the field measurements so far performed, the discrete echoes have been found to predominate, in amplitude, over the periodic components. Hence, it is generally possible to extract the discrete echo information and apply it to the system calculations, independently of the periodic effects.

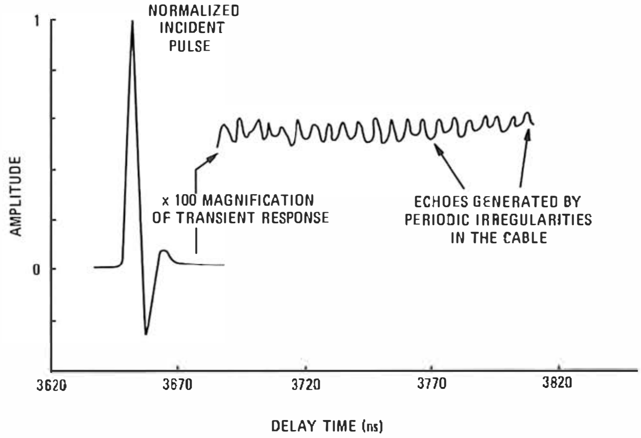


FIG. 7—An example of a through-pulse-echo test response recorded on a non-operational 1·2/4·4 mm coaxial cable

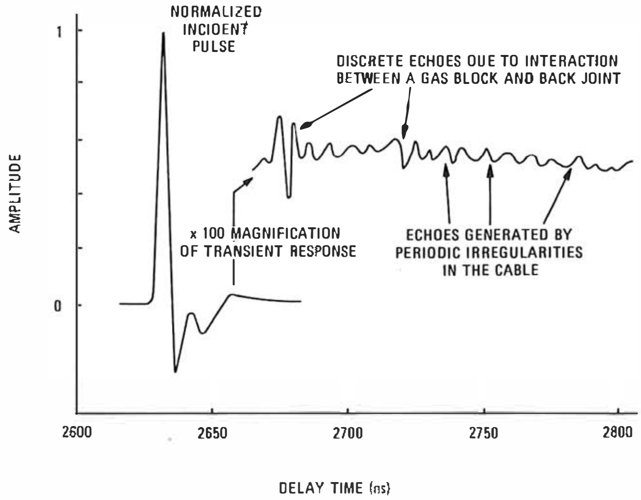


FIG. 8—An example of a through-pulse-echo test response recorded on an installed 1·2/4·4 mm coaxial cable

PULSE-ECHO APPLICATION

If through-pulse-echo measurements are performed and an unacceptable level of forward echo is detected, then the problem of accurately locating the offending cable joint or cable section arises. This can be achieved by using the test equipment in a return pulse-echo mode[14], as indicated in Fig. 9. Advantage may be taken of the signal averaging process to perform equalized return pulse-echo tests. The wideband equalization ensures that the positional resolution is maintained, whilst the signal averaging provides the operating range necessary to overcome the effective loss.

To illustrate the necessity for such a technique, a series of measurements has been performed on a coaxial cable that was artificially degraded. Furthermore, a comparison has been made between conventional[15] and equalized return-pulse-echo measurements.

The arrangement of test cable sections (see Fig. 10) consisted of 2 structurally uniform cable lengths, between which was installed one length of cable whose structure had been badly degraded. Performing a through-pulse-echo measurement resulted in the high level of echo depicted in Fig. 11. An attempt to locate the source of these echoes with a conventional 2 ns pulse-echo equipment was not satisfactory as can be seen by the response shown in Fig. 12. Repeating

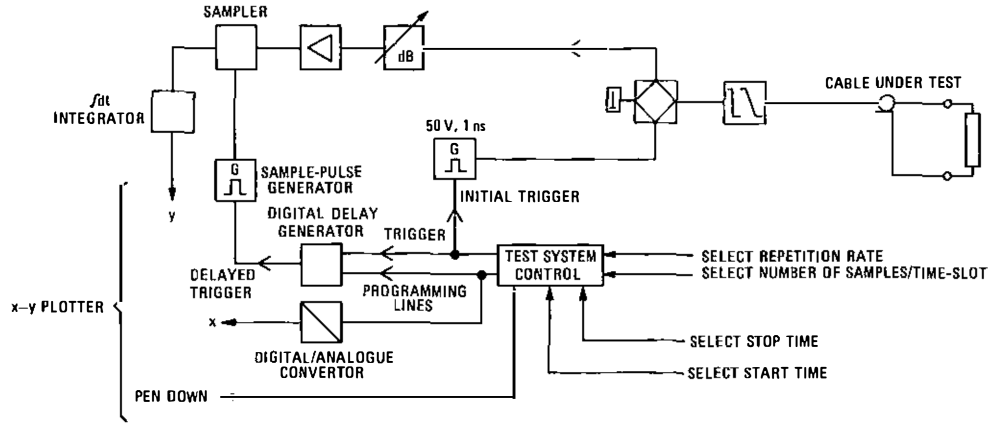


FIG. 9—Block diagram of through-pulse-echo test equipment reconfigured for equalized pulse-echo testing

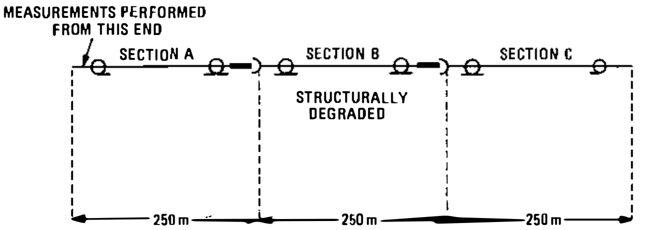


FIG. 10—Connexion of 3 coaxial cable pairs to form a 750 m cable test section

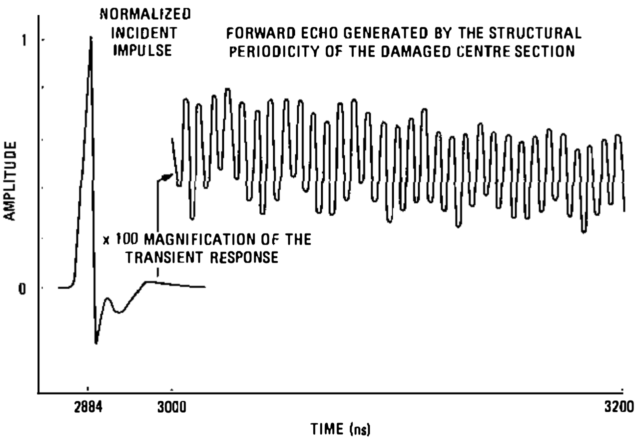


FIG. 11—Through-pulse-echo response of a 750 m cable test section

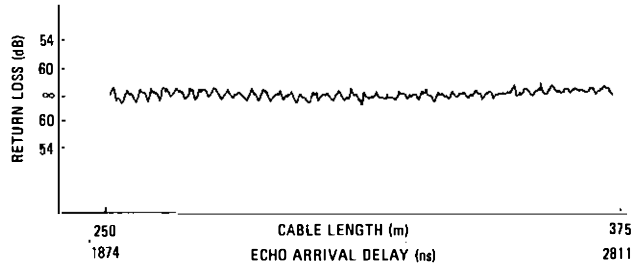


FIG. 12—Echo response of a 750 m cable test section using 2 ns pulse-echo equipment

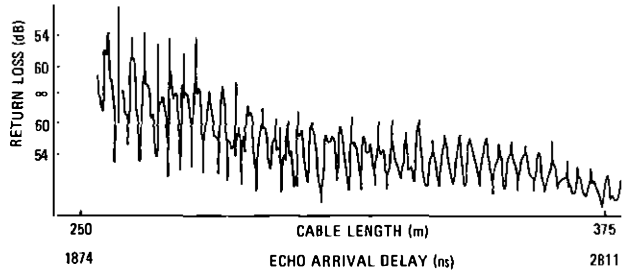


FIG. 13—Equalized and signal-averaged return pulse-echo response of a 750 m cable test section

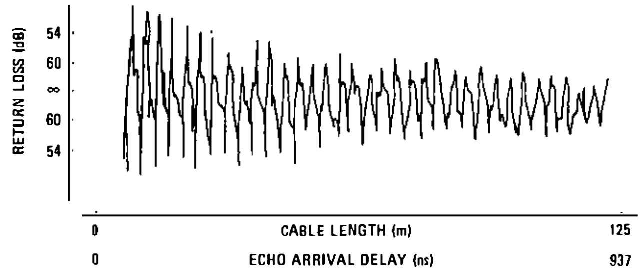


FIG. 14—Return pulse-echo response of a structurally degraded 250 m coaxial cable length

the measurement with the aid of wideband equalization and signal averaging gave the echo response shown in Fig. 13. Clearly, this identifies and locates the echo source quite positively.

It is interesting to compare the results of Fig. 13 with Fig. 14, which was produced by performing a 2 ns pulse-echo measurement directly on the centre 250 m (degraded) section. A high degree of correlation between the 2 results is evident. The major difference being the slow roll apparent in Fig. 13 which was caused by an instrumentational problem associated with the prototype equipment.

PRACTICAL APPLICATION

The test equipment and measurement techniques that have been described are required for both installation and maintenance of high bit-rate digital transmission systems. Hence, there is a requirement to simplify the presentation of results so that a quick decision regarding acceptability can be made on the evidence of the echo data presented. One approach at present being investigated involves the use of a calibrated graticule within which the echo response must remain if the cable is to be deemed acceptable. An example of such a graticule, which has been computed for a 565 Mbit/s system,

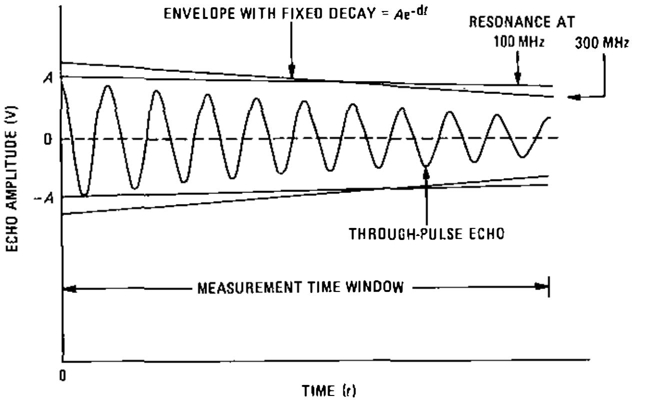


FIG. 15—An echo-response graticule for tests of coaxial cable used for routing 565 Mbit/s digital line systems

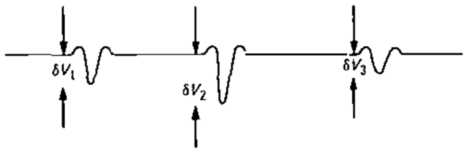


FIG. 16—Echoes generated by discrete echo sources

is shown in Fig. 15. The same effective echo power level for each of the threshold lines shown is assumed.

Clearly, the results appear to be insensitive to the resonant frequency of the echoes and would, therefore require the use of only one calibrate line. This can be explained by returning to equation (15) where it was shown that

$$\sigma_E^2 = \frac{k(AN)^2}{4\alpha V_p} f_m. \qquad \ldots\ldots (15)$$

Now, α is dependent on $\sqrt{f_0}$,

therefore, $$10\log_{10}\sigma_e^2 = k' - 5\log_{10}(f_0), \qquad \ldots\ldots (19)$$

where k' is a constant and the term $5\log_{10}(f_0)$ is frequency dependent.

Such an approach may be considered a little crude, but it is thought to he quite adequate for this particular application. However, in a marginal case, it is not too difficult to form a more accurate estimate by applying the stated equations.

A similar approach could also be adopted for the discrete echo components, or alternatively they could merely be summated on a worst-case basis, as indicated by Fig. 16. The worst-case eye-closure would then be given by the expression

$$E = \hat{V} - \Sigma_i|\delta V_i|. \qquad \ldots\ldots (20)$$

Combining all of the effects, the overall transmission system signal-to-noise ratio is given by

$$\frac{\{\hat{V} - \Sigma_i|\delta V_i|\}^2}{\sigma_N^2 + \sigma_E^2}. \qquad \ldots\ldots (21)$$

Practical verification of such an approach is being pursued with a series of experiments on both 120 Mbit/s (4B3T line code) and 250 Mbit/s (binary) transmission systems that model the 556 Mbit/s system. The preliminary results have so far been very encouraging and full details of this work will be reported by the BPO Research Department when tests have been concluded.

CONCLUSIONS

A novel system-oriented coaxial-cable testing technique, derived for very high bit-rate digital transmission system installation and maintenance purposes, has been outlined. The problems associated with physically realizing a suitable instrument have been considered and a prototype equipment described. This has been shown to offer considerable advantages over existing measurement techniques. In particular, the fault-location capabilities of the test method far exceed those of conventional pulse-echo equipments. Furthermore, the method also offers a fairly direct route to the prediction of system error-probability degradation.

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The Regenerator 5A—A Microelectronic Project for Strowger Exchanges

Part 2—Later Designs

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UDC 621.38—181.4: 621.395.34

Part 1 of this article dealt with the origin of the project and described the Regenerator 5A, Mark I equipment. Under the British Post Office procurement policy of competitive tendering, new designs were accepted for operational use. The principal design features and modes of operation of the later designs are discussed in this final part of the article. Procurement, production and installation aspects are included.

INTRODUCTION

The Regenerator 5A, Mark I, which established the viability of the electronic device for Strowger exchanges, was produced at a time of rapid advances in metal-oxide-semiconductor (MOS) microelectronics technology and its practical applications. It was therefore decided that further supplies should be procured by competitive tendering, to ensure that these advances in technology were exploited in the designs submitted. Accordingly, the outline specification used to guide the original development was replaced by a formal specification. This was performance-based, but some mandatory requirements were included. There was, however, sufficient flexibility for manufacturers to exploit their individual expertise.

Pye TMC Ltd., who had produced the Mark I regenerator, offered a new design similar in principle but notably improved, which, after British Post Office (BPO) approval, was coded the Mark II type. Some 100 000 of the Mark II designs are now in service.

GEC Ltd. offered a different design, also using MOS technology, which was approved and coded Mark III; about 10 000 of this type have been installed. However, the company developed an improved design which was coded the Mark IV, and some 30 000 equipments of this later design are now in use.

In regard to technical acceptability, the Mark II and Mark IV equipments are considered by the BPO to be of equal status.

REGENERATOR 5A, MARK II

Design Features

In principle, the Mark II design is very similar to the Mark I, in that it uses MOS 4-phase dynamic logic and the same basic functional sequences. The circuit elements are, however, simpler, resulting in easier production and increased reliability. A block diagram of the Mark II equipment is shown in Fig. 8, which can be compared with the block diagram of the Mark I given in Fig. 3 of Part 1 of this article. The main-circuit elements and the connexions at the interfaces are identical for each design. Therefore, the main-circuit elements are not included in Fig. 8 (nor in Fig. 11, which shows the block diagram of the Mark IV).

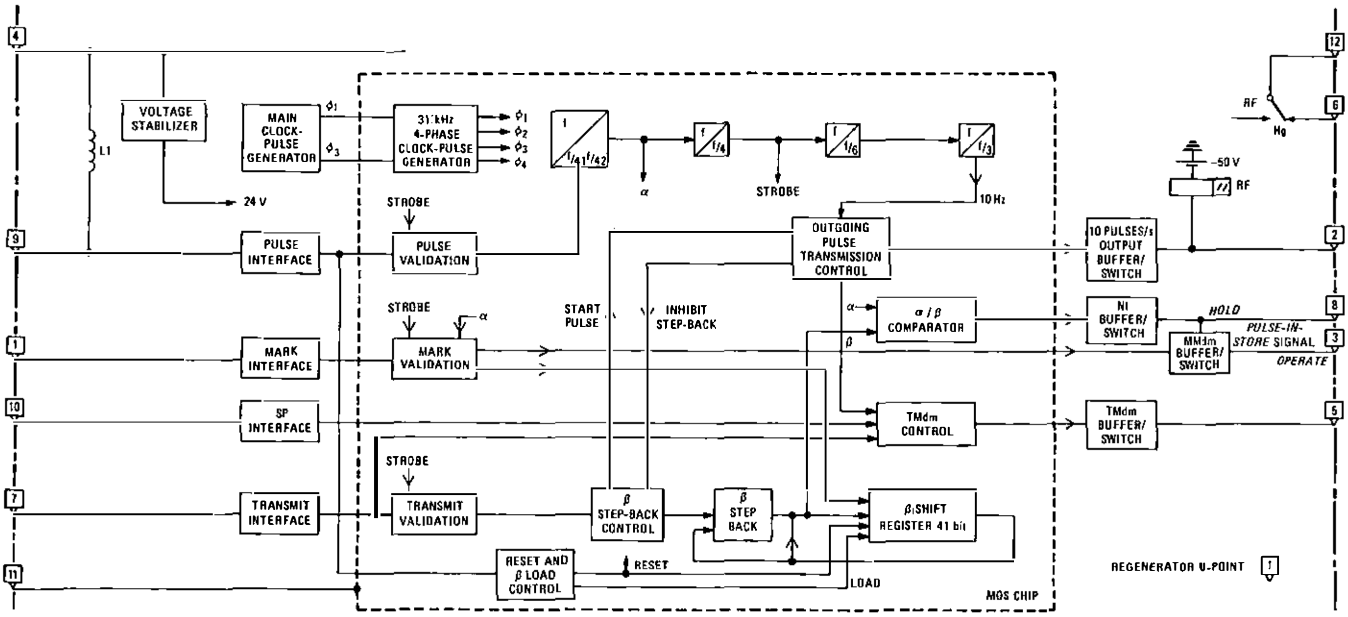

FIG. 8—Block diagram of Regenerator 5A, Mark II

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† Mr Lock is with the Telecommunications Development Department (TDD), Telecommunications Headquarters, Mr Scott, who was with the TDD, is now retired

The principal differences of the Mark II design, compared with the Mark I design, are outlined below.

Internal Power

A single −24 V internal supply, permanently connected, is used instead of 2 voltage supplies being switched on each time the regenerator is seized. With the new arrangement, it is not necessary to provide a delay element in the supply to the output buffers to avoid the generation of spurious signals.

Clock Frequency

The clock frequency is notably lower: 31 kHz compared with 480 kHz; thus the divide-down counter arrangements are simplified.

Interface Elements

Instead of semiconductor switches, simple resistive-networks are used to translate the incoming main-circuit signals to logic levels suitable for input to the chip.

Validation of Input Signals

Input signals are validated against spurious conditions, as in the Mark I, but the controlling strobe is 5·5 ms instead of 4·1 ms, thus increasing the discrimination.

Pulse Reception and Storage

The basic principles are the same, the pulses are counted by delaying α pulses to correspond with the number of pulses in the digit and marking the end of each digit by inserting β pulses in a β register. Instead of using 2 registers, however, the function of the α register is performed by one of the counters in the divide-down chain.

Output Buffer-Switches

The output buffer-switches are driven direct from the chip, instead of via intermediate transistor stages.

Output Pulses

The main outgoing pulses, at 10 pulses/s, $66^2/_3\%$ break ratio, are taken from a single change-over mercury-wetted relay, while the auxiliary pulses, at 10 pulses/s, $66^2/_3\%$ make ratio, are taken direct from the output buffer. This eliminates the need for a relay having 2 change-over contacts.

These changes in design enabled a simplified form of construction to be adopted. The Mark II design uses only one circuit board and the MOS functions are accommodated on one chip; the total number of components has been reduced from 137 to 85. The construction and component layout of the Regenerator 5A, Mark II, are shown in Fig. 9.

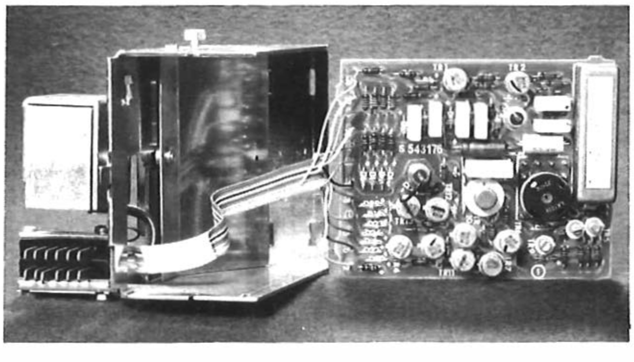


FIG. 9—Regenerator 5A, Mark II

Outline of Operation

In the idle state, with the main circuit unseized, the internal power and clock-pulse supplies are already established, and all bistables and the β register, are held in the reset state.

When the main circuit is taken up by a call, the regenerator is seized and extends a signal to the chip to load the β register with a single β pulse, in synchronism with the α pulses from a divide-by-41 counter, which also has the capability of dividing by 42 on receipt of an incoming pulse. The α pulses and the circulating β pulse then appear in synchronism at the α/β comparator until incoming-pulse storage commences.

During pulse storage, each validated incoming pulse changes the counter mode from divide-by-41 to divide-by-42 for one count cycle, resulting in the α pulse being delayed relative to the β pulse by one shift-bit period. At the end of the train of incoming pulses, the total delay in shift-bit periods corresponds to the number of pulses in the train. The end of the train is marked in the β register by the loading of another β pulse in synchronism with the delayed α pulse. Further pulse trains are similarly counted and marked by additional β pulses in the β register. When storage commences, the α/β comparator detects that the α and β pulses are out-of-synchronism and the *pulse-in-store* condition is extended to the *hold* lead of relay BY in the main circuit.

Following storage of a complete train of pulses, switch MMdm is closed, extending the *pulse-in-store* signal to the *operate* lead to operate relay BY, thus connecting the regenerator pulsing-contacts to the outgoing path.

Transmission of outgoing pulses commences after a complete train of pulses has been stored; a signal via the *transmit* lead results in the β step-back element delaying the first β pulse one shift-bit period, while the outgoing pulse-transmission control sends an output pulse to the main circuit. The β step-back sequence is repeated for each stored pulse in the train until the first β pulse reaches the position of the second β pulse indicating the end of the digit. Pulse transmission then ceases, the outgoing inter-digital pause (IDP) relay-sequence follows in the main circuit, and a further *transmit* signal starts transmission of the second train. This action is repeated until all stored pulses have been transmitted. The remaining single β pulse and the α pulse then appear again at the α/β comparator in synchronism, the *pulse-in-store* signal ceases (releasing relay BY), and the regenerator is held in the seized state for the duration of the call. On cleardown, the seizing signal is removed and reset conditions are restored to the bistables and the β register.

Testing and Installation

Although the Mark II was, in principle, very similar to the Mark I, the specification and design realization were different, therefore it was essential to carry out type-approval tests in the TDD Circuit Laboratory and the field.

Following laboratory tests and field trial of prototypes, arrangements were made by Telecommunications Headquarters (THQ) Service Department for the performance of the first 6500 Mark II regenerators to be monitored; all equipment failures were investigated by the manufacturer, who undertook to provide details of component failures.

The object of the test programme was not only to validate the changed design under installation and service conditions, but also to obtain data from a significantly large quantity of devices for a joint study of performance and reliability by the BPO and the manufacturer. The data was required for other MOS projects then at early development stages.

The performance evaluation programme was more closely controlled than that of the Mark I, and extended over 3 years, yielding useful information on failure mechanisms and reliability, details of which are given later in this article.

REGENERATOR 5A, MARKS III AND IV

Design Features

The Mark III and Mark IV regenerators have an internal power switch; an inductance/capacitance (LC) oscillator as the main clock pulse source; input and output circuit elements interfacing with the main circuit; and a single MOS chip, using 4-phase dynamic logic.

The MOS chip incorporates logical elements controlling clock pulse and strobe generation, signal validation, pulse-reception, counting and storage, outgoing pulse generation and transmission, and auxiliary output signals to the main circuit.

In the Mark III regenerator, the inductor that maintains the holding performance of relay B in the main circuit was accommodated inside the case, instead of being mounted externally as with the Marks I and II designs. The object was to simplify production and improve the appearance.

During BPO approval trials of the Mark III, an obscure failure mode was discovered, and an extra circuit element had to be added to eliminate the fault; the extra components were fitted on a small additional board mounted on the main circuit board. During production of the Mark III, it became increasingly apparent that the congestion due to the additional board more than offset the advantages of mounting the inductor inside the case. The component layout was therefore rearranged and the inductor mounted externally while the opportunity was taken to incorporate other improvements. External mounting also reduced heat dissipation within the case, increasing functional and reliability margins. The modified regenerator, known as the Mark IV, has superseded the Mark III. The construction and component layout of the Mark IV is shown in Fig. 10 and its block diagram is shown in Fig. 11. (The Mark III block diagram is not included in this article because it is similar in basic principles to the Mark IV.)

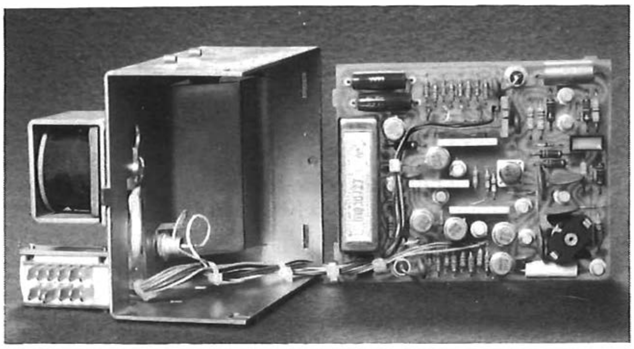


FIG. 10—Regenerator 5A, Mark IV

Internal Power Switch

On seizure by a call, the −50 V supply to the regenerator is extended to a −27 V stabilizer, which provides power to the input interfaces, clock-pulse generator, and clear circuit. To avoid the generation of spurious output pulses on seizure, the −27 V supply is not switched to the output buffers until the chip seizure is complete.

Clock-Pulse and Strobe Generation

The ϕ_1 and ϕ_3 pulses generated by the 8·7 kHz LC oscillator are expanded to 4-phases (ϕ_1–ϕ_4) within the chip. The 3·45 ms strobe used for the validation elements, and the 10 Hz supply which provides the outgoing pulses, are derived within the chip by the interaction of 2 Johnson counters[7].

Input and Output Circuit Elements

These arrangements are similar in principle to those of the Mark II regenerator. The input elements are simple resistive networks and the output buffers are transistor switches, driven

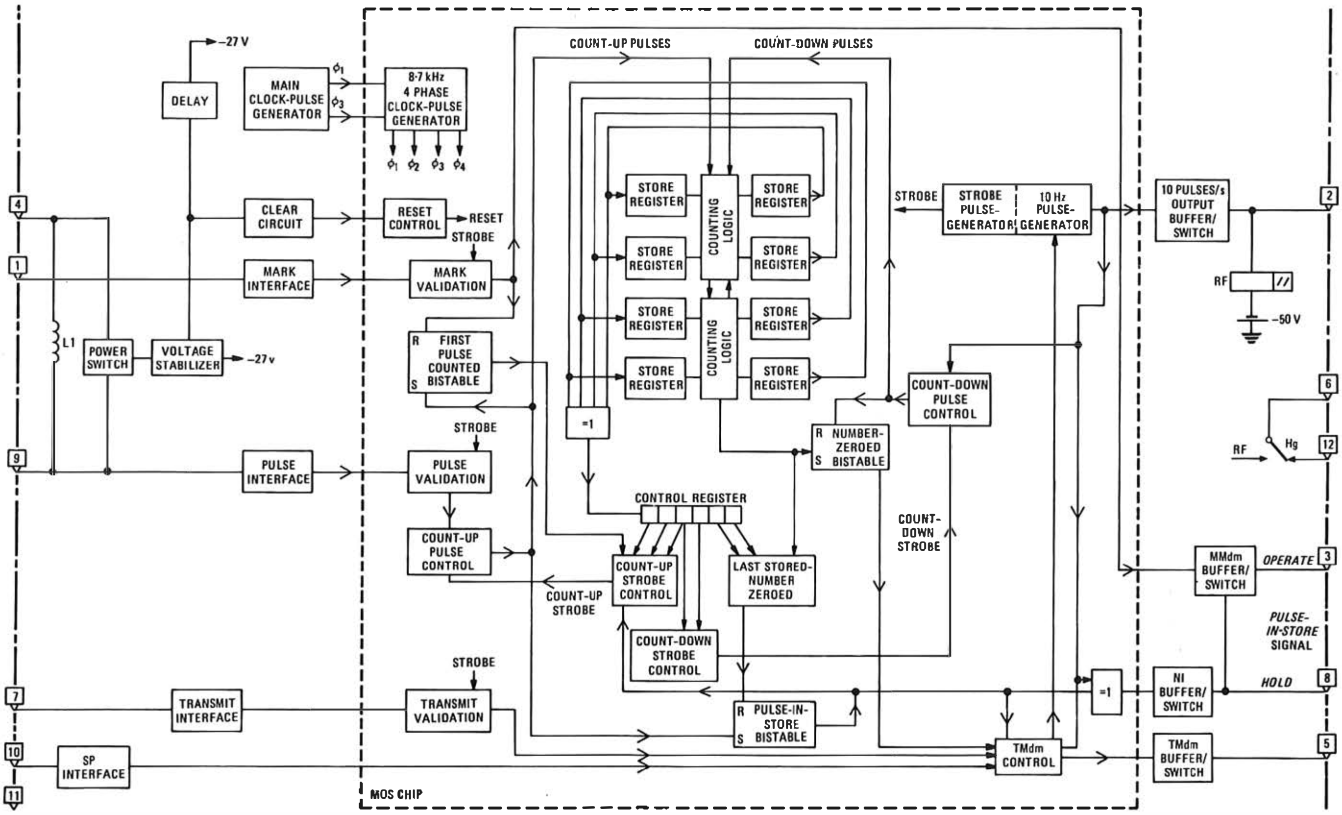


FIG. 11—Block diagram of Regenerator 5A, Mark IV

direct from the chip. The output from the 10 Hz transistor switch is repeated and inverted by a single change-over mercury-wetted relay to provide the main 10 pulses/s outgoing pulses and is also taken direct to provide the 10 pulses/s auxiliary output pulses.

Signal-Validation Elements

Incoming signals from the relay contacts in the main circuit are validated against spurious conditions in the same way as with the Mark II, but a strobe of shorter periodicity is used, and extra bistables are provided to maintain effective discrimination.

Incoming Pulse Storage and Output Pulse Transmission

Incoming pulses from the main circuit are stored in 4-bit parallel binary form in 4 registers, each having 8 store locations. The binary information for a stored digit occupies one location in each register and circulates under 4-phase clock-pulse control. A control register monitors the circulating information and, by detecting appropriate conditions, ensures that, during pulse reception from the main circuit, the digit trains occupy successive locations and that, during output pulse-transmission, they are counted-down in the correct order.

Outline of Operation

The regenerator is seized when the main circuit is taken up by a call; internal power and clock-pulse supplies are established and a *clearing* signal extended to the chip, to clear all store locations. The output buffer-switches are inhibited until the clearing sequence is complete.

The first incoming pulse from the main circuit, after validation, results in a *count-up* pulse being sent from the count-up pulse control to the storage registers, this pulse is stored as binary information and recirculated under clock control every 1·034 ms. This first count-up pulse changes the pulse-in-store bistable to the set position, which signals *pulse-in-store* to the main circuit. The first count-up pulse also resets the first-pulse-counted bistable, to indicate to the count-up strobe control that further pulses in the train should be added into the same circulating location in which the first pulse is stored. Thus, the second validated pulse received by the count-up pulse control is extended to the store registers by the count-up strobe, applied from the strobe control at the correct instant for the second pulse to be added to the first, as it recirculates through the stores. The remaining pulses in the train are added in the same way until the circulating information finally represents the full value of the digit.

At the end of the train, the *mark* signal from the main circuit ceases; this action sets the first-pulse-counted bistable to indicate to the count-up strobe control that the second digit should be stored in the location immediately after that in which the first digit has been stored.

When the first pulse of the second train is received and stored, the first-pulse-counted bistable is again reset, to indicate, as before, that each remaining pulse in the train should be added to the first pulse location as it recirculates through the stores. This sequence is repeated for each of the remaining pulse trains. For transmission, a signal on the *transmit* lead is, after validation, extended via the TMdm control to start the 10 Hz pulse generator, which applies an outgoing pulse to the main circuit via the buffer-switch and relay, and also to the count-down pulse control to await the application of a count-down strobe. When the control register detects that the digit being transmitted has reached the appropriate position in the storage registers, a strobe from the count-down strobe control results in a pulse from the count-down pulse control being applied to the stored number to reduce it by one.

This sequence is repeated as each outgoing pulse is applied to the count-down pulse control, until the stored digit is reduced to zero. A pulse from the counting logic then sets the number-zeroed bistable, which applies a signal via the TMdm control to stop the 10 Hz pulse generator. The IDP in the main circuit follows, after which, in response to further signals on the *transmit* lead, any stored digits remaining are similarly counted-down and transmitted.

The control register detects when the digit being counted down is the last in the store; when this number is zeroed, the pulse from the counting logic sets the number-zeroed bistable as before. In addition, in this case, the pulse causes the last stored-number zeroed element to reset the pulse-in-store bistable. The *pulse-in-store* signal is maintained, however, until the end of the last outgoing pulse, to avoid a premature removal of the *pulse-in-store* signal to the main circuit. When the last pulse ends, the *pulse-in-store* signal ceases, and the regenerator remains in the seized state for the duration of the call.

Testing and Installation

The Marks III and IV designs were subjected to rigorous tests in the TDD Circuit Laboratory and tests in the field. The question then arose as to whether special arrangements should be made to install regenerators in a wide range of circuits and monitor the operational performance, as had been done with the Marks I and II. It was decided that the earlier monitoring procedure should be repeated because

(*a*) the design approach used forms of pulse counting, storage and retransmission entirely different from those of the earlier types,

(*b*) while the MOS chips could be subjected to a variety of physical and electrical tests, it was recognized that it is difficult, if not impossible, to check for correct operation with all combinations of external stimuli[8], and

(*c*) the arrangements would make available information on component reliability for which there was a continuing need in telecommunications development activities.

The value of the monitoring procedure was confirmed when an obscure form of malfunction was detected by maintenance staff at one of the trial exchanges. This enabled a joint investigation team of BPO and manufacturer's representatives to identify the basic cause. Modification to the chip was required, and early detection of the fault during the monitoring procedure enabled it to be rectified before large scale production started.

REVIEW OF THE PROJECT

Replacement Programme

Since the start of the replacement programme in 1970, some 140 000 electronic regenerators of various designs have been installed. Present indications are that the ordering programme will be complete in the early 1980s, by which time the number in service will have increased to 250 000.

Maintenance and Repairs

New routine maintenance and repair procedures were introduced which took account of the fundamental differences between the electronic regenerator types and the electromechanical Regenerator 1A, thus ensuring that the savings envisaged when the project was planned were realized in practice.

In the outcome, the reliability of the electronic regenerator has now enabled the annual allocation of resources for regenerator routine maintenance to be discontinued. The annual maintenance allocation for each Regenerator 1A is 1·07 man-hours; the ultimate planned total of 250 000 electronic regenerators in service will thus yield substantial annual savings.

Routine Tests and Adjustments

Routine maintenance testing of the electronic regenerator as a separate item has been eliminated, although its general functional performance is checked when the associated main circuit is given a periodic test by automatic routiner or tester. In contrast, the electromechanical regenerator requires unplugging for individual routine functional tests, readjustment and lubrication. Furthermore, in some exchanges, a special daily manual check is necessary to verify that none of the code-pins have been ejected from the frame because this fault, which is prevalent when the regenerator is working in association with some main circuits prone to relay-interactions, would otherwise remain unnoticed and cause misrouted calls.

Repair Procedures

Repair of faulty electronic regenerators is concentrated at the BPO Factories Division, Edinburgh; in consideration of the small quantities likely to require attention, it would have been impractical to have carried out repairs at exchange sites, and uneconomical at Regional repair centres. This arrangement has proved very effective; at the present time, with 140 000 Regenerators 5A in service, one technician is able to maintain a good repair service for all Regions. In contrast, the Regenerator 1A is overhauled and repaired on site, requiring stocks of replacement parts to be held at each exchange.

Centralized repair also makes it easy to co-ordinate arrangements for regenerators that develop faults during the 12-month guarantee period to be checked and returned to the manufacturer for free repair.

The question of ensuring future supplies of the MOS integrated circuits when the ordering programme ends is under consideration. It is prudent to make advance arrangements as future production runs may be costly and, in addition, it cannot be assumed that the p-channel metal-gate process used to produce the chips will continue indefinitely. Manufacture and storage of a sufficient quantity of complete integrated circuits is a possibility, but may be precluded on technical and cost grounds because there could be deterioration during storage and the throw-away value of any surplus would be high. An economically-attractive alternative is to have the chips manufactured in wafer-form and kept in a suitable location, possibly at the processor's plant; at this stage of production, the cost is relatively low, and batches can be tested and encapsulated only as required.

Additional Benefits

In addition to the savings arising from the revised maintenance practices, there were other less obvious benefits derived from the Regenerator 5A, as outlined below.

Reduced Wear of Pulsing Contacts

The life of the pulsing-relay contacts in the main circuit, which repeat all incoming pulses to a regnerator, has been notably increased because the load-current switched at the contacts is less than one-third of that when using the electromechanical type.

Increased Reliability of Switch SP

The use of a semiconductor switch in place of mechanically-operated contacts was particularly advantageous in the case of the contacts of switch SP. In the electromechanical regenerator, these are formed by the resetting plunger and set code-pins and, while they are not used electrically in all circuits, they have been a frequent cause of failure due to oily debris and dust that collect at the contacting points during operation.

Stability of Outgoing-Pulse Characteristics

The pulse-repetition-frequency (PRF) of the electronic regenerator is controlled within very close limits since it is derived from a master oscillator which is stable over a prescribed temperature range. The mechanical governor, which controls the PRF of the Regenerator 1A, is adversely affected at low temperatures and, at some exchanges the working environment has had to be heated to counteract this effect.

The break-to-make ratio of the outgoing pulses from the electronic regenerator is determined by the counting sequences of clock-controlled logical elements and, consequently, is substantially constant at 2 : 1 for the main pulses and 1 : 2 for the auxiliary pulses.

Absence of Mechanical Shock and Vibration

The electronic regenerator is free from mechanical shock and vibration, and thus avoids the intermittent contact failures and microphonic noise which could result from the operation of the Regenerator 1A magnets.

Reduced Disturbance

The removal of the relay-set covers and unplugging, testing and replugging of the regenerator, is minimal with the electronic device. This reduces the incidence of relay contact failures caused by disturbance to the equipment.

Removal of Regenerator Alarms

If an electromechanical regenerator does not restore to normal after completion of a call, an urgent alarm is given which, at an unattended exchange, may require call out of maintenance staff. Alarm arrangements are not required with a Regenerator 5A, thus eliminating call-outs and reducing maintenance costs.

Dormant Faults in Existing Equipment

In any telecommunication system, or unit of equipment within a system, there may be dormant faults which have remained unnoticed because they have not caused immediate component failures or have not had any perceptible repercussions on functional performance[9]. Some dormant faults encountered during the regenerator project caused immediate failure of the electronic regenerator, and were relatively easy to identify. Others resulted in various forms of malfunction often of an intermittent nature, and identification and location of these was more difficult; some examples are described below.

Catastrophic Failures of Semiconductors in Inputs and Outputs

During the Mark I installation programme, breakdowns of semiconductors in the transmit interface were found to be due to contact faults between the resistors in the resistance capacitance networks, provided in the main circuit to quench magnets RM and TM (see Fig. 2 of Part 1). During reception of incoming pulses, the contact fault resulted in the induced voltage spikes from inductor L1 in the *seize-and-pulse* lead (U9) being coupled through to the *transmit* lead (U7) and thence to the interface semiconductors. The quench components are located in adjacent positions in the rear of the relay-set and investigations showed that the fault was widespread, but had escaped notice as it had no apparent effect on the performance of the electromechanical regenerator. There must have been, however, some degradation of quenching efficiency, with a corresponding reduction in the working life of the relay contacts which controlled the magnets. The Mark I regenerator was the only design affected by this fault as, in the later types, additional protection was provided in the input elements.

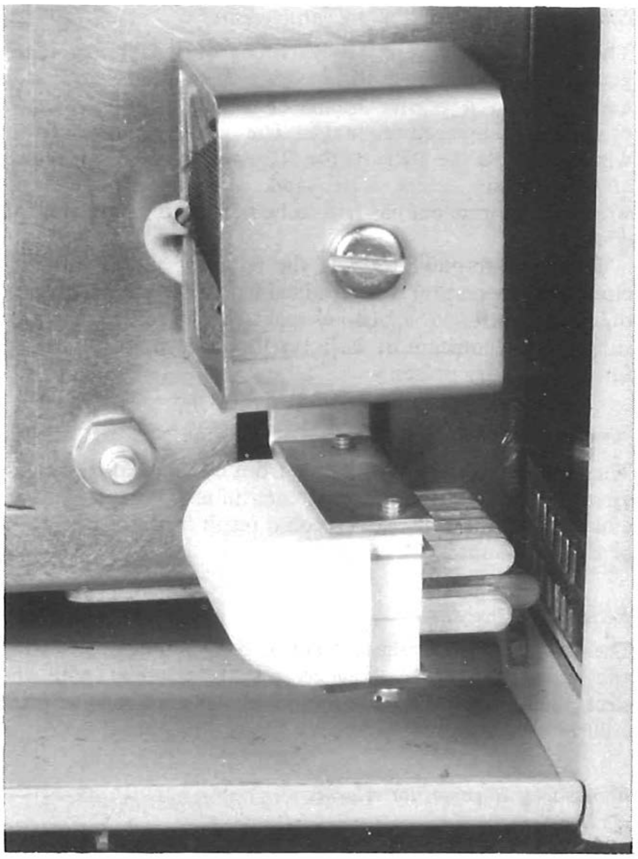


FIG. 12—Plug-and-socket alignment by elongated blade

Failures of semiconductors in the MMdm and TMdm output buffer-switches were found to be caused by electrical overstress. The MMdm and TMdm buffers are wired to plug blades 3 and 5 respectively, and investigation showed that, when regenerators were plugged into the relay-set sockets in some early equipment, it was possible for these blades to make contact with socket spring 4, to which the −50 V supply is connected. This overloaded and destroyed the buffer-switch semiconductors.

In operational use, the brackets that locate the regenerator in the relay-set had become splayed by repeated plugging and unplugging of the device for maintenance purposes. This allowed appreciable misalignment between the blades and socket springs when plugging-in the regenerators; as the springs in some early equipment protrude across the face of the socket, there is a high risk that the blades will make incorrect contact.

In the case of the electromechanical regenerator, incorrect contact with the −50 V spring caused the relay-set fuse to rupture, without damaging the regenerator. The electronic regenerator was protected against this fault by providing an elongated plug-blade 4, (see Fig. 12). Plug-blade 4 is the first blade to enter the socket, thus locating the plug and the remaining blades relative to the corresponding socket springs, and avoiding incorrect contact. In addition, arrangements were made for the locating brackets to be re-adjusted where necessary before an electronic regenerator is plugged in.

Functional Failures

The relay contacts in the main circuit which control the magnets in the Regenerator 1A, switch currents of around 750 mA and, as a consequence, damage to the contact surfaces occurs and can cause intermittent failures. However, the high value of current tends to offset the effect of the damaged surfaces and failures are usually few until near the end of the contact life. In the case of the electronic regenerator, the impedances of the inputs were high and the currents small (around 750 μA). Damaged contacts under these conditions resulted in a marked increase in intermittent faults, which was countered by reducing the input impedances to increase the current so that the contacts were adequately wetted.

Relay IS, whose contacts control the transmit function, is of a slow-to-release design, and is particularly prone to hesitation-chatter during release. The transmit magnet in the Regenerator 1A absorbs the effects of the contact chatter. In severe cases, it was found possible for contact chatter to be recognized as a signal by the validation elements in the electronic regenerator, and re-adjustment of relay IS was necessary.

During the trials, intermittent failures of electronic regenerators under test in unit automatic exchanges were found to be due to the release-alarm relays, common to a group of regenerators, having incorrect coils of 3 Ω instead of 0·5 Ω. The relay is connected in the common earth path for the transmit elements and the higher resistance resulted in an increased potential on the common earth during operation. When several electronic regenerators were in use simultaneously, this caused malfunctions. The incorrect coils had been in use with Regenerators 1A at exchanges for many years.

Procurement and Manufacture

The decision not to have a BPO standard design of electronic regenerator developed and documented for competitive procurement proved advantageous. At the launch of the project, the procurement policy was to produce, as quickly as possible, a state-of-the-art design which met the functional requirements, even though it was likely it would soon be overtaken by technological advances.

This aim was achieved with the Mark I regenerator, and the 10 000 regenerators ordered was a large enough quantity to permit economic production and validation in the wide range of circuit applications, without too great a commitment to a design that might become outmoded. In the event, even before completion of the Mark I programme, MOS technology and its applications had advanced sufficiently for improved designs to become possible. The experience and confidence gained by the BPO during the programme enabled arrangements for bulk purchase on a competitive basis to be started for a large scale installation programme.

The formal performance-based BPO specification produced for competitive tendering was based on the outline specification used for the Mark I type, but was strengthened in some details and also modified in places to avoid putting unnecessary constraints on the design approach of individual manufacturers.

At this stage of the project, the BPO D4000 scheme,[10] for the specification of MOS integrated circuits had become available; therefore, requirements for the regenerator were formulated in subsidiary specifications in the D4000 series and called up in the main regenerator specification.

Manufacturing difficulties, particularly in the early phases, centred mainly on the MOS integrated circuits. Processing methods were still evolving and, at times, yields of satisfactory chips were very low. In addition, practices had to be developed and introduced for handling the integrated circuits during assembly operations to protect them against electrostatic discharges from personnel and tools, which could otherwise have destroyed the input gates. These protection arrangements involved earthing of the operative, by means of an earthed bracelet, and the earthing of tools and working surfaces; an alternative method was the commoning of the integrated circuit pins by means of a metal spiral-spring or clip, until assembly operations were complete.

Reliability Data from Operational Use

The assessment trials were intended to provide information on the general reliability and failure mechanisms of the regenerator and its components; in particular, the MOS chips. The collection and collation of the information was aided by a specification requirement that each regenerator must be marked with a serial number and date of manufacture. Records were kept of the date each regenerator was put into service, the period of operational use, fault reports and failure mechanisms.

The Mark I regenerator was essentially a pioneering type, which established the viability of the project. During its manufacturing programme there were progressive variations and improvements in components and manufacturing techniques, particularly of the MOS chips and their processing. Analysis of the results of this trial was therefore confined to determining the overall failure rate of the regenerator, which, at the end of the monitoring period, was 50/1000/year.

The later trials were organized to provide more detailed information. To-date, the Mark II results have been analysed and are discussed below; the Mark III trial has ended and the results are being collated; the Mark IV trial is still in progress.

The Mark II trial involved 6500 regenerators, installed at 24 exchanges over a period of 6 months, and performance-monitoring was carried out for a total of 40 months. At intervals, the results were analysed and interim reports issued. Each report contained up-to-date curves, plotted on Weibull probability paper,[11] of cumulative percentage failures against hours of operational use for both the regenerators and the MOS chips. At the end of the monitoring period, the final curves indicated that the regenerator failure rate was then 8·7/1000/year, and was reducing with time. Extrapolated to 4 years, the failure rate was 7·3/1000/year. The corresponding chip failure-rates were 4·8/1000/year and 4/1000/year. Analysis of the failure mechanisms showed that manufacturing defects such as dry joints, incorrect components and wiring faults, had been virtually eliminated by improved production and quality-control measures introduced during the Mark I programme. Components which failed were, in the main, transistors and MOS chips. The transistor failures were due principally to the electrical overstress condition caused by misalignment of the plug-blades and the socket, and chemical attack by residual traces of plating-fluid inside the encapsulation (see. Fig. 13). This latter problem was a temporary production deficiency which has been corrected by the semi-conductor manufacturer.

The majority of the chip failures were open-circuits in the aluminium interconnexion tracks (which are 10 μm wide) caused by corrosion, examples of which are shown in Figs. 14(a) and (b). The manufacturer identified the immediate cause of failure and an investigation by the BPO Research Department established that the primary cause of the corrosion was moisture inside the hermetic encapsulation. This phenomenon is still under investigation[12]. Although this problem also appeared to be a temporary manufacturing deficiency, it was recognized that there was a need to strengthen further the procurement specification for the MOS integrated circuits. Therefore, the D4000 specifications have been amended in respect of control of the internal atmosphere of the encapsulation.

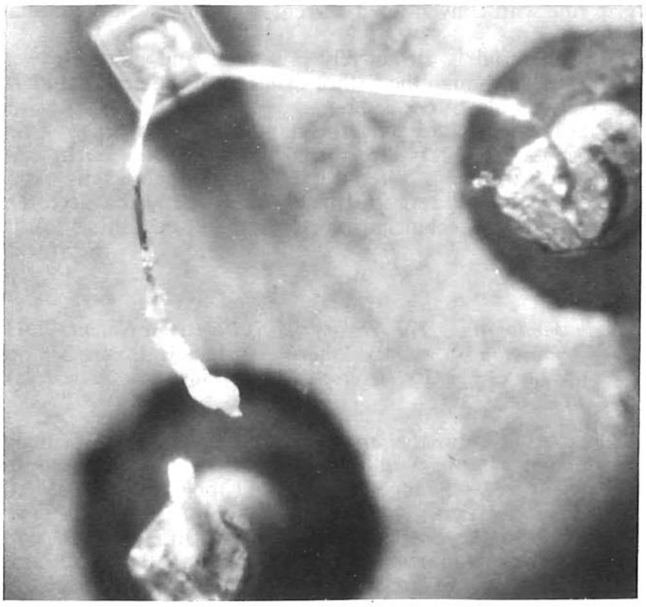
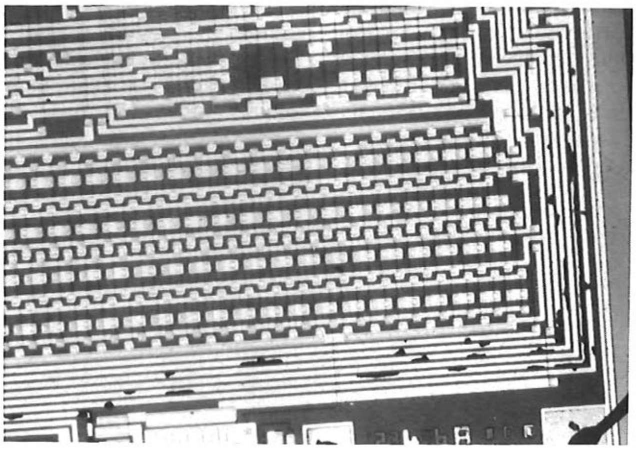
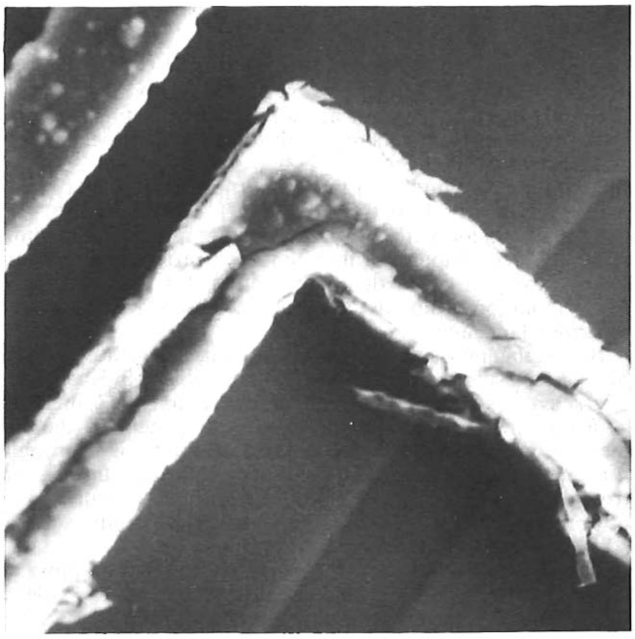


FIG. 13—Corrosion of transistor bond wire by residual plating-fluid



(a) Corrosion of interconnexion tracks



(b) Corrosion of single track

FIG. 14—Corrosion of aluminium metallization on MOS chip

CONCLUSIONS

The performance of the electronic regenerator, assessed over a period of 7 years, has fully justified the decision to proceed with the development at a time when there was a high element of risk. The electronic regenerator provides a much better quality of service than the electro-mechanical type it replaces; maintenance requirements and costs are minimal and there are clear indications that the operational life of the electronic regenerator will exceed the service requirements by a considerable margin.

Procurement of supplies of regenerators using a performance-based specification, rather than a detailed one for a BPO standard type, has proved satisfactory and expedited the development of improved designs. However, these had to be separately assessed and validated against specificaton requirements—a costly and time-consuming procedure which, with competitive procurement, may have to be repeated. It is unlikely however, that a new design will be offered for this particular item due to the need to complete the programme quickly and the ultimate quantity involved.

Dormant faults, which had existed and had been tolerated for many years by Strowger equipment, caused considerable damage to regenerators, complicated design validation tests and adversely affected service performance. This highlights the need for a critical examination of existing apparatus and circuits during design of any new electronic device to be used in close association, so that potential hazards can be identified and, if necessary, catered for in the new design.

In view of the rapid rate of technological change, it is essential that, in any microelectronic project using custom-designed chips in a limited production run, arrangements should be made to ensure that sufficient supplies of integrated circuits will be available for future maintenance.

ACKNOWLEDGEMENTS

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Book Reviews

Basic Electronics (Fourth Edition). B. Grob. McGraw-Hill. xv + 768 pp. 559 ills. £7·90.

Unexpectedly, out of the 32 chapters, only 4 (with, possibly, part of a fifth) are about electronics. It is a pity that the title is misleading: the book is actually an extraordinarily good introduction to circuit theory, with some electrical technology and electronics included.

Assuming absolutely no previous knowledge of electricity, the book leads us into the subject in a carefully paced and explicit discussion with not a trace of pomposity. Each short self-contained chapter forms a unit in a progressive learning system that is quite detailed enough for private study. Esoteric jargon is not used; the concepts are well expressed in simple language.

By keeping mathematics to a minimum, the author protects his basic-textbook theme, and preserves an independence of associated studies; the topic of complex numbers is included as a unit in the learning system. The treatment of the elementary material (which covers most chapters) is thorough; for the more complicated topics (for example, filters), the treatment is elementary. Physical aspects and colour coding of components are included, as are practical points such as soldering and the use of meters and tools.

The chapters on electronics are less thorough than those on circuitry, and here the treatment justifies the book's title; a lot of ground is covered, though not in very great depth. Yet this is consistent with the rest of the book, in that it serves as an excellent vehicle for initial studies in this field.

Summaries, objective self-examinations, essay questions and problems conclude most sections.

There is some American influence discernible (for instance, in the chapter on 60 Hz power lines), and, for determining the magnetic polarity of a solenoid, a left-hand grip rule assuming true electron flow is used, instead of the right-hand grip rule with conventional current flow that is more familiar in the UK.

The material is attractively presented and generally well illustrated, although the author defies his own list of standard circuit symbols on occasion.

Presumably by accident, the standard and coverage of the book makes it suitable for the early levels of the Technician Education Council's Telecommunications Technicians Certificate programme. Indeed, I would recommend that lecturers in any first-year technician course should inspect this book.

B. Stagg.

Angle Modulation: The Theory of System Assessment. J. H. Roberts, B.SC., F.I.M.A. Peter Peregrinus Ltd. xv + 278 pp. 45 illus. £12·75; overseas (excluding the Americas): £14·90.

The specialist in the mathematical treatment of angle-modulated systems would probably find this book useful because it treats a range of important topics concerned with angle modulation. Chapters on noise, echoes, interference, amplitude-modulation-to-phase-modulation conversion, threshold-extension devices in analogue systems, and digital systems are included. A unified theory based on the characteristic function is used.

The book is difficult reading for the non-mathematician.

M. C. Davies.

A Standard Code for Radiopaging

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UDC 621.396.6: 621.3—182: 621.396.1

This article describes the development of a standard code format for radiopaging services. The code is to be adopted for use in the London radiopaging system and the proposed British Post Office (BPO) national radiopaging system. Manufacturers and their professional associations were invited to meet and advise the BPO as an open group during the course of its development. The code format was designed such that it can be easily adapted for use in almost any environment where a radiopaging service is required. Therefore, it can truly be described as a standard code format, and it may be freely utilized by other administrations and organizations.

INTRODUCTION

To date, the world market for wide-area radiopagers has been sufficient to support only a few manufacturers and most of these have invented their own radio-signalling code to suit their particular design philosophy. Thus, operators of radiopaging services (for example, the British Post Office (BPO)) are faced with the prospect of being limited to a single source of supply for pagers or of making limited, *ad hoc*, arrangements to deal with the situation. The BPO public radiopaging service, recently opened in London, has been designed with special features to operate with a mixture of types of paging codes. (The London radiopaging system will be described in the January 1979 issue of this *Journal*.) While this method is initially satisfactory (although expensive), only a few types of code format could be accepted by the BPO before the waste of transmission time, inherent in changing from one type of code to another, became excessive. Further, it is highly likely that the BPO will implement a national radiopaging scheme which will use time division of the radio channel to achieve national coverage of the service; in such a scheme, avoidance of time wasting would assume great importance.

The BPO was therefore faced with the option of arbitrarily limiting the number of types of code format to be employed in the national system, or of developing a standard code format. Manufacturers and their professional associations were invited to meet and advise the BPO as an open group on matters affecting such a standard. At that time, the European Selective Paging manufacturers' Association (ESPA) had also been engaged on a similar task with a view to creating their own standard code and they welcomed the BPO initiative and accepted the invitation. Also, the Electronic Engineering Association sent a representative; thus, manufacturers who were unable to attend were represented at the meetings. The group thus formed was entitled the *Post Office Code Standardization Advisory Group* (POCSAG).

OPERATIONAL REQUIREMENTS

Prior to the establishment of the POCSAG, the BPO had drawn up a list of requirements for a standard code. ESPA had done likewise and, when the 2 lists were compared, the similarity was remarkable. Thus, within the POCSAG, there was no difficulty in reaching agreement concerning the principal operating requirements. The major requirements of a standard code format that were identified initially are as follows.

Code Capacity

The code capacity should accommodate 1 million pagers with up to 4 addresses per pager. (The preferred number of users in the most popular zones of a UK national system was at least 120 000.)

Paging Rate

It was necessary that the paging rate should be greater than 6 calls/s, so a target of 10 calls/s was chosen.

Radio Frequency

The 153 MHz band was selected for use in the UK, but it was established that the code should be usable on any radio frequency that might be allocated to radiopaging.

Radio-Channel Bandwidth

A radio-channel bandwidth of 25 kHz has been allocated to the BPO radiopaging service. The code should, however, be usable in a 12·5 kHz bandwidth radio channel.

Modulation

Any type of modulation was considered suitable, provided that it contributed to a cost-effective solution.

Lost-Call Rate

A lost-call rate of less than 2% at the edges of any proposed transmission area, or typical urban radio environment, was considered acceptable.

False-Call Rate

It was agreed that the false-call rate due to unrejected transmission errors should not exceed 1 in 10^8.

Paging Delay-Time

For the great majority of calls, the time from the receipt of the last digit in the control terminal to the completion of transmission in all zones required should be less than 2 min.

Messages

It was concluded that the ability to convey messages (for example, the name or telephone number of the call originator) was a feature desirable for future use, but that the provision of this feature should neither add appreciably to transmission costs, nor add to the cost of pagers designed to receive an address only.

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† Telecommunications Development Department, Telecommunications Headquarters

Single-Channel Working

To provide national coverage using a single radio-channel was a necessity. (Information transmitted in one zone may be different from information transmitted in an adjacent zone.)

BASIC SYSTEM ORGANIZATION

Before any specific code format could be considered, those aspects of a radiopaging system which could influence performance were assessed against the basic operational requirements of a standard code. As a result of this assessment, it was possible to narrow considerably the subsequent work in determining specific features of the code format.

Bit Representation

To satisfy the joint requirements of code capacity (4×10^6) and paging rates, it was considered that only binary-digital codes needed to be studied. In addition, it was recognized that binary-digital techniques could greatly simplify transmission network design and maintenance. Thus, codes such as the CCIR† 5-tone were rejected.

Three bit-encoding systems were studied, direct frequency-shift-keying (FSK), biphase FSK and 4-phase FSK. Direct FSK was chosen for economic and technical reasons; for example, the transmitter line delay-equalization requirement in simultaneous transmission schemes is minimally onerous.

Simultaneous and Sequential Transmission

Tests conducted by the BPO indicated that, for a given data signalling rate and receiver, there was insignificant difference in performance between simultaneous or sequential operation of adjacent transmitters. However, simultaneous transmission is more suitable for heavily-populated areas and sequential transmission is best suited for sparsely-populated areas. Further studies indicated that a mixture of the 2 transmission modes might be desirable; thus enabling the benefit of each system to be gained, according to local conditions. For this reason, it was decided that the standard code should be designed to be suitable for both types of transmission mode.

Receiver Power-Supply

It was recognized that the code format should enable battery-saving techniques to be incorporated in the design of receivers. (A BPO specification calls for at least 13-weeks operation from a single set of dry batteries.)

Number of Bits per Call

To achieve the highest calling rate for a given data signalling rate, the code should use the minimum number of bits consistent with reliable signalling and a low false-call rate.

CODE SELECTION

A review was made by the POCSAG of all likely codes known to have been adopted by manufacturers or Postal, Telegraph and Telephone (PTT) administrations who were operating public radiopaging services. None of these existing codes was found to meet all the basic requirements and yet be fully acceptable to the majority of members. It was therefore necessary to develop a new code format. Several original code formats were proposed and rejected.

Eventually, Mr. P. Mabey, of Philips Research Laboratories, conceived the basis of the standard code format, and his proposal was welcomed enthusiastically. Some small modifications to improve its performance characteristics and to increase its capacity and battery-saving capabilities have since been included.

FORMAT OF THE STANDARD CODE

Codewords

In the standard code, every pager address is represented by a transmission codeword. Two special codewords are reserved for common signalling purposes such as synchronization. Other codewords are provided for future uses, such as the transmission of a caller's telephone number or name. In all, it has been found possible to cater for a population of over 2-million pagers, each with 4 addresses, thus exceeding the target by 100%. This capacity could be useful if several countries decided to transmit on a common channel-frequency. Each pager address therefore consists of 21 pager-identity bits and 2 address or function bits.

Types of Codewords

Each codeword is derived from the 31, 21, 2 (plus parity) Bose-Chaudhuri-Hocquenghem (BCH) error-correcting code. Use of this code will allow receivers correctly to identify codewords containing up to 2 bit errors and yet reject all received codewords with 3 bit errors. (There is no specified requirement in the POCSAG recommendations that receivers must discriminate in this respect.) The structures of address code words and message codewords are shown in Fig. 1.

Synchronization Codeword

The synchronization codeword, which may not be used as an address codeword, is given below:

0 1 1 1 1 1 0 0 1 1 0 1 0 0 1 0 0 0 0 1 0 1 0 1 1 1 0 1 1 0 0 0

Address Codeword

In the structure of an address codeword (see Fig. 1), bit 1 is always a zero. This distinguishes it from a message codeword.

Bits 2–19 are address bits corresponding to the 18 most significant bits of a 21 bit identity assigned to the pager. The 3 least-significant bits are not transmitted, but serve to define the frame in which the address codeword must be transmitted (this aspect will be discussed later in the article). Hence, the total number of identities is 2^{21} (over 2 million).

Bits 20 and 21 are the 2 function bits that are used to select the required address from up to 4 assigned to a pager. Hence, the total number of addresses is 2^{23} (over 8 million).

Bits 22–31 are the parity-check bits, and the final bit (bit 32) is chosen to give even parity.

Message Codewords

A message codeword always starts with a 1, and the message always follows directly after the address codeword.

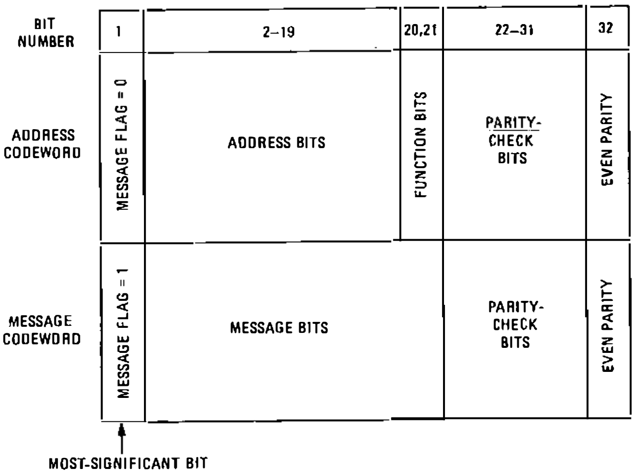

FIG. 1—Codeword format

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† CCIR—International Radio Consultative Committee

Message codewords have 20 message bits (bits 2–21 inclusive) and these are followed by the parity-check bits. The structure of a message codeword is shown in Fig. 1.

Idle Codeword

In the absence of an address codeword or a message codeword, an idle codeword is transmitted. The idle codeword is a valid address codeword, which must not be allocated to pagers. The idle codeword is

0 1 1 1 1 0 1 0 1 0 0 0 1 0 0 1 1 1 0 0 0 0 0 1 1 0 0 1 0 1 1 1

Transmission Format

In the control arrangements of a paging system, it is convenient to store the calls gathered over a period, say of 2 min, to queue the calls and then transmit them in batches. This minimizes the on-time of transmitters and allows time division of the radio channel. In the standard code, each transmission consists of a preamble followed by batches of complete codewords, each batch beginning with a synchronization codeword. The format of the signal is shown in Fig. 2. Transmission ceases when there are no further calls.

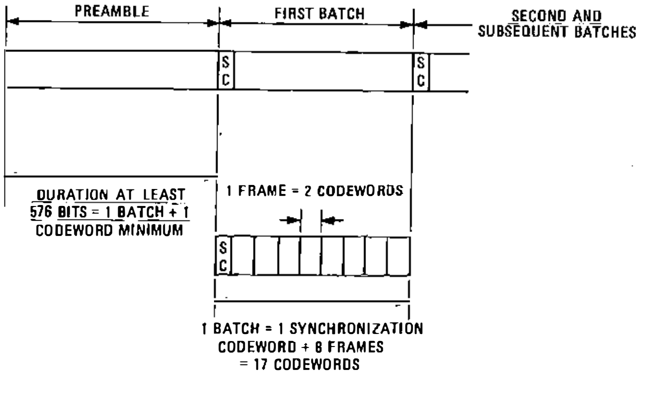
Preamble

Each transmission starts with a preamble to enable conservation of battery power by the use of sampling techniques and to allow easy acquisition of bit synchronism by the pagers. The preamble is a pattern of reversals, 101010 . . . , repeated for a duration of at least 576 bits; that is, the duration of a batch, plus a codeword. Immediately after transmission of a preamble, the first batch of codewords is transmitted.

Batch Structure

Codewords are transmitted in batches; each batch comprises a synchronization codeword followed by 8 frames, each containing 2 codewords. The frames are numbered 0–7, and the pager population is similarly divided into 8 groups. Each pager is allocated to one of the 8 frames according to the 3 least-significant bit of its 21 bits identity (for example, 000 identifies frame 0 and 111 identifies frame 7) and will only examine address codewords in that frame. Therefore, each pager's address codewords must be transmitted only in the frame that is allocated to those codewords. However, since the pager need only be turned on for its particular frame, battery saving would be possible during the other frames.

Message codewords, for any receiver, may be transmitted in any frame, but will immediately follow the associated address codeword. A message may consist of any number of codewords transmitted consecutively and may embrace one or more batches, but the synchronization codeword must not be displaced by message codewords. Message termination is indicated by the next address codeword or idle codeword. In any frame, an idle codeword will be transmitted whenever there is no address codeword or message codeword to be transmitted.



SC—Synchronization codeword

FIG. 2—Transmission format

BPO APPLICATION OF THE STANDARD CODE FORMAT

The proposed BPO national paging system might need a capacity of up to $1 \cdot 6 \times 10^6$ discrete paging-numbers; that is, 10-digit paging dialling codes. The code format described in this article will be adopted for the BPO radiopaging service.

Basic Characteristics of the Radio Transmission

The standard code format is suitable for transmission by present or any foreseeable transmission media, provided that suitable pagers are available. In the UK, the characteristics of the transmission carrying the standard code are given below. The reasons for the choice of these characteristics may be found in the final report of the POCSAG. Other users could vary these characteristics to suit their convenience without alteration of the basic code format; this aspect is discussed later in this article.

Transmission Rate

The transmission rate will be 512 bit/s with a tolerance better than 1 part in 10^5.

Modulation

The modulation applied to the transmitter will be direct FSK—non-return to zero (NRZ). The nominal system frequency deviation will be $\pm 4 \cdot 5$ kHz. A positive frequency deviation will represent binary 0, and a negative frequency deviation will represent binary 1.

Transmitter Frequency Tolerance

The tolerance on the frequencies of the transmitters will not exceed 5 parts in 10^6. (This limit is applicable only to transmitters used singly or in the sequential mode.)

Modulation Rise-Time of the Transmitters

The modulation rise-time of the transmitters is defined as the 10–90% frequency transition rise-time; this will be 250 μs $\pm$ 25 μs.

Characteristics for Simultaneous Operation of Transmitters (Quasi-Synchronous Mode)

In a simultaneous transmission system, the following parameters have to be carefully controlled to minimize the effects of destructive interference in the radio environment.

Carrier Frequency Offset Limits

The carrier frequencies of the individual transmitters will be on the nominal frequency or off-set by 500 Hz or 1000 Hz. The tolerance on these frequencies will be ±50 Hz.

Line Delay Differential

Transmitters receive transmissions through lines of various lengths, hence, line delay equalization will be employed. The maximum line delay differential between 2 adjacent transmitters in the same zone will, after equalization, be 250 μs.

Effects of Telegraph Distortion

The magnitude of the time difference due to telegraph distortions, observed when any 2 adjacent transmitters are compared, will not exceed 10% of an element exclusive of any time differences introduced by unequal line delays, i.e. 195 μs at the given transmission rate.

System Description

The proposed BPO national paging system will make use of the flexibility that may be obtained from control terminals that are based on mini-computers. The mini-computers will carry out the functions of accepting and checking input signals, of encoding these signals and of managing the system.

Up to 16 control terminals may be used, each containing the files of up to 10^5 paging numbers. The control terminals will be interconnected by a network of data links to permit exchange of information and system synchronization.

To provide national coverage, the UK will be divided into about 40 contiguous paging zones. Customers may contract for service in any combination of zones. Initially, a single radio channel will be employed. Thus, to avoid co-channel interference, the zones will be organized into 3 sets and the paging transmissions will be sequenced such that adjacent zones do not transmit simultaneously. When traffic demands, a second radio channel can be added to the existing transmitter network.

Paging calls will be routed by the public switched telephone network (PSTN) to the nearest control terminal which, if necessary, will relay the paging number to the control terminal that holds the file for that paging number. The file will be accessed to provide the address code of the paging receiver to be called and the zones required. This data is then sent to the control terminals that control the zones required.

PERFORMANCE SIMULATION TESTS

It was considered that any recommended code should first be tested for compliance with the requirements for signalling reliability and false calling; the only method of test that was considered valid was a simulation test. A digital computer was used to simulate the functions of the code format generator and decoder and the effects of the various transmission paths, including line connexions. It was not possible to test the code under every condition that might be encountered, but the main tests were made under conditions which simulated real operational conditions. The tests were carried out not only on the candidate code, but also on another code whose performance in the field was known. This latter code was used as a benchmark and served for calibration of the simulator.

To test the impairment effects of noise, 2 types of noise signal were simulated. The first was random noise, simulated by a method which used a random-number generator. Secondly, a recorded error-pattern, that is, the modulo-2 (exclusive-OR) difference between the transmitted and received versions of a pseudo-random bit sequence, was available from tests being made for the BPO in Birmingham area. This data was obtained from a system using direct FSK and, hence, was directly applicable to the type of system being considered for radiopaging. Sample error vectors were obtained which, in total, amounted to 1 million bits of data.

During the preliminary work leading to the simulation tests, it became obvious that the mechanisms of a decoder had a significant effect upon the performance of the code. The original simulated decoder was improved in performance, and subsequent investigation showed that the code format, in conjunction with a suitable decoder, could easily surpass the POCSAG requirements. The results shown in Table 1 were derived from the simulation which used the measured error-rate data obtained from Birmingham. These are representative of a paging receiver under severe reception conditions, and show that there is good reason to have confidence in the standard code format.

TABLE 1

Performance Simulation Results

Extent of each Transmission	Confidence Limits	Decoder Performance
One batch per Transmission	95% lower success-rate limit	98·91%
	95% upper falsing-rate limit	$7{\cdot}38 \times 10^{-11}$
Four batches per Transmission	95% lower success-rate limit	98·76%
	95% upper falsing-rate limit	$6{\cdot}11 \times 10^{-11}$
Sixteen batches per Transmission	95% lower success-rate limit	98·67%
	95% upper falsing-rate limit	$5{\cdot}98 \times 10^{-11}$

OPTIONAL USAGE OF THE STANDARD CODE-FORMAT

This article has described the standard code format and its proposed application by the BPO. However, other administrations and users might require different facilities. The code has been designed such that it can be easily adapted for use in almost any realistic paging environment and can thus be truly described as a standard code format. The following options might be exploited by paging-receiver or system designers for implementation of the standard code to other radiopaging systems.

Battery-Saving Option

The coding format caters inherently for a battery-saving type of receiver.

Message Facility

The message facility is an optional feature of the system. A convenient method of introducing messages would be by the use of Telex, Datel, or any other convenient machine language via the PSTN. Alternatively, operators could translate from human to machine language. Where switched telephone networks provide automatic transmission of a caller's telephone number, such transmissions could be of use in those situations where that information would provide sufficient message content.

Success Rate and False-Call Rate

The code format specified has a minimum Hamming distance[†] of 6 bits. This implies that up to 2 bit errors can be corrected with only a small probability of a false call resulting, but with an enhanced success rate compared with the case of no error correction. The possibility exists of improving the false-call performance by accepting fewer bit errors. The penalty for this would be a lower success rate. However, the success rate could be improved by repeating transmissions where and when the traffic allows, at the expense of a higher false-call rate.

[†] The Hamming distance between 2 codewords can be defined as the number of components by which they differ; for example, if
u = 1 0 0 1 0 1 1 0 0 0 1, and
v = 1 1 0 0 1 0 1 0 1 0 1
then, d(u, v) = 5 = Hamming distance

Sequential or Simultaneous Operation of Transmitters

The standard code format is suitable for systems in which the transmitters operate simultaneously or those in which they operate sequentially, or even systems in which some groups of transmitters operate sequentially but others operate simultaneously. Where the traffic is light, sequential operation would enable transmitters with relaxed frequency tolerances to be used, but the rate at which paging calls could be transmitted would be reduced compared with simultaneous operation.

Simultaneous operation would permit the paging calls to be transmitted quickest but, in this case, the transmitters would need to have improved frequency tolerances and the modulating signals applied to adjacent transmitters would need to be delay equalized to within close limits (of the order of a quarter of a bit).

Group Calling

The BPO radiopaging service caters for common calling of small groups of users by sequentially transmitting the address codewords assigned to the individual members of the group. For larger groups, this method could be very time consuming. Alternative methods for large groups could be used which involve the reservation of a small proportion of the available address codewords. For example, some easily recognizable codewords related by their parity-check bits, may be reserved.

Adaption to Smaller Systems

The standard code format can be adapted for use in smaller systems in various ways. Three suggested methods are given, all of which will increase pager sensitivity.

Use of Smaller Code Sets

The POCSAG code is based on the 31, 21, 2 (plus parity) BCH code, which gives a capacity of 2 million pagers, each with 4 functions. By using only those codewords found in the 31, 16, 3 or 31, 11, 5 (plus parity) BCH codes, smaller code sets (with increased Hamming distances) can be realized; these codes, each having up to 4 address functions, could support radiopaging systems having 64 000 and 2000 subscribers respectively. If standard receivers are then used, the false-call rate will be markedly improved. Alternatively, receivers able to accept a larger number of errors could be used. Hence, increased sensitivity and/or a reduced false-call rate could be achieved.

Paging-Call Repetition

Repetition of paging calls would markedly increase the success rate of receivers, but would also have an adverse effect on the false-call rate unless the number of acceptable errors was decreased.

Reduction of Bit Rate

Reducing the bit rate (for example, to 256, 128 or 64 bit/s) would increase the sensitivity of the receivers. The clock rate of the receiver would need to be programmable to achieve this.

Any one or any combination of these methods may be used to increase system efficiency. It is suggested that any of the methods can be realized with a negligible increase in LSI decoder chip size and might be set by simple programming.

CONCLUSIONS

Over a period of some 2 years, the POCSAG studied the requirements for a standard radiopaging code. In the course of this work, a number of proprietary code formats, already in use, were studied but, eventually, it was preferred to devise a purpose-built code. The studies indicated that cyclic block codes of the BCH form were satisfactory and, of these, the family of 31-bit codes (plus parity) were the most suitable. While these codes have a limited capacity, this problem was relieved by using a multiplexing technique, which also offers an inherent battery-saving possibility.

Studies were made of the effect of the line and radio transmission path characteristics in respect of the rate at which binary signals could be transmitted. It was concluded that the land line links connecting the paging control centre to the transmitters would limit the transmission rate, particularly in the overlapping service areas of a system where the transmitters were operated simultaneously. However, even in such conditions, a rate of 512 bit/s was found to be easily attainable.

A set of target objectives for a wide-area code, agreeable both to numerous manufacturers and the BPO, was derived and studies were directed to meeting these objectives. By application of the principles described, a digital (binary) code was devised which amply meets these objectives. Its properties are summarized below.

(*a*) The standard code is suitable for use in a 25 kHz (or a 12·5 kHz) channel in any likely frequency band. Standard radio practices need not be violated. Cross calling between this and other radiopaging codes is likely to be minimal.

(*b*) A user capacity of over 2-million subscribers, each having 4 address functions, is available. Although this capacity is twice as large as required, only minimal savings would have been achieved by restriction to a smaller capacity. The large capacity might possibly simplify international use of the code.

(*c*) The code is suitable for simultaneous (quasi-synchronous) or sequential transmission from multiple transmitters. Both simultaneous and sequential transmission may be used in the same coverage scheme. In simultaneous schemes, a total of 2 positive and 2 negative offsets and the nominal frequency should be sufficient for total coverage, the unit of offset being approximately numerically equal, in hertz, to the transmission rate in bit/s; for example, 500 Hz offset at 512 bit/s.

(*d*) Messages, such as the caller's name or telephone number can be transmitted. The use of this facility will have to await the development of suitable pagers, control equipment and means of message input, but these problems will undoubtedly be overcome.

(*e*) At a signalling rate of 512 bit/s the calling rate is 15 paging-calls/s but less when messages are transmitted. The maximum rate may be necessary to cover very large cities of about 10-million people.

(*f*) Two battery-economy features are provided, these being concerned with economy when transmission is absent or when transmission is present, irrespective of the transmission being of the standard code format or some other.

At a transmission rate of 512 bit/s, the allowable line delay-differential between adjacent transmitters is at least 250 μs and possibly as much as 440 μs. Allowable differentials of this order permits optimum planning and maintenance of the transmission scheme, irrespective of whether it is simultaneous or sequential.

The code may be received by many different designs of decoder and there is no preferred design. The performance simulation tests conducted by the BPO have indicated that it is not difficult to design receivers which would achieve more than 98% success rate at design sensitivity and yet experience a false-calling probability of less than 10^{-8}. It is emphasized that the design sensitivity field relates to poor reception conditions; which would be experienced only at the edge of a service area; the vast majority of receivers will be operational under better reception conditions and will yield much better results.

Benefits and Freedom of Use

Many paging-system operators, especially PTTs, may be faced with the same difficulties as confronted the BPO. Code standardization and the availability of conforming pagers from a number of manufacturers could generate increased confidence amongst these users by removing fears connected with single sourcing. Also, a standard code should give impetus to the development of appropriate semiconductor devices and bring about the benefits of large scale production and component harmonization, thus reducing pager costs and increasing the market.

Prospective manufacturers may note that, since the code is a new one, no manufacturer has any established position in its use. There are no patent rights on the code format, but neither is there any restriction on patenting particular reception or decoding methods.

Since a set of requirements for wide-area paging have been derived and a code agreed which makes it possible to meet these requirements, it is concluded that the POCSAG has met its objectives. All those who have been concerned with this study have become convinced that long term benefits are to be gained by agreeing on a standard code. It is now in the hands of manufacturers to implement the realization of pagers conforming to the code.

The POCSAG Report

The report of the POCSAG studies will be available shortly to PTTs, radiopaging operatives and pager and component manufacturers, on application to the authors.

ACKNOWLEDGEMENTS

The authors would like to thank all the manufacturers and their associations who so readily participated in the development of the POCSAG standard code, both directly and indirectly. Thanks are also given to all their colleagues in the BPO who contributed throughout the course of the POCSAG studies.

Number Changing in the Portsmouth Area

F. F. MAKIN†

When it was decided to change the existing Portsmouth ring-and-core arrangement to a number-group linked-numbering scheme, as in many large conurbations, there was practically no freedom to manoeuvre because prime levels were already largely in use. Normally operations are so phased that released codes are first intercepted for a period, and then connected to number-unobtainable tone well before the level is used for a subscribers' numbering range elsewhere in the charging group.

Recently, 12 000 numbers at Havant were changed to their ultimate 6 figure range, together with the rationalization of several short access codes. The exchange previously had mixed 4 and 5-digit numbering schemes, which added to the complexity of the change by needing more than one prefix (for example, Havant 7*XXXX* became 47*XXXX* and 47*XX* became 4847*XX*). Customers calling Havant numbers were obviously confused for some days, even though the single changed-number announcement (CNA) covering both prefixes, had been worded as simply as possible.

The Havant change-over, which took place early on a Monday morning, was smoothly accomplished, despite the complications of restricted line-plant availability. However, a hectic few days followed, putting a tremendous strain on the CNA equipment; so much so that an engineering team was set up at short notice to construct additional access relay-sets. This expedient action certainly helped to contain the situation in which customers were variously expected to dial their usual code followed by the new Havant number, or use a new code and number, or merely dial only the new number. As a result, the prefixes used to change the Havant numbers were dialled in almost every conceivable position in various dialling sequences, with inevitable wrong-number and no-tone effects. To overcome these shortcomings, a scheme has now been evolved locally so that separate CNAs can be connected to the individual levels serving the 4 and 5-digit numbering schemes, using 2 or 3 simple announcements in place of one combined announcement.

At the same time, Fareham, in a dependent charging group on Portsmouth group switching centre, had 14 000 number changes but a different approach was possible. The change took place on a Sunday morning and gave rise to no problems worth mentioning, due to adopting dual access to called numbers via both the old and new codes and numbers. CNA was introduced to late-choice outlets and then gradually extended to earlier-choice outlets, first on own-exchange calls and later on incoming calls—a strategy to which the public responded well.

It has been found most helpful in the administration of the work and in the service given to the public, to use a time delay to free old codes from persistent use, by introducing incoming linked-numbering working at the time of number change, with its outgoing counterpart following at least 6 months later. Effecting these changes in the existing Strowger environment has the major advantage of affording positive control on implementation dates, especially where a sizeable programme is involved. The cost effectiveness of linking number changes to equipment modernization must play its part, but there are many instances where a little additional expenditure on a Strowger exchange now would permit a simpler, and hence cheaper, change-over when modernization takes place.

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† Portsmouth Telephone Area

Highland Telegraphs, 1870–72

D. MacDONALD†

UDC 621.394 (091): 621.394 (412)

FOREWORD

This article reproduces a prize-winning entry to the Institution of Post Office Electrical Engineers' 1976/77 essay competition. The author reviews events during a period of great significance in the history and growth of telecommunications in the UK—the nationalization of the telegraph service in 1869 and the 'Highland and Islands' telegraph scheme of 1870.

Details of entry to the IPOEE 1978/79 essay competition are given on p. 208 of this issue.

Editor

INTRODUCTION

The scheme to provide an electric telegraph service to the Highlands and Islands of Scotland during the period 1870–72 greatly fired the public imagination, not only because of the obvious commercial advantages of the service or because the populace could see the reality of it in the form of poles and wires, but because during this period any introduction of a technical innovation, even one of 30 years' standing, was welcomed by the forward-looking Victorians as something to be added to their list of achievements.

Because of the local interest in the scheme, which provided almost complete telegraphic cover, and because of the national interest engendered by the transfer of the telegraphs from the private companies to the control of the Post Office, there is an abundance of literature dealing with this period. Therefore, it has been comparatively easy to gather accounts of the progress of the 1870–72 Highlands and Islands scheme. However, to present a précis of the facts while maintaining chronological continuity, and also to capture some feeling of the atmosphere of the time, has proved difficult.

It is realized that an effort may be required on the part of the reader to unite these fragmented statements into a coherent chronicle of events, but if any of the separate facts reported provide a topic of interest or information, then the article will have served a purpose.

Several proposals had been forwarded in the 1850s for the public control of electric telegraphs, but in Edinburgh, in 1865, a more determined campaign was launched by the Chamber of Commerce and the newspaper publishers to replace the systems of the private telegraph companies by a state monopoly. The application of a standard charge for passing messages irrespective of distance (as existed in the Postal Service) offered a great advantage to the newspaper interests centred outside London, and it was mainly due to the sustained pressure of these newspapers over a period of 3 years, that the campaign succeeded.

It can be imagined that the "private enterprise lobby" in Parliament was very strong since, after several unprofitable years, a steadily increasing traffic from 1867, coupled with an increase in tariff for local telegrams from sixpence to one shilling for 20 words, was yielding substantial profits and, in some cases, dividends of 10%. However, on 31 July 1868, an Act of Parliament was passed that laid out the fundamental concept of State ownership. The Act stated that:

> "*Whereas the means of communication by electric telegraphs within the United Kingdom of Great Britain and Ireland are insufficient, and many important districts are without any such means of communication. And whereas it would be attended with great advantage to the State as well as to merchants and traders, and to the public generally, if a cheaper, more widely extended, and more expeditious system of telegraphy were established in the United Kingdom of Great Britain and Ireland, and to that end it is expedient that Her Majesty's Postmaster General be empowered to work telegraphs in connection with the administration of the Post Office*".

This left only the details of compensation and the method of raising the money to be resolved.

In 1869, after exhaustive negotiations, Mr. Gladstone, the then Prime Minister, announced agreement. The 1869 Act incorporated the Act of 1868. The total compensation of £5 715 048 8s 11d was divided among 6 companies and, according to some of the recipients, was "generous to a fault".

THE TRANSFER TO STATE OWNERSHIP

At the close of duty on Friday, 5 February 1870, the State formally took over electric telegraphs and, on the following day, opened a public service from 2488 offices, the majority of which were at railway stations. The plant involved comprised 48 378 miles of land lines, excluding railway wires, and 1622 miles of submarine cable and all associated apparatus. The new Telegraph Department also employed many of the private company employees or, where redundancies occurred, paid adequate compensation.

By 1872, the number of telegraph offices had doubled to 5000, the number of telegrams increased from 10 M to 15 M and the number of words transmitted by the press increased from 2 M to 220 M.

To comply with the spirit of the 1868 Act in providing a public service, it was necessary to extend lines that would be expensive and slow to show a return on capital (to such places as Stornoway and Ardnamurchan), in addition to the comparatively less-costly exercise of providing service to locations close to existing lines. To this end, Post Office officials had, for some time previous to the transfer, been surveying the existing systems and planning the extensions of new ones. The planning and estimating of the new lines was

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helped by the almost-completed 6-inch and 25-inch-to-the-mile ordnance survey of most of Great Britain. The ordnance survey was being carried out by army personnel from the Royal Engineers.

That this survey was still in progress was probably an advantage, since the men who were to construct the new lines were from the same corps as the cartographers, and it can be assumed that there was close liaison between them.

Let us take a look now at the Highlands, the men, and the project.

SERVICE PRIOR TO 1870

Northern Scotland, like the rest of Britain, was served mainly by telegraph lines built along railway tracks. The railway companies had either leased the lines to the private companies, or were using them themselves for both business and railway signalling. However, not every railway station offered public access to the system; such stations as Muir of Ord, Kildary, Invershin or Lentran were not opened for telegraph traffic until the end of 1870.

The west of Scotland from Oban northwards, was completely devoid of any telegraphic communications. The extent of the telegraph service in Scotland prior to 1870 can be seen from Fig. 1, which shows the network that existed and the routes that were provided in the period 1870–72. In the east, a line had been constructed in 1868 by the Electric and International Telegraph Company from the then northernmost railway station of Golspie, via Helmsdale and Dunbeath to Wick and Thurso. A submarine cable had been laid via Hoy to Kirkwall and another to Shetland. The Shetland cable, however, was not in use at the time of the transfer as it had been badly strained by strong currents and, because of bad weather, the repair ship S.S. *Hoyle* was having difficulty in retrieving the cable for repairs.

Prior to the transfer, the Post Office had been augmenting the existing lines from Edinburgh to the north; a payment of £40 000 had been made to the Highland Railway Company, so that, by February, 1870, the telegraph service had reached Kingussie. The telegraph service had reached Inverness from the south by way of Aberdeen but, since the opening of the Aviemore to Grantown railway in 1863, it had also reached Inverness via Forres.

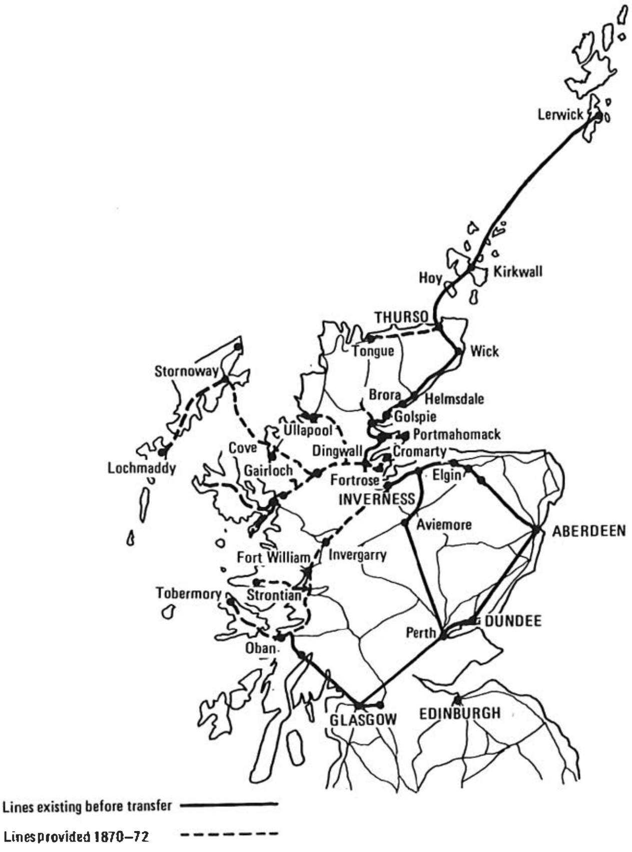

FIG. 1—Telegraph routes at 1872

FIG. 2—The Post Office and local staff at Drumnadrochit

In preparation for the opening of business, the Post Office had set aside separate offices attached to Post Offices in the Highland Counties; for example, at Dingwall and Ardgay in Ross-shire, and at Kingussie, Beauly and Inverness in Inverness-shire. Thus, in November 1869, the first Post Office wires to be installed in Inverness were run from the old terminal at the railway goods shed, over the roof of Smith the hairdresser to a new office in the Post Office, High Street.

Messages were also to be taken at existing offices in railway stations as before, until new arrangements could be made. Message forms were sold individually or in bundles of certain quantities and, for the standard number of 20 words, had an embossed shilling stamp. For an increase in the number of words, adhesive stamps were used at the rate of threepence for every additional 5 words or fraction of 5 words. There was to be no charge for delivery within one mile of a Post Office but, for the fast rate of delivery beyond this, the charge was to be sixpence per mile.

On Saturday, 6 February 1870, the 30% increase in business over the country generally was surpassed in the north of Scotland by a 100% increase which, in Inverness, was maintained even during the following Monday. This was to give rise to a hope that the standard rate might be reduced to sixpence for 20 words, but more important perhaps, was the fact that the increase in demand for the new service was such that the existing system was unable to cope.

Photographic evidence of the period is somewhat scarce, however, the view of the Drumnadrochit Post Office (*circa* 1890), shown in Fig. 2, is typical of the Post Offices of the day.

SOME REASONS FOR THE INCREASE IN DEMAND FOR SERVICE IN INVERNESS

Since Cromwell's time, there had been no appreciable increase in the population of Inverness but, in the 1870s, as again in the 1970s, the town was expanding rapidly. The population of 12 500 in 1860 had risen to 14 400 by 1870, a much greater rate of increase than that of Scotland as a whole.

The increase in population can be attributed to many factors, including the beginning of tourism due to the improved rail and steamer communications, and to a popular interest in the Highlands generally. The Highland sporting estate, made fashionable by Queen Victoria, caused an increase in the building trades and in the business of supplying fencing and general estate requirements. Shippers of coal and lime kept the harbour and canal busy with the coming and going of sailing and steam ships. To such diversity of interests as tanning, brewing, rope and sail making, as well as several boat-building yards, can be added the supplying of telegraph wire and apparatus.

Probably the greatest factor in the commercial expansion of the 1870s was the railway. The original route south, via Aberdeen, had been superseded by the more efficient Forres-Grantown-Aviemore line in 1863; the railway to Strome in the west was completed in August 1870, and the railway was extended from Golspie to Helmsdale in the north. This growth of the rail service, combined with the steamer links to Glasgow and the south-east, made Inverness an important communications centre.

The opening of the Lochgorm Works in 1855, for repairing and altering rolling stock, had, by 1870, progressed to the designing and building of steam locomotives, carriages and wagons. The expertise required in such an undertaking produced highly skilled engineers, whose energies were channelled into a diversity of enterprises—among them the supply and fitting of house telegraphs and, later, the installation of the first private automatic telephone exchange in Britain, at Skibo Castle.

Another important activity in the area was the trade in fish and the servicing of the fishing fleet and its escort of Royal Navy gunships. The fisherman had by this time realized the value of the telegraph in directing their catches to the best market, and this was to be given as one of the many reasons for expanding the service.

THE CAMPAIGN FOR IMPROVED SERVICE

From the inception of the State-owned telegraph service in the north of Scotland, there was an incessant and justified campaign to have the service improved. The campaign was in the form of complaints from the Press, who were dependent on the telegraph for much of their news, and by memorials to the Postmaster General by local action-groups.

In September 1870, the Invergordon Times newspaper reported: "The Post Office seems to be quite unable to undertake the work placed at its disposal".

In the same month, The Advertiser (Inverness), complained: "Telegraph disarrangements in the north—there is something altogether inexplicable in the management—or mismanagement—of the supply by the Post Office of telegraph news to the northern press".

On 24 September 1870, there was held a well attended meeting in Inverness, at which specific examples of both postal and telegraph ineptitudes were given. Some complaints, such as the case for having mail-sorting coaches on the Inverness train so that mail arriving at the railway station at 9 a.m. could be delivered by 9.30 a.m. instead of 11 a.m. would, in modern times, be considered unreasonable. However, in pointing out the parsimony of the Post Office in not providing a donkey for the old man who nightly carried 50 pounds of mail from Drumnadrochit to Fort Augustus, we may have more sympathy.

The method of delivery of the Portree mail gave particular offence, not only to the public but to the recently operative Dingwall-Skye Railway Company. After prolonged negotiations in London with the Post Office, no adequate terms were offered to the railway company for a mail contract, and the Post Office proceeded to deliver the mail by the simple expedient of sending a man as a passenger and carrying the letters as baggage from Dingwall to Strome. At this point, instead of going direct to Portree by the waiting steamer, he travelled to Kyle, stayed overnight, and arrived in Portree the following day. This dispute between the Post Office and the railway company was to have repercussions on the telegraph service in the following years.

From the meeting in Inverness a memorial was sent to London, ". . . The fact is, so far as concerns the north of Scotland, no dependence can now be placed on the telegraph in regard to expedition, and men of business have consequently lost confidence in it. The memorialists hope a remedy will be provided without delay and that not only additional through wires will be erected, but a complete local circuit of wires also. The service was infinitely superior when worked by the old Telegraph Companies and the lower tariffs charged do not compensate for the lengthened delays and uncertainties."

The reply to the memorial from the Postmaster General was considered unsatisfactory and further representations were made. Eventually, at the end of December 1870, Mr Scudamore, Receiver and Accountant General and Chief Administrator of the Post Office replied that a new wire was in the course of erection between Inverness and Edinburgh and that the link between Inverness and Edinburgh via Aberdeen was to have an improved system of apparatus on the wire; that a new wire had been erected between Inverness and Lairg and that the hours of receiving messages at Inverness Post Office would be extended from 9 p.m. to 10 p.m.

It is likely that the new system of apparatus was Mr Varley's translator or a similar method of automatic repeating of the signal, thus reducing the inaccuracies and time-lags inherent in the manual relay-system. The telegraphing of news from London to Edinburgh at this time had achieved a high degree of efficiency; the news was first sent by pneumatic tube from Temple Bar to Telegraph Street, divided among several operators who transferred it onto punched tape at about 40 words per minute for simultaneous transmission by a Wheatstone automatic transmitter (see Fig. 3) to Edinburgh and several other cities.

The extension of the opening hours was the result of the business men of Inverness maintaining that most of their transactions were carried out between 9 p.m. and midnight, at which time the old telegraph-company office had been open.

It is unlikely that the alleged rate of inaccuracies under Post Office management was any greater than that under the private companies because most of the operators had been re-employed by the Post Office at the transfer.

Meanwhile, in Stornoway, similar representations were being made by Sir James Matheson, Bart., who guaranteed £300 per annum revenue and argued that, if Tongue was to have service, then surely Stornoway, with its larger population, should also be served.

It is probable that, but for the transfer, a cable across the Minch would already have been laid. The Northern Ensign had, in July 1869, reported—"We learn that the telegraph extension to the Isle of Lewis is enjoying favourable attention by the parties interested. Mr Holmes, who had so successfully

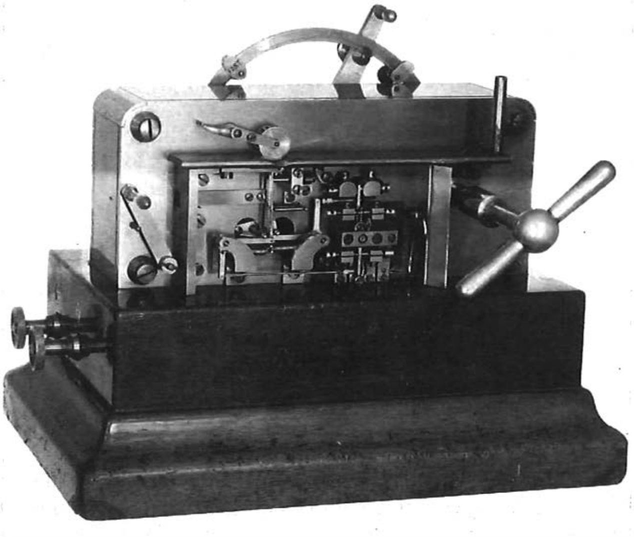

FIG. 3—Wheatstone automatic transmitter

promoted the Orkney and Shetland schemes and is the moving spirit of enterprises to connect North Europe with Great Britain, has undertaken to have the scheme carried out. We trust the day will not be far distant when Stornoway will have a telegraph station".

However, on 16 September, 1870, in reply to Sir James Matheson's memorial, the Postmaster General replied—". . . that the Department will make every endeavour to establish telegraphic communications between the Island of Lewis and the Mainland before the commencement of the herring fishing season next year". Only one month later—on 16 October—a "government official" was surveying suitable landing places for a submarine cable, which it was anticipated would be an extension of the railway telegraph from Achnasheen via Kinlochewe and Poolewe.

In February 1871, Cameron of Lochiel asked the Postmaster General if it was intended that the West Highlands should participate in the advantage of the Telegraph Act 1868 and, if so, when communication could be expected to be established with the Head Post Offices of Fort William and Fort Augustus. In reply, the Postmaster General said that 12 000 to 15 000 miles of wire had been erected to date and the West Highlands would not be neglected, the lines were to be entirely re-arranged and extended. It was hoped that the lines to Fort Augustus and Fort William would be completed by the end of May. Three weeks later, Post Office officials were surveying the route from Oban to Fort William.

All this demand for new service and increase in traffic—Inverness was passing 250 messages daily—caused such a strain on the Department's staff, that it became evident that additional staff were needed.

THE MEN

As early as August 1869, it had been rumoured in Inverness that when the Government took over the telegraphs, the construction and maintenance would be done by non-commissioned officers and men of the Royal Engineers.

After the end of the Crimean War in 1865, there had been no opportunity for practical instruction in telegraphy at the Royal Engineers School of Military Engineering at Chatham, although the standard 40-day theory course was maintained as part of the curriculum, with more advanced studies available for those who wished to specialize.

In the 1870s, there was much talk of Army reform, particularly in the purchase of commissions but, for the Royal Engineers, as for the Royal Artillery, entry was by open competition. From the school at Chatham (a school which was proclaimed the finest in the world) there graduated the most able, technical, scientific and military men of the British or any other army. Such men as Kitchener, who graduated in 1870 (and who later was to avenge the death of another engineer, General Gordon), and Sergeant Mackenzie, who was soon to bring the telegraph to Poolewe.

In 1870, Colonel Gosset, of the Royal Engineers, perceiving the opportunity of gaining practical experience for the Corps, as well as assisting the hard-pressed new Telegraph Department, offered the service of the Corps to the Post Office on the same terms as existed in the employment of his men on the Ordnance Survey. The Postmaster General eagerly accepted and, in April 1870, the 22nd Company was formed under Captain Webber with Lieutenants Ramsay and Jekyll, and Sergeants Ross and Morrison, for the purpose of operating the instruments, maintaining the lines and erecting new lines.

After a brief course at Chatham, the Company undertook the task of renewing the road line from Uxbridge to Oxford, either 8 or 9 working wires and, after many difficulties due to inexperience, successfully completed the work and established themselves as skilled telegraph mechanics. This success, and the demand for more new lines, resulted in the formation of another company—the 34th—who, after training, at the close of 1870, were posted to Inverness†.

Sappers were not normally used as unskilled labour; indeed, during the recruiting drive of 1872, the Inverness Advertiser states that—"Ordinary men are not taken for the Corps, they must be a mechanic of some kind".

Although Britain had proclaimed neutrality in the Franco-Prussian War, there was a general upsurge in the training of the militia and the preparedness of the regular army. By the summer of 1871, rifled ordnance was mounted on the walls of Fort George, breechloaders were issued to the local militia and, by the time the Fife Yeomanry arrived for their summer camp, this, the largest fort in Europe, was not only surrounded by hundreds of tents, but also had them pitched on the ramparts. Here was more than enough labour. It must have been a welcome relief for the 93rd Regiment (The Argylls) to be taken out of the midst of militia, and detailed for pole erection duties on the proposed Inverness–West telegraph.

To the south-west, in May, 1871, the SS *Clansman* sailed from Greenock with Captain Wilby and a party of the 90th Regiment, to be employed, under the superintendance of the Royal Engineers, on the construction of the Oban–Fort William lines.

THE PROPOSALS

In February 1871, a survey was made in the Oban–Fort William area, and estimates prepared. It was decided to join up with the existing Inverary–Oban line at Connel Ferry, cross to Benderloch, by the Shian Ferry and Appin to Ballachulish, thence across Loch Leven, along the shores of Loch Linnhe to Fort William, and then to Ardnamurchan. This route required submarine cables to be laid across Connel, Shian, Loch Leven and Corran.

In March 1871, Lieutenant Moore was preparing an estimate to link Inverness and Fort William via Fort Augustus. To serve the Black Isle, it was intended to carry the wires from Conon Bridge to Fortrose and, as a result of the memorial sent in by Cromarty Town Council, the route was to be continued to Cromarty. From Tain, a line was to serve Portmahomack from the railway station at The Mound, Dornoch. Lieutenant Moore was soon to make a survey from Garve to Ullapool.

The proposal to link Portree and Stornoway with the mainland was to meet with some obstacles. Negotiations for a mail-carrying contract with the newly operational Dingwall–Skye Railway Company had broken down and legal proceedings were pending. Because of this situation, it was decided not to use the railway poles, but to erect poles from the Post Office at Dingwall, along the southside of the town across the Dingwall–Skye railway and then to follow the public road by Strathpeffer and Garve to Achnasheen. A line would then be constructed to Kyle and one via Kinlochewe and Poolewe to An Sguiteach, near Cove.

Although it had been accepted Post Office policy to take an alternative route when in dispute with a railway company, the case of the Dingwall–Skye Railway Company was taken up in the House of Commons, and a debate followed. Was it less costly to maintain a line along the railway or the highway? Was the annual charge for a railway wayleave more expensive than the interest on the capital investment required for a new line along the road? Meanwhile, as the argument continued, the stores had been ordered, despatched from Hartlepool, and the poles erected by Sergeant Mackenzie and the men of the 93rd along the Strathpeffer road.

For the Islands, plans were being prepared to link Kyle with Portree and Dunvegan. For Harris, a line was to be erected from Stornoway to Rodel and from Rodel a cable would be laid to serve Uist.

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† The 34th Company remained attached to the Post Office until 1884. During the year 1871, the 22nd and 34th Companies constructed between them, more than 3200 wire-miles of telegraph lines

THE LINES

Compared with the junction telephone routes of the 1890s, the telegraph routes of the 1870s were of light construction. On routes carrying 4 wires and installed along rail track, there were as few as 16 poles per mile, and, where 10 or less wires were run, poles of 5 inch diameter were considered ample. Along the roadways of the Highlands, the poles were spaced approximately 32 to the mile.

Although the Bethel process of preservative treatment had been patented in 1838, the general system of treating seasoned wood up to 1870, whether of foreign or English larch, had consisted of the external application of creosote or copper sulphate, or charring the butts over a slow fire. After charring, a special mixture of tars and quicklime was applied while the area was still hot. After being placed in lime for several months, the poles were painted.

With the advent of coal-gas production on a large scale, coal-tar creosote became readily available, and a wise decision was made by the new Telegraph Department that the Bethel process would be used. The specification stated that 1 cubic foot of wood was to contain 12 pounds of creosote.

The galvanized iron conductors were usually of No. 8 gauge. This weighed approximately 390 pounds per mile and was of 0·17 inch diameter, and the breaking weight was 1840 pounds. The wire was first stretched by tightening to about half its breaking weight, according to the prevailing temperature. The *Britannia* joint was standard in through-sections, and at terminations, the wire was looped around the insulator and bound.

The lengths of alternate pole arms were 20 and 28 inches respectively, therefore, if vertically-adjacent wires sagged they would not be in contact. An earth wire was connected to the arm bolts or the insulator spindles.

EXECUTION OF THE WORK

In the summer of 1871, the Norwegian brigantine *Agil* arrived at Gairloch with a cargo of 2000 poles, unloaded 500, and sailed to Poolewe, where several hundred poles were unloaded. The remainder of the cargo was landed at Tobermory for the construction of the Mull telegraph network.

From Connel, a fatigue party of the 90th Regiment had installed the line of poles to the southern edge of Loch Etive and from the northern side of Loch Etive across Benderloch to Shain Ferry. The route was continued from the northern side of Loch Creran across Appin and from Ballachulish towards Fort William.

On 30 June 1871, the Anglo-American Telegraph Company's cable ship, the screw-steamer SS *Robert Lowe* laid the Oban to Mull cable; on 3 July, the Loch Etive cable above Connel Falls; on 4 July, the Loch Creran cable near Shian Ferry; on 5 July, the cable to Ardnamurchan at Corran Ferry and, on 8 July, the Islay and Kintyre cable. It is most likely that the Loch Levan cable was also laid sometime between these dates.

To the north, by the end of August 1871, Portmahomack was linked to the newly supplemented railway telegraph, and the Cromarty line was soon to be completed.

Meanwhile, in London, the argument for using the railway companies poles having prevailed, and a form of preliminary agreement being reached, orders were sent to recover the poles erected along the Dingwall-Strathpeffer road, and for the soldiers to proceed to Achnasheen.

For Sergeant Mackenzie and his assistants, as they quickly and successfully erected the line past Loch Maree, the weather was warm, but wet. Great interest was shown in the telegraph by the local people—even to the extent of taking precedence over such topics of local interest as the fast ripening crops, the smallness of the herring catches, and the potato blight showing as black patches in the fields.

On 25 August, the line reached the terminal pole at An Sguiteach and the arrival of the Stornoway cable was awaited. The arrival of this cable was, however, to have a setback—the burning down of the Silvertown Works at North Woolwich on 7 June. When the fire broke out, a mere 15 miles of cable had been loaded onto the SS *Robert Lowe*, the cable was cut and the remainder abandoned in the factory. It is quite probable that the 15 mile length was used for the Oban-Fort William extension, since this work was started only 3 weeks after the fire. At the time, it was expected that a new cable would be ready by October.

In April 1871, wires were run from the Post Office in High Street, Inverness, across the street to the Highland Club, from there to the Steeple and then to the towers of the suspension bridge over the River Ness. From the bridge, the wires were carried on poles along the public road to Fort Augustus and Fort William. Towards the end of June, the line had reached Fort Augustus and, by August, had arrived in Fort William.

In August 1871, Portmahomack, Aviemore and Grantown were opened for public business. In September, the offices at Castletown, Brora, Dornoch and Appin (also Bannockburn) were opened, and those at Drumnadrochit and Fort Augustus were opened on 13 October 1871.

At the beginning of 1872, with no indication of the completion of the manufacture of the Stornoway cable, the natives of the Lewes became agitated—"If Tongue can have the telegraph, why not Stornoway with its population now of tens of thousands and its important fishing industry? . . . etc." (During 1871, 45 000 cran of herring were dispatched from Stornoway to the Continent.)

On 25 June 1872, a southern newspaper reports—"There is a fair prospect of the cables intended to serve Stornoway, Skye and several places on the Clyde being laid by, or before, the end of next month. About 60 miles of cable for the purpose have just been completed at the Silvertown Works, North Woolwich and the SS *La Plata* is at present alongside the works engaged in shipping the wire conductor. The expedition will be under the charge of Mr. D. Lumsden of the Post Office's Engineer-in-Chief's Department. The work will be of a somewhat costly nature and, looking at the comparatively small traffic likely to arise in connection with it, the Post Office certainly deserves credit for taking it in hand at the earliest opportunity consistent with the many more important works it has accomplished during the short time it has been in possession of the Telegraphs".

On Tuesday, 24 June 1872, the SS *La Plata* arrived in Stornoway. After inspection of the landing place at Loch Ewe and delays due to the weather the cable lay commenced on the 28 June. The shore-end cable was landed and brought up the beach to terminate in a jointer's tent, which had been erected to accommodate the test equipment used to assess the performance of the cable section during the laying operations. By one o'clock everything was prepared, and the SS *La Plata* started paying out the cable; performance tests were made every half-hour during the voyage.

No problems arose and, after her arrival in Loch Ewe at 6.30 p.m., the following message was transmitted to Mr. Donald Munro, Stornoway Town Chamberlain—"I have much pleasure in informing you that the cable connecting the Western Hebrides with the Mainland has been successfully completed today".

On the following Monday, the SS *La Plata* arrived back in Stornoway and, after coaling, left for Lochmaddy, arriving there on the Tuesday. A line had been erected from the Post Office around the Loch to the point on the opposite shore where the cable was to be landed. From this point, on the following day, the cableship set-off for Rodel. After laying several miles of cable, a fault occurred; the cable was cut and the ship returned to Lochmaddy, where she was detained by high winds until Saturday, 5 July, on which day the cable was successfully landed at Rodel.

The successful completion of the circuits from the Western

Isles, Kyle, Gairloch and Ullapool was not yet achieved. It is suspected that the Post Office were now at the mercy of the Dingwall–Skye Railway Company, since all had been hazarded on using their lines. Towards the end of August an agreement on the annual payment was reached (£1250), but negotiations over the lump-sum were to continue for several months.

However, the result of the £1250 payment was that the wire which had lain for so long wrapped around the railway fence at Achnasheen, was connected to the railway telegraph; an operator was sent from Inverness to Stornoway and, on the last Monday of August 1872, the office in Stornoway opened for public business.

At the beginning of October 1872, Dunvegan, Easdale, Harris, Invergarry, Isle Ornsay, Broadford and Loch Carron joined Strome in opening for business.

There still remained an anomaly—an extra shilling charge for all messages passed from Stations on the Dingwall-Skye railway; one shilling to the Post Office and one to the railway company. This surcharge was finally removed in March 1873 when the Post Office paid the lump sum of £4250, and announced, "The Postmaster General having now acquired the Dingwall-Skye Railway Companies telegraph, messages to and from stations on that line will, in future, be placed on the same footing and be subject only to the same charges as other telegrams".

CONCLUSION

The Highlands and Islands scheme of 1870–72 was a great success in its day, and the network was to remain substantially unaltered for 60 years. The remnants of the original routes can still be found, as can the occasional pole in the Lochaber area, albeit relegated to carrying a customer's local-line connexion.

The Stornoway cable, laid by the SS *La Plata*, remained in service until 1933, when it was replaced by a telephone cable.

The success of the scheme can be judged by noting that, at the end of 1872, Knoydart, that remote and lonely peninsula, was the only place where people were still clamouring for service—as some of them are today.

A Self-Contained Trailer-Mounted Generator

R. P. McKAY and C. R. STEPHENS†

To improve working conditions for external staff, many electrically-powered tools and mechanical aids have been introduced over the years. These include lights, pumps, flashing beacons, drills, chain saws and brazing units (for brazing joints on coaxial tubes). The power for these tools is provided by either a 110V AC generator or a 24V battery charged by a gas-driven generator.

Both these motor driven generators are noisy, and this often leads to justifiable complaints from nearby residents, especially when work is taking place at night. Unfortunately, many operations in the external field have to be carried out 24 h/d; and this is particularly true of work on coaxial cables where tubes can be released to working parties only during the night, when traffic on the systems is low. In order to reduce noise, and avoid complaints, work often proceeds without the generators running, resulting in rapid deterioration of the batteries due to the heavy load put on them. This is especially true of the brazing unit, and, where coaxial work is taking place, it is often necessary to transport to site several heavy and cumbersome batteries.

In view of the concentration of coaxial cable work within the London Telecommunications Region to a small specialized work force, and bearing in mind the likelihood of a change to 110V brazing, it was decided to construct a self-contained unit having an engine-driven generator capable of supplying power to braze coaxial tubes continuously, using either a 24V or 110V brazing unit. It was thought that the whole unit could be housed in a modified trailer toolcart and, with the use of a suitable insulating material, could be sound-proofed. In addition to brazing, the unit was to be capable of providing power for as full a range of mechanical aids as possible and should, therefore, have 24 V and 110 V outlets.

The requirements given to the drawing office, who were asked to design and specify the unit, were that it should contain an engine-driven generator with 110V AC and 24V DC outlets and should carry sufficient fuel for a reasonable working period. A pair of heavy-duty 24V batteries for brazing were required, plus storage space for the brazing equipment, a submersible pump for wet manholes and a number of lighting leads. The completed unit was required to be towable by standard British Post Office (BPO) vehicles and easily manoeuvrable by personnel on site. The unit when in use was to be reasonably quiet.

To contain the equipment required, the existing cart superstructure was dispensed with and the cart redesigned and rebuilt from the bare chassis. A new steel-angle subframe was mounted on the chassis and clad with 12·7mm exterior-grade plywood covered with 0·9mm aluminium sheet for protection. Various internal compartments were constructed to house the equipment required, and sufficient removable panels and hinged lids were incorporated to allow for ease of access and to facilitate maintenance.

Considerable care was taken in planning the equipment positions in the interior of the trailer to achieve the correct static balance. It had been decided to adopt liquid petroleum gas (LPG) as the fuel for the engine and the difference in weight between full and empty gas cylinders had to be allowed for. Telecommunications Headquarters (OP 4.2.1.1) had advised a maximum vertical towing eye load of 27·2kg and a minimum of 11·36kg. This was to ensure that the rear suspension of the towing vehicle was not overloaded, while maintaining correct adhesion. A number of layouts was considered before deciding that the generator should be in the front, equipment in the centre and two 11·34kg LPG cylinders in the rear.

The unit consisted of a 3·5kVA dual-voltage generator (24V DC and 110V AC) coupled directly to an 8·5 horse-power internal combustion engine driven by LPG. Two heavy-

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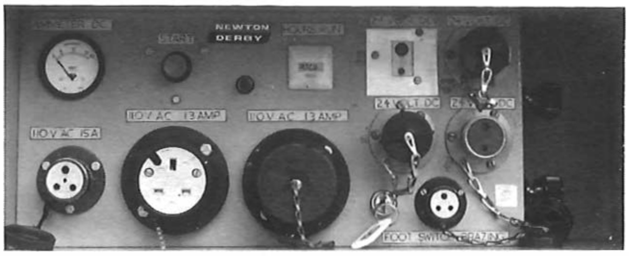
† Centre Telephone Area, London Telecommunications Region

Self-contained trailer-mounted generator

duty Varley paste batteries connected in series provide the power for brazing and a standard 24 V BPO battery provides power to four 24 V outlets. All batteries are trickle charged by the generator. The main control panel is readily removable after disconnecting 2 power cables from the generator. One 15A and two 13A, 110V AC socket outlets and four 5A, 24V DC socket outlets are provided. Two brazing terminals, for connexion of the brazing tongs, are easily accessible from the side of the control panel. To prevent the full load of the brazing tongs being placed onto the generator, a foot switch for operating the tongs is connected to a special socket provided on the panel. Operation of the foot switch energizes a relay which disconnects the generator from the batteries, at the same time connecting the batteries to the brazing terminals on the control panel. The relay is energized from the generator, and, thus, brazing cannot take place unless the generator is running. Upon release of the foot switch, the brazing terminals are disconnected and the generator resumes trickle charging the batteries. An ammeter, showing the rate of charge of the 24V battery, and a push-button starter have been provided and the engine has its own recoil starter. An hours-run meter is also fitted, and a 15 A resettable circuit-breaker is included for safety.



Control panel

Although primarily designed for use by coaxial cable working parties, it was realized that the toolcart would be doubly useful as a dual purpose unit if it was made suitable for other external work. Therefore, a key-operated switch has been included on the control panel, which, when turned off and the key removed, will isolate the brazing circuits from the electrical system, allowing the use of the socket outlets only.

To meet the over-riding operational requirement that the completed toolcart should be as quiet as possible in use, bearing in mind it was to be used in high-density residential areas, the generator compartment was lined with a sound-absorbent fire-proof material. Because this results in a fairly high running temperature inside the compartment, extractor fans are fitted to assist cooling. As the engine had an 8·5 horse-power rating it was necessary to fit an exhaust system comprising an expansion box in addition to a silencer.

To date, the completed toolcart has been given an exhaustive field trial by Centre Area staff, and approximately 300h running time has been recorded under full-load conditions of brazing, pumping, and lighting. Brazing can be carried out continuously with approximately 10–15s recovery time of the battery. The unit is quiet in operation and is also easily manoeuvrable by one man on site, and our conclusions are that it has amply satisfied the original design requirements, although, as a result of the field trial, various minor modifications are being carried out to the cooling and silencing systems.

Prestel in the North West

J. H. SKELLAND †

Prestel (previously known as *Viewdata*), one of the most exciting British Post Office developments of recent years, will be introduced in Manchester in early 1979. Planning for its introduction in the Manchester Central Telephone Area is well in hand. The nerve centre of the system will be 2 proprietary computers installed in purpose-built accommodation situated on the sixth floor of Dial House, a large telecommunications complex in the city centre.

The Prestel service will be available to customers in the Manchester director area and the non-director adjacent charge-groups, over the public switched telephone network (PSTN). Liverpool area customers will have direct access to the Manchester computers over dataplex links until Prestel computers are installed in Liverpool. Customers connected to Manchester director area exchanges will gain access to the Prestel computers via the Manchester tandem exchange. Traffic from the non-director adjacent charge-group exchanges will route via the incoming trunk units to a special switching unit already in use to connect information and similar services. Suitable interface equipment will be used to connect the PSTN to the computers.

Once the Prestel service becomes operational in Manchester, careful monitoring of traffic to this service will be required in order to assess its growth potential and the effect of the additional traffic on the telephone network.

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† Manchester Centre Telephone Area

Lives of Plant and Depreciation

Part 1—Depreciation

N. FERRIDAY, C.ENG., M.I.E.E.†

UDC 620.169: 657.372.3

This first part of a 2-part article describes the methods used in the British Post Office for accounting for depreciation of telecommunications plant. The amount of depreciation charged is determined by the plant life. Part 2 will describe statistical methods of life assessment.

INTRODUCTION

The British Post Office (BPO) Telecommunications Business is very capital intensive with a net book value for fixed assets of £6049M at March 1978. Depreciation of capital expenditure on these assets is a very large operating expense, being £373M at historical, and £710M at current prices in the year ending March 1978. A breakdown of the charges is shown in Fig. 1. To ensure that the BPO Accounts[1] are realistic, it is essential that capital expenditure is depreciated as accurately as possible. To do this, a regular programme of life assessment is carried out and is considered by the *Committee on Lives of Plant and Depreciation* (usually known as the *Lives of Plant Committee*).

The procedure was described in an earlier article[2], but a full-time group in Telecommunications Headquarters (THQ) has since been set up and studies are now more detailed. Principles of depreciation and life assessment have been described previously,[3] but there have been many developments since then, and this article outlines some of the current concepts and methods. Part 1 deals with the method of depreciation accounting in the BPO, and Part 2 will describe some statistical methods used in calculating lives.

RECORDING OF EXPENDITURE

The main medium for recording expenditure on engineering works is the Cost Statement. Telephone Areas record the money spent on stores, labour and contract work, and classify payments by the type of activity and plant into the appropriate class of work (COW). Stores expenditure is normally recorded against a particular COW when equipment is issued; for example from Area Section Stock. A further accounting record is made when the equipment is returned. Labour expenditure consists of wages paid, but the time spent is analysed from time sheets so that the correct amount is charged to each COW. Contract payments, which often include the purchase of stores, are recorded in the Cost Statement when charges have been incurred. Area Cost Statements are accumulated in the Regions and thence in the Telecommunications Finance Department of THQ.

For telephone instruments, there is a different procedure. Stores expenditure is recorded (capitalized) when the telephones are purchased, and not each time they are issued. Correspondingly, stores recoveries are not recorded each time the telephones are returned to stock. The method is termed *capitalization at purchase* (CAP) and has important consequences for depreciation accounting.

For certain types of plant, much more detailed accounting records are kept, and these form the basis of the various asset register systems. Accurate and consistent recording of expenditure, by whichever of these means, is the foundation of realistic depreciation, as well as other financial work.

CAPITAL EXPENDITURE

Expenditure can be divided into 2 main categories: revenue or current-account expenditure, and capital or investment expenditure.

Current-account expenditure is generally that required to keep the system running; for example, spending on maintenance, operators, directories and billing. It is necessarily

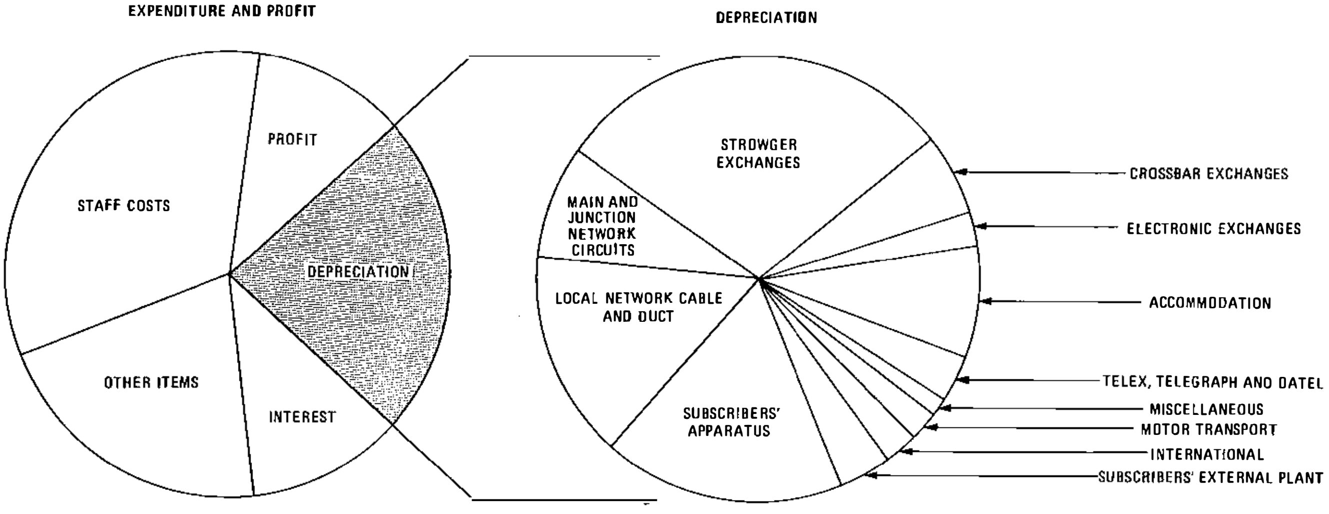

FIG. 1—Depreciation charges in BPO Telecommunications

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† Operational Programming Department, Telecommunications Headquarters

incurred and tends to be fairly stable, so it is reasonable to write it off as a charge against revenue each year.

Capital expenditure is that needed to modernize and extend the system; it is different from current-account spending in that it is optional (in the short term at least) and, hence, tends to be less regular. Also, it confers no immediate benefit and returns may be spread over a long period. Investment in plant, such as cable or exchanges, is capitalized and gives rise to fixed assets. Certain expenditure such as that on training or research, although clearly investment, is not capitalized because the results may be intangible. Also, investment expenditure that is minor or does not merit more elaborate treatment may be considered as revenue expenditure. Depreciation and lives of plant work is concerned with only capital expenditure.

BOOK LIFE AND ASSET REGISTER DEPRECIATION

There are 2 main methods of plant accounting used in the BPO. The first is known as the *book method,* which was used for all plant and is still used for most. In this method, bulked expenditure on assets is treated as a whole and depreciated over a *book life*, and is written out of the accounting ledgers at the end of the book life; the latter is determined purely by lives of plant work. The second method is *asset register depreciation*, in which units of plant are individually recorded and depreciated and arc written out when the units are actually recovered.

Although many of the concepts of depreciation are the same, there are important practical differences in these methods, and they are outlined later in this article.

CONCEPTS OF DEPRECIATION

While the need for depreciation accounting has been accepted since the last century, the exact purpose, definition and methods have been subject to debate, and this is still continuing. Three possible definitions of depreciation are:

(*a*) the loss in service value, not restored by maintenance, due to the consumption or prospective retirement of plant;

(*b*) a sum that needs to be set aside to replace assets at the end of their operating life;

(*c*) a method of spreading the (net) cost of assets over their useful life so that stable and realistic accounting and pricing policies can be followed.

Definition (*a*) has the problem that service value is a difficult concept to define and, in the case of most BPO plant, almost impossible to calculate. Definition (*b*) has the disadvantage that, in practice, plant is rarely replaced on a like-for-like basis at the end of its life; it may be replaced by a different or more-advanced system, or not replaced at all. Definition (*c*) is more pragmatic and is the least controversial. However, it gives no basis for answering important questions such as what should be done in the case of technical and business change, or how changing price levels should be dealt with. Despite their differences, all 3 definitions agree that the cost should be spread over the useful life of the asset and, for many purposes it is unnecessary to choose between them.

The initial cost, or capital value of an asset is termed the *gross book value* (GBV) and the depreciated value is the *net book value* (NBV). Annual depreciation, D, is cumulated to give accumulated depreciation, AD, so that, at the end of life, L, the accumulated depreciation is equal to the GBV less any *net recovery value* (NRV). The following relationships can therefore be derived:

$$AD_t = \sum_{0}^{t} D_t,$$

$$NBV_t = GBV - AD_t,$$

$$AD_L = GBV(1 - NRV/100), \text{ and}$$

$$NBV_L = GBV \times NRV/100,$$

where the NRV is expressed as a percentage of the GBV, t represents the time period, 0 is the start of life and L the end. These relationships are illustrated in Fig. 2, where equal instalments of depreciation in each (short) time period are assumed; that is straight-line depreciation, giving

$$D = \frac{(1 - NRV/100) \times GBV}{L}.$$

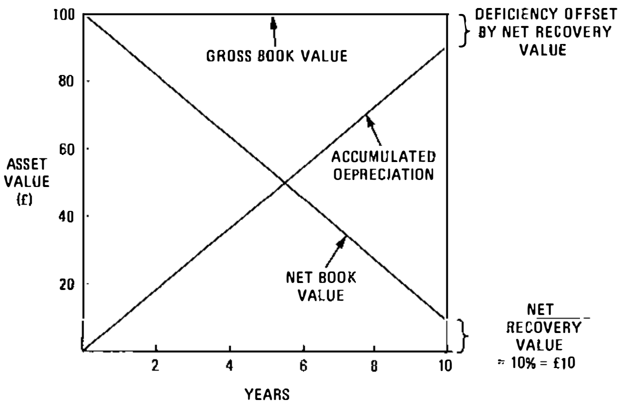
Normally, depreciation is not calculated directly, but a rate R, expressed as a percentage of the GBV, is calculated. This is then applied to the GBV as follows:

$$R = \frac{(1 - NRV/100) \times 100}{L}, \text{ and}$$

$$D = R \times GBV/100.$$

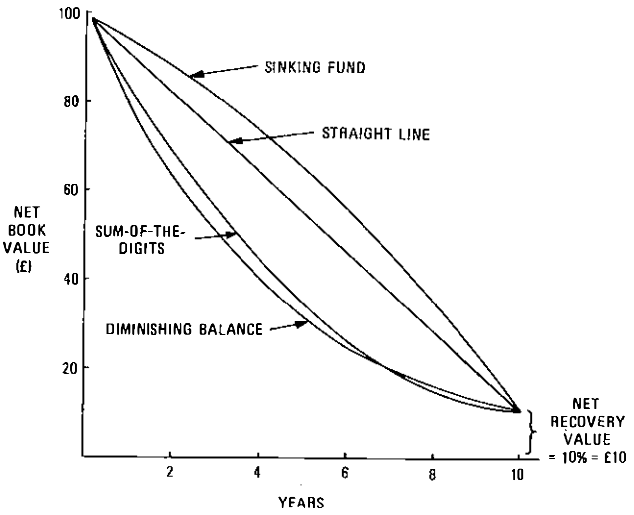
Ideally, the NBV should follow the true value of the asset throughout its life but, in the case of the BPO, there is usually no market value and no reliable way of assessing the value of the asset to the BPO. It is therefore necessary to adopt a formula.

In addition to straight-line depreciation, there arc other methods, such as diminishing-balance, sum-of-the-years-digits and sinking-fund, and these are illustrated in Fig. 3.



Note: Asset life 10 years

FIG. 2—Depreciation of an asset



Note: Asset life 10 years

FIG. 3—Various methods of depreciation

None of the methods is necessarily realistic, but the BPO (in common with most other telecommunication authorities) uses straight-line depreciation. This has the advantage of being simple in concept and application and, especially where there are many different assets impossible to value individually, it is as realistic as any method.

TOTAL SERVICE LIFE AND LIFE IN ONE POSITION

Total service life (TSL) is the time from purchase of an item to its being scrapped or abandoned. Life in one position (LIOP) is the time between installation and recovery, and there can therefore be several LIOPs in the TSL of an equipment. As described previously, accounting entries are normally made at the time of installation and recovery; therefore, LIOP is used for depreciation. An exception is telephone instruments where expenditure is recorded on purchase; in this case, TSL is used. In many cases, recovered equipment is not re-used and the LIOP and the TSL are then the same.

Net Recovery Value

When expenditure is depreciated over the LIOP, there may still be a re-use value at the end of life and, even if the plant is not re-used, there can still be a disposal value. To take account of this, the NRV as a percentage of the GBV is computed as follows:

$$NRV = \left[GBV - \frac{(n-1)C_r + C_s}{n}\right] \times \frac{100}{GBV},$$

where n is the number of lives in one position in the TSL; that is, TSL/LIOP,

C_r is the cost of recovery and reinstallation,

C_s is the loss on recovery and scrapping of the plant.

The second term in the brackets indicates the average *loss per life* that arises from n—1 re-uses and one scrapping. The actual value of NRV varies according to the value of n, and to the relative costs of stores, labour, provision, recovery and indirects. Scrap value is normally not high and can approximately be offset by the cost of recovery. A significant NRV is therefore usually obtained only where equipment is re-used to any extent; subscribers' apparatus is a notable example.

A significant problem arises because plant is only depreciated down to the assessed NRV. The NBV should, in theory, be offset by the actual NRV received at the end of life but, in practice, this may not happen. Standard accounting practice requires that any difference should be credited, or debited, to *Surplus on Sale of Assets* in the Profit and Loss Account. In the BPO, this practice is followed for assets on fixed asset registers. For certain other plant, where re-use is not significant, a nil NRV is used (100% depreciation), and proceeds of recovery go to the Profit and Loss Account. In the remaining plant groups, accounting for actual recovery still takes place in the capital account, but this practice is currently under study.

DEPRECIATION OF BULKED ASSETS

The concepts described are all relevant, but apply to individual assets where the expenditure is at a fixed point in time and can be depreciated over the life of the asset concerned. BPO assets are generally not depreciated individually, and various procedures are used to handle the cumulative, bulked expenditure. The quite different procedures for asset registers are outlined later in this article.

Plant Group

The COWs cannot always be depreciated directly, but must first be rearranged. This occurs because several COWs may contain the same type of plant and such COWs should be combined for lives of plant and depreciation purposes; less frequently, COWs are split into several plant groups.

After the direct costs have been rearranged, it is necessary to add certain indirect costs. Costs related to stores handling are necessarily incurred in construction work, and are therefore capitalized and included as fixed assets. It is, however, policy to capitalize only certain indirects termed *plant capital cost* (PCC) indirects. Other costs, such as the cost of planning and research (incurred at THQ), which may be included as overheads in costing studies, are excluded. The resulting blocks of expenditure, made up of one or more COWs with indirects, are termed *plant groups* and the costs are referred to as *plant capital costs.*

Number of Items

In most plant groups, there are large numbers of similar items; for example, Teleprinters No. 15. The lives that these items have, however, vary widely and, to overcome this, an average life for all the items is derived. This life is then used to determine depreciation and to write out expenditure.

Diversity of Items

In some plant groups, there are very different types of plant, which may have quite different lives. An example is subscribers' apparatus, where cordless switchboards have a 5-year life and extendable PABXs a 20-year life. In such cases, a separate average life for each type of plant is derived and these lives are then combined using a method known as *equating*. A simple example of an equated life is shown in Table 1.

TABLE 1
Simple Example of Equating

Plant Type	Current Capital Value (P)	Life (L)	P/L
A	100	10	10
B	200	20	10
A and B	300	—	20

Equated life (EL) = 300/20 = 15,

or, for n items, EL = $\sum_{i=1}^{n} P_i / \sum (P_i/L_i)$.

The equated life is not a straightforward average, but is a form of weighted average, with a set of weights chosen to ensure that the sum of the individual depreciation charges P_i/L_i is correct.

Vintage Lives and Tranches

Expenditure in a financial year is considered as a block, and depreciation is charged from the following year until the end of book life. The book life is normally applied to each year of expenditure. Each year's expenditure remaining in the ledgers is called a *vintage*, and the sum of these constitutes the GBV. A vintage will be written out of the ledgers at the end of assessed life and, because the vintage lives are the same, there is a first-in-first-out principle in operation. In practice, it is not necessary to depreciate each vintage separately because the total depreciation charge in any one year is simply the annual rate multiplied by the total GBV, as illustrated in Table 2.

In some cases, the assumption of the same life for each vintage is clearly inappropriate; a good example is Strowger equipment, where impending obsolescence causes a marked shortening of life with each subsequent vintage. In such cases, depreciation is effected in convenient periods of expenditure, often 5 years, called *tranches*, and each tranche

TABLE 2

Derivation of Total Annual Depreciation Charge

Vintage	GBV	Life	Rate (as % of GBV)	Annual Depreciation
1	200	10	100/10 = 10	10% × 200 = 20
2	300	10	10	10% × 300 = 30
Total = 1 + 2	500	10	10	10% × 500 = 50

is regarded as a separate plant group with its own life, rate, NRV etc. This obviously means more work, but it gives greater accuracy in depreciation accounting.

Change of Life

When plant is re-assessed, the assessed life for depreciation is often changed. (This may be due to actual changes in life caused by changed policies and practices, or simply new information and data enabling more accurate lives to be estimated.) When the life changes, the annual charge (GBV/L) must be changed; in addition, all the previous depreciation based on the previously assessed life must be corrected. To do this, the historic depreciation is recalculated using the new life, and a deficiency (if the new life is shorter), or a surplus (if the new life is longer), is derived. This is then written off in the year concerned or, if this would lead to an unacceptably large perturbation in the BPO Accounts, over a number of years related to the remaining life of the plant in question.

ALLOWANCE FOR INFLATION

The concepts above are valid if the value of money is constant. Where this is not so, there is a major problem of whether, and how, to allow for inflation in depreciation. During periods of inflation in the economy, when operating costs and prices are rising, the value of assets and, possibly, income also rises. It is then proper that depreciation, whether regarded as a charge for consumption of assets or as a means for providing for plant replacement, should also increase. At present, there is no legal requirement for the effect of inflation to be shown in accounts and it is not fully recognized in, for example, tax assessments. The method of allowing for it has been the subject of much controversy, and the Accounting Standards Steering Committee report (1973), the Sandilands report, the Morpeth report and the Hyde report express a variety of views.

In the BPO, depreciation is carried out initially at historical cost but, for certain plant, *supplementary depreciation* has been charged for many years. For each plant group concerned, a price index is calculated by comparing the yearly changes of price of a representative selection of plant. This index is then applied to all vintages, and the depreciation thereby raised. A particular vintage will be affected each year it remains in the Accounts, so that plant with long lives will show a significant uplift in capital value and depreciation. The GBV of local duct, for instance, is £417M at historical cost, but £1309M at replacement cost.

Until recently, a very important feature of the indices was that they were based on price changes of particular items. They did not, therefore, fully take account of technological change (for example, substitution of cheaper polyethylene cables for lead ones) and, in this sense, are similar to other indices such as the Retail Price Index. In some cases, however, supplementary depreciation was not charged in plant groups where "... by reason of technical advances, current values and replacement costs are no greater than historical costs ...". The system was rather inconsistent and, in the light of the various reports on inflation accounting, new indices have been devised. They are broader based, such as cost per circuit kilometre for the main network.

ASSET REGISTERS

Because plant groups are depreciated as a whole, while containing many items that ought to be depreciated separately, depreciation is not very accurate. Because plant is simply written out of the ledgers at the end of assessed life, there is no accounting check of whether the assessed lives are actually achieved and, hence, are consistent with the accounting entries. The BPO Accounts could, therefore, be reflecting the wrong quantity of assets, and depreciation could be under-provided on assets actually retired. Even if average and equated lives were absolutely correct, inaccuracy in depreciation would still occur because the actual wide variation of lives cannot be properly represented by averages. For these reasons, the external auditors, Coopers and Lybrand, have qualified the BPO Accounts for several years; to overcome this, the BPO is developing asset registers. These are registers where the date of installation, values, and assessed life of assets are recorded. Each item is depreciated individually, at a rate determined by the assessed life, but is written out of the register when it is actually recovered. A correction for any deficiency in its depreciation is made at that time. By this means, cumulative errors for the plant group are avoided and the GBV is realistic and depreciation is not under-provided. However, it is still necessary to have accurately assessed lives because the NBV and annual depreciation depend on them.

Asset registers are a better method of depreciation accounting, but they are difficult and expensive to set up and run. There are now registers for: junction cables, motor vehicles, research and development plant, buildings and other minor plant groups. Registers are to be introduced in 1978–79 for HF and audio main network cables and for TXE4 equipment. It is intended to introduce asset registers in some form for most of the remaining plant groups. Plant such as local cable and subscribers' apparatus, present almost insuperable problems, and alternatives to full registers may be needed. In the case of telephones (stores cost only), a bulk asset register is already in operation. Quantities of telephones purchased and retired (scrapped, abandoned or sold) are used directly in preparing the Accounts to ensure that the ledgers reflect the true numbers of telephones. Although bulk asset registers may give better approximations to historical GBVs than depreciation of bulked expenditure, they are not entirely satisfactory because they may exclude installation costs and because a first-in-first-out principle of write-out may be unavoidable, leading to errors in the NBV and GBV.

LIFE ASSESSMENT AND PROCEDURES

From the foregoing, it is clear that values of life and NRV have to be assessed for plant as soon as capital expenditure is incurred. These values must take account both of past events, and of factors and policies that will influence the future. The methods of assessing life are complex and varied, but can be broadly divided into engineering judgement and statistical assessment. In some cases, such as when a new item of plant is being introduced, only a judgement can be made, but wherever possible, statistical methods are used as they give objective and potentially accurate results. There are certain standard statistical methods for life assessment, and these will be described in Part 2 of this article.

Because life assessment is a complex and time-consuming job, a specialist group in Operational Programming Department was set up to do the detailed work. Each type of plant is assessed on a nominal 5-year cycle and a full report produced. This is then agreed by the Lives of Plant Committee, to which representatives from the Departments concerned with the plant are co-opted during the year of review. The results are then ratified by the Managing Director's Committee, Telecommunications and the BPO Board and used in preparing the BPO Accounts. As well as producing reports for each type of plant, the Lives of Plant Committee is required to:

set up and maintain special record systems, such as samples; study aspects of depreciation; develop methods of life assessment; and produce lives and NRVs for costing purposes.

IMPORTANCE OF LIVES AND DEPRECIATION

Depreciation is a huge expense, so it must be as realistic and accurate as possible. A change in assessed life can make a noticeable impact on profits, as evidenced by the deficiency of £85M in 1972 when the lives were reduced following decisions on the obsolescence of Strowger equipment. The primary financial target for the BPO is the real return on its assets, which is basically profit before interest divided by current net assets (that is, NBV at current prices), and this is set at 6%. As with profit, the achieved return is affected by depreciation and, hence, by plant lives. These accounting measures ultimately affect the financing and tariffs of the BPO and, thus, resource allocation. Individual plant lives also affect particular tariffs and investment decisions. For these reasons, detailed and thorough studies need to be made, and active co-operation of all parts of the business is essential.

CONCLUSION

Part 1 of this article has emphasized the importance of depreciation in the BPO, and has outlined the way in which it is carried out. Part 2 will deal with the major determining factor of depreciation, plant life, and will describe the methods of statistical assessment that are used to calculate it.

References

[1] Post Office Reports and Accounts, 1977–78.

[2] KYME, R.C. Lives of Plant and Depreciation. *POEEJ*, Vol. 63, p. 96, July 1970.

[3] KNIGHT, N.V. Depreciation and Service Life of Telecommunications Plant. IPOEE Printed Paper No. 209.

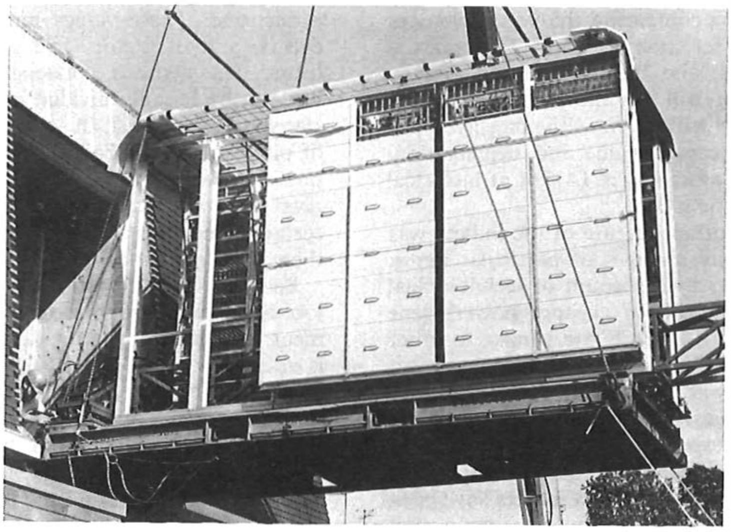
Modular Delivery of an Electronic Exchange

P. C. ASHTON†

A trial of a new concept in rack delivery, developed by STC Ltd. for electronic-exchange equipment, was recently held in the Eastern Telecommunications Region. A TXE2 exchange provided by contract was the trial exchange. The equipment contractor had requested delivery to the selected site of racks formed into suite modules, instead of individually as is the usual practice. The site itself presented a number of problems, the major one being that it had a first-floor apparatus room with equipment access via a stairwell within the building. Investigation of the building's fabric showed, however, that a suitable temporary aperture could be formed and, following consultation with the equipment contractor, a temporary apparatus doorway on the first floor was prepared.

Exchange layout proposals were shown to facilitate the creation of 2 modules, each of 2 suites comprising 6 racks per suite. The 2 suites forming a module were so arranged that standard gangway widths were achieved. Although the exercise was primarily intended to prove the concept of modular delivery, the contractor took the opportunity to undertake some of the normal site-installation activities at the factory. These included the provision of the suite overhead ironwork, cable grid, inter-rack cabling and some inter-suite cabling, all of which were subject to inspection prior to delivery to site. Manoeuvring of a module was facilitated by the use of air bearings, like small hovercraft, positioned at each end of the assembly. These were controlled by valves mounted on a console at one end of the structure, and compressed air, via a supply hose, was supplied from a commercial air compressor.

A completed module was mounted on a standard container flat-bed, covered by a fitted weatherproof sheet and transported to site by a low-load lorry. Once on site, the flat-bed was lifted to the doorway by crane, docked onto locating pins


Module in position for transfer to apparatus floor

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† Eastern Telecommunications Region

and the gap between the container bed and the apparatus floor sealed. After coupling the air supply to the valve controls, the module was "floated" into the apparatus room. It was found extremely easy to position the module accurately to the floor markings, and the entire operation, from lifting the container to positioning on the floor, took approximately 20 min. In total, 3 modules were delivered, the first being a dummy module to prove the lifting and docking arrangements. One of the later modules also contained a spare rack devoted to various slide-in units so that investigation could be made into the effect of vibration and fatigue on equipped racks transported in this fashion.

The trial adequately demonstrated the viability of delivering racks in this manner and gave an indication of the possible benefits in cost and time saving, coupled with better quality and product control. Further experiments will be conducted at other sites by the contractor in cooperation with the British Post Office.

Book Reviews

Technician Mathematics 1. M. G. Page, B.SC. (HONS.) (ENG.), C.ENG., F.I.MECH.E., F.I.PROD.E., F.S.S. Cassell and Co. Ltd. (Cassells TEC series). xiv + 402 pp. 129 ills. £2·75.

In his preface, the author states that this book has been written to satisfy completely the syllabus of the proposed new standard unit in level 1 of Mathematics for Technician Education Council courses, and there is little doubt that, from a student's point of view, this objective has been achieved with commendable success. The style is based on a previous successful book by the same author and the coverage, especially in the more elementary subject matter, is very thorough.

The first section of 140 pages deals with computation and includes the binary system and a useful, but comparatively brief, introduction to statistics. The next section, of little more than half the length of the first, nevertheless covers adequately the syllabus in basic algebraic processes, although there are occasional small lapses, such as the introduction, without any explanation, of what, to the uninitiated student, must be the rather bewildering unit of MN/m^2. Geometry is dealt with in the following section of slightly greater length and, again, the treatment is adequate, but subject to minor weaknesses and uneven emphasis. For instance, although there are excellent illustrations of triangles and circles, there are virtually no diagrams depicting the geometry of solid figures. Neither prisms nor pyramids merit diagrams of any sort and a curious omission in both cases is the definition of such "right" solids in terms of a regular polygon, although the latter, never properly defined, is dealt with more fully under the heading of trigonometry. Another similar criticism in this section is the reference to the perimeter of an ellipse, with no diagram or explanation relating to an ellipse. The final section on trigonometry is characteristically clear and thorough in its treatment, but rather too much space is devoted to very detailed instructions on how to use an electronic calculator, which the author avows to be his favourite tool.

The many good features of this book, for example clear and thorough treatment of fundamentals, a wealth of worked examples and of problems with answers, are marred to some appreciable extent by over-elaboration of detail, especially in the section on computation, and by the failure to explain in sufficient depth a few of the more difficult points of the subject matter. The latter failure also extends to some of the examples taken from workshop practice; for example those towards the end of the section on trigonometry, and these may well occasion students not versed in such techniques some considerable difficulty.

As with most new books, typographical errors occur, but their extent and nature are not such as to give rise to much misgiving as to the value of the book, and they will no doubt be corrected on subsequent revision. To summarize, this book should prove to be a valuable aid to the technician at the beginning of his studies and should prove a sound basis for his later work in mathematics.

B. L. G. Hanman

Coupling of External Electromagnetic Fields to Transmission Lines. Albert A. Smith Jr. John Wiley & Sons Ltd. x + 132 pp. 64 ills. £10·25.

This is very much a book for the specialist who needs to calculate the transverse and longitudinal (or, in the USA terminology used, differential and common-mode) currents induced into transmission lines when they are subjected to a variety of electromagnetic fields.

The book is more than a reference book, yet not a complete textbook. The first topic treated is that of a 2-wire dissipative transmission line remote from earth, illuminated by a non-uniform electromagnetic field. The formula for the transverse current at any point is quoted but not derived; a bibliography at the end of the book indicates where proof may be found. For the man who is more concerned with solving practical problems, this lack of self-contained completeness is no disadvantage. From the general formula quoted, sending-end and receiving-end currents are derived as special cases. As an extension to this treatment, the case of a single wire close to earth, and connected via terminations at each end to a perfectly-conducting earth plane, is dealt with by the method of images. Formulae and graphs, enabling the attenuation of various 2-wire lines to be estimated, are included.

In the second chapter, the general equations quoted in the first are applied to derive rather simpler results that give the currents in loads connected to loss-free transmission lines illuminated by plane waves, firstly parallel to the terminations and secondly parallel to the conductors. Results of some calculations for special cases are presented as graphs.

In the third chapter, the general equations presented in the first are applied to 2 special cases where the field affecting the transmission lines is highly non-uniform: (*a*) where the excitation is by a small loop, and (*b*) where it is produced by a short dipole.

In the fourth and final chapter, the excitation of shielded conductors is dealt with, and graphs giving results of calculations for some typical cases are included. Five appendices and a bibliography complete the book. The contents of some of the appendices are readily available elsewhere (for example, tables of trigonometrical functions). Unfortunately, in my copy at least, the wording on the right-hand side of the bibliography (p. 126) has been cut off.

The formulae used in the book, although cumbersome, do not require for their understanding any mathematical ability beyond that required to cope with the traditional transmission-line equations, and an engineer who has a practical problem to solve should be able to use the book effectively. Except to such engineers, the volume is likely to be of very limited value.

As with so much of the literature on induction, one is left wondering whether, had experiments been conducted and the results shown to be in close agreement with the calculations, confidence in those calculations to solve everyday problems would have been enhanced.

L. J. Bolton

Institution of Post Office Electrical Engineers

General Secretary: Mr. R. Farr, THQ/NP 8.3.2, Room S 04, River Plate House, Finsbury Circus, London, EC2M 7LY; Tel.: 01-432 1954

RESULTS OF 1977–78 ESSAY COMPETITION

Prizes and Institution Certificates have been awarded to the following competitors in respect of the essays named.

The Council of the Institution records its appreciation to Messrs. R. H. Adams, D. W. Stenson and J. Axon who kindly undertook to adjudicate on the essays entered for the competition.

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 £20

Mr. D. L. Gaunt, Executive Engineer, Telecommunications Personnel Department, Telecommunications Headquarters: *Don't Shoot the Microprocessor—It's Doing its Best.*

Prizes of £12

Mr. J. G. Philip, Executive Engineer, Scottish Telecommunications Board Headquarters: *Communication by Public Speaking.*

Mr. J. G. Wardle, Assistant Executive Engineer, Midland Telecommunications Region Headquarters: *Electronic Switching Principles.*

Prize of £6

Mr. R. E. Wilson, Assistant Executive Engineer, York Telephone Area: *The Humble Pole.*

Certificate of Merit

Mr. K. R. Rawlings, Assistant Executive Engineer, Eastern Telecommunications Region Headquarters: *Carter and After.*

Section 2

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

Prize of £20

Mr. D. A. Heath, Technical Officer, Southampton Telephone Area: *The Future Switching Network.*

Prize of £15

Mr. M. N. Fletcher, Technical Officer, Blackburn Telephone Area: *A Call Tracing Unit for TXK1.*

Prize of £10

Mr. F. Eastham, Technical Officer, Blackburn Telephone Area: *The Long Day—Vintage '54.*

Prize of £5

Mr. R. F. Lambarth, Technical Officer, Norwich Telephone Area: *Radio Service or Diplomatic Service.*

Certificates of Merit

Mr. E. W. Fair, Technical Officer, Stoke-on-Trent Telephone Area: *Testing of Long Distance Private Circuits.*

Mr. M. F. Cruise, Technical Officer, Blackburn Telephone Area: *A Subjective Explanation of Trunking and Grading.*

ESSAY COMPETITION 1978–79

To further interest in the performance of telecommunications engineering work and to encourage the expression of thought given to day-to-day engineering activities, the Council of the Institution of Post Office Electrical Engineers offers cash prizes totalling £50 and up to 5 Certificates of Merit in each of the following sections:

Section 1. The most meritorious essays submitted by members of the Institution in BPO grades below the Senior Salary Structure and above the grades in Section 2, and including BPO engineering staff of the rank of Inspector.

Section 2. The most meritorious essays submitted by BPO engineering staff below the rank of Inspector.

The Council reserves the right to limit the amount of prizes and numbers of certificates awarded if, in its opinion, the essays submitted do not attain a sufficiently high standard.

In judging the merits of an essay, consideration will be given to clarity of expression, the correct use of words and to presentation and neatness. Although technical accuracy is important, a high technical standard is not essential. Marks will be awarded for originality.

Competitors may choose any subject relevant to engineering activities in the BPO. Manuscript entries are acceptable, A4 size paper should be used and the essay should contain 2000 – 5000 words. A 25 mm margin should be ruled on the left-hand side of each page for marking purposes. Competitors are required to certify their entry, at the end of the essay, in the following terms.

"*In forwarding the foregoing essay of .... words, I certify that the work is my own unaided effort, both in regard to composition and drawing.*

Name (block capitals) ....

Grade..

Signature..

Official Address ...."

The essays must reach

The Secretary,
The Institution of Post Office Electrical Engineers,
2–12 Gresham Street,
London EC2V 7AG

by 15 January 1979.

Prospective competitors may wish to note that awards of prizes and certificates are entered on the staff records of recipients, and that copies of prize-winning essays are retained in the central library of the Institution.

CONSTITUTION OF THE COUNCIL 1978–79

The Council for 1978–79 is constituted as follows.

Mr. J. F. P. Thomas, Chairman

Mr. D. Wray, Vice-Chairman

Mr. C. E. Clinch, Vice-Chairman

Mr. C. F. J. Hillen, Honorary Treasurer

Mr. A. G. Leighton, representing Group 1 (members in the Headquarters Departments and the London Regions holding posts in bands 1–8 of the Senior Salary Structure).

Mr. J. W. Rance, representing Group 2 (members in the provincial Regions holding posts in bands 3–8 of the Senior Salary Structure).

Mr. R. D. Edwards, representing Group 3 (members in the Headquarters Departments (London) holding posts in bands 9–10 of the Senior Salary Structure).

Mr. F. K. Marshall, representing Group 4 (members in the London Regions holding posts in bands 9–10 of the Senior Salary Structure).

Mr. D. G. Rossiter, representing Group 5 (members in the provincial Regions and in Headquarters Departments (provinces) holding posts in bands 9–10 of the Senior Salary Structure).

Mr. J. M. Avis, representing Group 6 (members in the Headquarters Departments (London) listed in Rule 5(a), with the exception of those in Group 14).

Mr. J. W. Turnbull, representing Group 7 (members in the London Regions listed in Rule 5(a), with the exception of those in Group 14).

Mr. L. W. F. Vranch, representing Group 8 (members in the provincial Regions and in Headquarters Departments (provinces) listed in Rule 5(a), with the exception of those in Group 15).

Mr. M. E. Barnes, representing Group 9 (members in the Headquarters Departments (London) listed in Rule 5(b) with the exception of those in Group 14).

Mr. J. E. Rosser, representing Group 10 (members in the London Regions listed in Rule 5(b), with the exception of those in Group 14).

Mr. R. C. Taylor, representing Group 11 (members in the provincial Regions and in Headquarters Departments (provinces) listed in Rule 5(b), with the exception of those in Group 15).

Mr. C. Stanger, representing Group 12 (Inspectors in the London Regions).

Mr. G. A. Gallagher, representing Group 13 (Inspectors in the provincial Regions).

Mr. R. O. G. Clarke, representing Group 14 (Draughtsmen, Illustrators and above, but below the Senior Salary Structure in Headquarters Departments (London) and London Regions).

Mr. K. Chinner, representing Group 15 (Draughtsmen, Illustrators and above, but below the Senior Salary Structure, in provincial Regions and Headquarters Departments (provinces)).

Mr. P. M. Annett, representing Group 16 (all affiliated members).

Representation for Groups 1, 6 and 8 was contested. The unsuccessful candidates, in descending order of votes cast where appropriate, were

Group 1	Mr. R. E. Stroud.
Group 6	Mr. J. M. MacKirdy.
Group 8	Mr. E. Critchlow, Mr. J. M. Smith, and Mr. T. G. Henderson.

CENTRE PROGRAMMES 1978–79

Eastern (Colchester)

Meetings will be held at the University of Essex commencing at 14.00 hours unless otherwise stated.

25 October: *Microprocessors* by D. L. Gaunt.

15 November: *Industrial Tribunals* by J. Beddoe.

7 December (at the Assembly Rooms, Norwich): *A Modern Approach to Engineering Training* by M. N. B. Thompson.

17 January (at the Marks Tey Motel, Colchester): *Modern Facsimile* by A. J. Bott.

21 February: *Second Generation Letter Mail Coding and Sorting* by E. G. Hills.

21 March: *Recent Developments in European Data Networks* by P. T. F. Kelly.

26 April (at Cambridge College of Art Auditorium): *Modernization—Which Way?* by J. S. Whyte, CBE, M.SC.(ENG), C.ENG, F.I.E.E. (President of I.P.O.E.E., Senior Director of Development).

London

Meetings will be held at the Central Electricity Generating Board (CEGB), Sudbury House, 15 Newgate Street, EC1 or at the Institution of Electrical Engineers (IEE), Savoy Place, WC2, commencing at 17.00 hours, with tea served from 16.30 hours.

2 October (IEE): *Modernization of the UK Telecommunications System* by J. S. Whyte, CBE, M.SC.(ENG), C.ENG, F.I.E.E. (President of I.P.O.E.E., Senior Director of Development).

23 October (IEE): *Modernization of Large Local Exchanges in the London Telecommunications Region* by J. P. Lawrence.

6 November (IEE): *The Changing Role of the Accommodation Services Engineer* by D. A. Spurgin.

27 November (CEGB): *Development of the Digital Main Network* by K. E. Ward.

11 December (IEE): *Technology in the Modernization of Mail Handling* by C. E. Clinch.

29 January (IEE): *Modern Facsimile Systems* by A. J. Bott.

13 February (CEGB): *Recent Developments in European Data Networks* by P. T. F. Kelly.

22 February (IEE): *Computer Aids for Modern Telecommunications Switching System Development* by W. O. Hatfield.

14 March (CEGB): *Introduction to Stored-Program-Control Software Development* by J. F. Buckley.

26 March (IEE): *System X, Part 1: System Organization* by J. Tippler.

17 April (CEGB): *System X, Part 2: Sub-System Techniques* by J. P. Kirtland.

24 April (CEGB): *System X, Part 3: Proposed Maintenance Organization* by E. Holligon.

2 May (IEE): Annual General Meeting followed by *The New Marketing Interface* by the Director of Telecommunications Marketing.

South Eastern

11 October (Sittingbourne) and 18 October (Guildford): *The Development of Digital Telephone Exchanges* by P. Deighton.

15 November (Hove): *The Changing Role of the Accommodation Services Engineer* by D. Spurgin.

6 December (Hove): *The Importance and Influence of Engineers in General Management* by A. P. Parsons.

10 January (Hove): *Technology in the Modernization of Mail Handling* by C. E. Clinch.

Other meetings are being arranged and will be announced later.

Local-Centre Secretaries

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

Centre	*Local Secretary*	*Address and Telephone Number*	
Birmingham	Mr. D. F. Ashmore	General Manager's Office, ED3.7, 84 Newhall Street, Birmingham B3 1EA	021-262 4831
Eastern (Bletchley)	Mr. D. R. Norman	General Manager's Office, ED9.3, Telephone House, 25–27 St. John's Street, Bedford MK42 0BA	(0234) 55860
Eastern (Colchester)	Mr. P. M. Cholerton	Eastern Telecommunications Region, PLG1.3.3, St. Peter's House, St. Peter's Street, Colchester CO1 1ET	(0206) 89458
East Midlands	Mr. D. W. Sharman	General Manager's Office, ES3.3, 200 Charles Street, Leicester LE1 1BB	(0533) 534409
London	Mr. M. S. Armitage	c/o LTR Registry, Camelford House, 87 Albert Embankment, London SE1 7TS	
Martlesham	Mr. A. F. Hare	PO Research Centre, ResD/R2.1.2, Martlesham Heath, Ipswich IP5 7RE	(0473) 643487
North Eastern	Mr. D. Spencer	North East Telecommunications Region, S133, Darley House, 79 St. Paul's Street, Leeds LS1 4LW	(0532) 37529
Northern	Mr. L. G. P. Farmer	General Manager's Office, UI 28, Swan House, Pilgrim Street, Newcastle-upon-Tyne NE1 1BA	(0632) 27212
Northern Ireland	Mr. W. H. Tolerton	General Manager's Office, EC1, Dial House, 3 Upper Queen Street, Belfast BT1 6LS	(0232) 24777
North Western (Manchester and Liverpool)	Mr. W. Edwards	North West Telecommunications Board, PLG112, Bridgewater House, 60 Whitworth Street, Manchester M60 1DP	061–863 7267
North Western (Preston)	Mr. J. W. Allison	MX26, Telephone Exchange, Preston Old Road, Marton, Blackpool FY3 9PR	(0253) 62162
Scotland East	Mr. W. L. Smith	Scottish Telecommunications Board, P223, Canning House, 19 Canning Street, Edinburgh EH3 8TH	031–222 2248
Scotland West	Mr. G. A. Dobbie	General Manager's Office, EX14, India House, 6–10 India Street, Glasgow G2 4PU	041–220 2697
South Eastern	Mr. J. M. Smith	South East Telecommunications Region, PL/LT1.2, 52 Churchill Square, Brighton BN1 2ER	(0273) 201318
South Western	Mr. R. C. Willis	South West Telecommunications Board, PL4.2.3, Mercury House, Bond Street, Bristol BS1 3TD	(0272) 295583
Stone/Stoke	Mr. K. A. Priddey	TP 7.2.3D, Post Office Technical Training College, Stone ST15 0NQ	(078 583) 3631
Wales and the Marches	Mr. D. A. Randles	Wales and the Marches Telecommunications Board, PW3.1.2.2, 25 Pendwyallt Road, Coryton, Cardiff CF4 7YR	(0222) 391370

Stone/Stoke

Meetings will be held at the City Central Library, Hanley, Stoke-on-Trent, or at the Post Office Technical Training College (POTTC), Stone and will commence at 14.15 hours with the exception of the Joint meetings on 11 December and 15 February which will commence at 19.00 hours, with tea at 18.30 hours.

16 October (Hanley): *The History and Importance of the Ironbridge Gorge Museum Area* by Mr. S. B. Smith, M.SC., A.M.A (Deputy Director and Curator of the Ironbridge Gorge Museum Trust).

20 November (POTTC): *Corrosion in Heating and Chilling Circuits—Its Cause and the Remedy* by P. S. Meutzel (Chief Chemist, Industrial (Anti-Corrosion) Services).

11 December (Hanley): *Private Digital-Exchange Developments* by R. C. Gibbs.

11 December (POTTC): *Body Imaging by Radio Waves* by P. Mansfield, B.SC., PH.D. (Nottingham University) (Joint meeting with the Institution of Electrical Engineers).

15 January (POTTC): *The Netherlands and Its Telecommunications Services* by J. James.

12 February (Hanley): *The Main Network—Present and Future* by K. E. Ward.

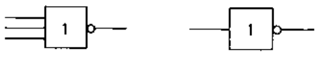
15 February (POTTC): *Semi-Conductor Sources in Optical-Fibre Transmission Systems* by D. H. Newman (Joint meeting with the Institution of Electronic and Radio Engineers).

12 March (POTTC): *Environmental Aspects of Telecommunications Buildings* by E. V. Pearce.

Notes and Comments

CORRECTION

The editors seek the indulgence of readers for the fact that the clarification given in the correction on p. 137 of the July 1978 issue only confused further by being incorrect. One could say that, the NOT was not a NOT nor was the NOR a NOR but the NOT was a NOR and the NOR was a NOT. To clarify finally the position, the symbols are reproduced below in their correct form.



NOR NOT

CONTRIBUTIONS TO THE JOURNAL

Contributions to the *POEEJ* are always welcome. In particular, the Board of Editors would like to reaffirm its desire to continue to receive contributions from Regions and Areas, and from those Headquarters departments that are traditionally modest about their work.

Anyone who feels that he or she could contribute an article (short or long) of technical, managerial or general interest to engineers in the Post Office is invited to contact the Managing Editor at the address given below. The editors will always be pleased to give advice and try to arrange for help with the preparation of an article, if needed.

GUIDANCE FOR AUTHORS

Some guiding notes are available to authors to help them prepare manuscripts of *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal*'s editors, printer and illustrators, and help ensure that authors' wishes are easily interpreted. Any author preparing an article is invited to write to the Managing Editor, at the address given below, to obtain a copy.

All contributions to the *Journal*, including those for Associate Section Notes, must be typed, with double spacing between lines, on one side only of each sheet of paper.

As a guide, there are about 750 words to a page, allowing for illustrations, and the average length of an article is about 6 pages, although shorter articles are welcome. Contributions should preferably be illustrated by photographs, diagrams or sketches. Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that is required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour prints and slides can be accepted for black-and-white reproduction. Negatives are not required.

It is important that approval for publication is given at organizational level 5 (that is, at General Manager/Regional Controller/THQ Head of Division level) and authors should seek approval, through supervising officers if appropriate, before submitting manuscripts.

Contributions should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

PUBLICATION OF CORRESPONDENCE

The Board of Editors would like to publish correspondence on engineering, technical or other aspects of articles published in the *Journal*, or on related topics. Letters of sufficient interest will be published under Notes and Comments.

Letters intended for publication should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Associate Section Notes

ABERDEEN CENTRE

The Centre's 1978 programme started with a visit to the Comex diving complex in Aberdeen, where we were shown training and decompression facilities used by deep-sea divers. This was followed by a close inspection of diving bells, and of a small submarine which is used in the North Sea oil fields.

During February, an illustrated talk on *Prestel* was given to members by Mr. T. Dunn from the Research Centre at Martlesham. A demonstration of the system showed its versatility.

During a visit to General Instruments Ltd. in April we were shown the manufacturing processes involved in producing integrated circuits. The session was brought to a close on 26 May with the annual general meeting, which was followed by a very successful social evening.

I. Pyper

DUNDEE CENTRE

A joint meeting with the Stirling Centre was held at Perth in February when more than 30 members were given an insight into *Prestel* by Mr. T. Dunn of the British Post Office Research Department. The lecture was made even more interesting by a demonstration of a Prestel terminal with an expert to show its use.

In March, a small party visited one of the gas pumping stations in the area. After a talk on the environmental aspects (considered unnecessary by many, as the party had had difficulty finding the station), we were shown the facilities provided. Perhaps it was fortunate that the station was not operational as we were able to see parts of the station which would not otherwise have been available, including engine compartments containing Rolls Royce Avon engines.

G. K. Duncan

NOTTINGHAM CENTRE

At the annual general meeting, held on 25 April 1978, the following officers and committee were elected for the 1978–79 session. The President, Mr. K. Chandler, kindly again accepted office for the coming year.

Chairman: Mr. B. M. Smith.
Secretary: Mr. M. Rush.
Treasurer: Mr. R. H. Marsh.
Assistant Secretary: Mr. M. P. Melbourne.
Librarian: Mr. P. Birchmore.
Quiz Secretary: Mr. J. D. Liley.
Committee: Messrs. R. Taylor, L. E. Smith, G. Fotheringham and A. P. Garner.

Three short films of general interest were shown after the annual general meeting.

On 7 June, our quiz team met the Evesham representatives in the Midland Region final. A close fought match resulted in our scoring 33½ points to Evesham's 30, and thus we go forward to the national heats.

The first event of the 1978–79 programme was held in June when members were invited to share an evening in the company of the Mansfield branch of the British Sub-Aqua Club. We heard a talk and saw a demonstration of the club's activities.

M. Rush

Forthcoming Conferences

Further details can be obtained from the conference department of the organizing Institution.

Institution of Electronic and Radio Engineers, 99 Gower Street, London WC1E 6AZ. Telephone: 01–388 3071

Television Measurement
21–23 May 1979
The Commonwealth Institute, London

Video and Data Recording
24–27 July 1979
The University of Southampton
Papers: Summary by 27 October 1978; final by 16 March 1979

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

Antennas and Propagation
28–30 November 1978
The Institution of Electrical Engineers

Trends in On-Line Computer Control Systems
27–29 March 1979
University of Sheffield

Electronic Test and Measuring Instrumentation
19–21 June 1979
Wembley Conference Centre

Computer Aided Design and Manufacture of Electronic Components, Circuits and Systems
3–5 July 1979
University of Sussex

The Post Office Electrical Engineers' Journal

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Subscriptions and Back Numbers

The *Journal* is published quarterly in April, July, October and January, at 55p per copy (80p per copy including postage and packaging); annual subscription: £3·20; Canada and the USA: $6·50.

The price to British Post Office staff is 36p per copy.

Back numbers will be supplied if available, price 55p (80p including postage and packaging). At present, copies are available of all issues from April 1973 to date with the exception of the April and October 1975 issues; copies of the July 1970 and April 1972 issues are also still available.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.

Employees of the British Post Office can obtain the *Journal* through local agents.

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Readers can have their copies bound at a cost of £5·25, including return postage, by sending the complete set of parts, with a remittance, to Press Binders Ltd., 4 Iliffe Yard, London SE17 3QA.

Remittances

Remittances for all items (except binding) should be made payable to "*The POEE Journal*" and should be crossed "& Co."

Advertisements

All enquires relating to advertisement space reservations should be addressed to Mrs. S. Underwood, Advertisement Manager, The Kemps Group, Forge House, Bell Lane, Brightwell-cum-Sotwell, Wallingford, Oxon. (Telephone: 0491 35448 or 0491 39370).

Advertisement copy should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S08, River Plate House, Finsbury Circus, London EC2M 7LY.

Distribution and Sales

Correspondence relating to the distribution and sale of the *Journal* should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG.

Communications

With the exceptions indicated above, all communications should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY (telephone 01-432 4840).

Model-Answer Books

Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Details of the books available are given at the end of the Supplement to this *Journal*. Copies of the syllabi and question papers are not sold by *The Post Office Electrical Engineers' Journal*, but may be purchased from the Department of Technology, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

IPOEE CENTRAL LIBRARY

Any member who does not have a copy of the catalogue can obtain one from the Librarian, IPOEE, 2–12 Gresham Street, London EC2V 7AG. Library requisition forms are also available from the Librarian, from honorary local-centre secretaries, and from Associate Section centre secretaries and representatives.

Alternatively, the panel below, or a photocopy, can be used (only by members) to borrow any book listed in the catalogue or in the updating lists published in recent issues of the *POEEJ*. The form should be sent to the Librarian at the address above; a self-addressed label must be enclosed.

IPOEE Central Library

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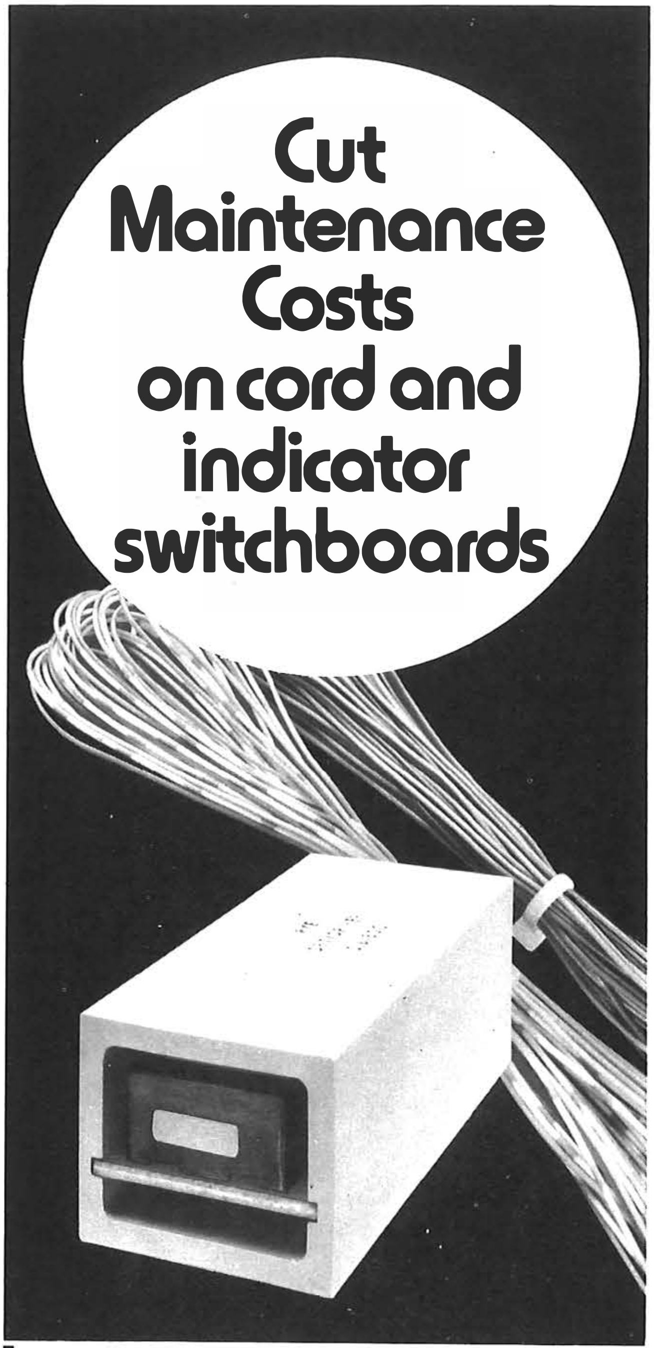

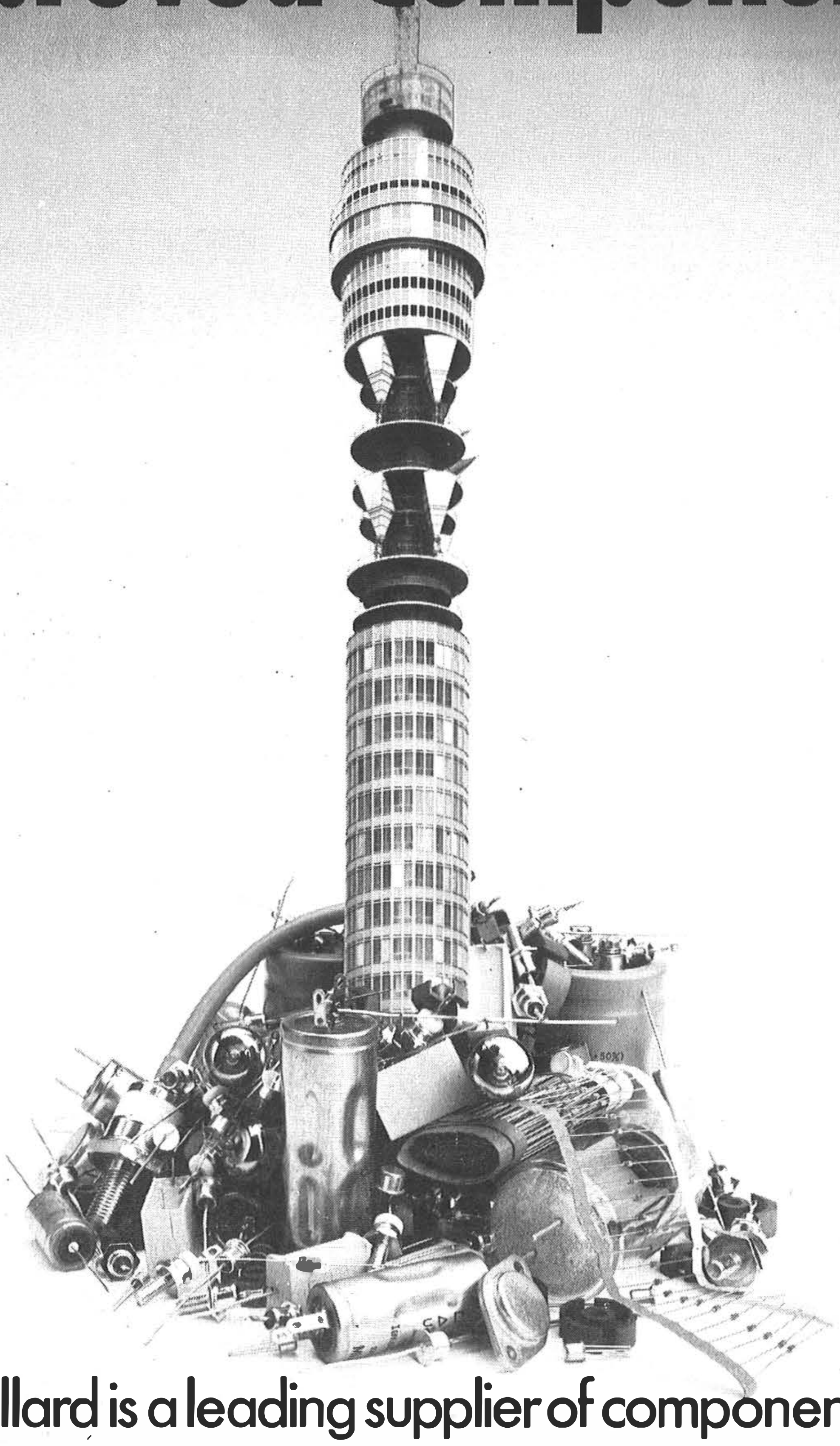

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