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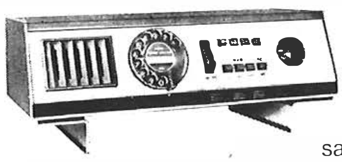

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The Post Office Electrical Engineers' Journal

EDITORIAL

Predominantly, the articles published in the *Journal* are concerned with present day and future developments of telecommunication equipment and systems. This is in keeping with the prime object of the *Journal* to inform on such matters. However, matters of historical interest are also included and, from comments received, are welcomed by the readership. Because of a partial relaxation of official security, it is now possible to reveal the significant and important contribution made by British Post Office personnel during the 1940s to the development of the first electronic computer. It is with pride that the *Journal* publishes in this issue (p. 108) an article entitled *COLOSSUS and the History of Computing*, which recognizes this fine achievement.

A new style of presentation of Regional Notes is introduced in this issue. The object is to give more prominence to these contributions, thereby reaffirming that Regional Notes are an integral part of the *Journal*. It is hoped that the new style of presentation will give added encouragement to potential authors to submit contributions.

The first 2 articles of a series on international telephony appear in this issue. The article on p. 81 introduces the series by relating the growth of the international telephone services to the developments in transmission, signalling and switching that have made them possible. The TXK2 exchange switching system is then described in the article on p. 86. Other articles in the series will describe the TXK5 and TXK6 exchange system designs and the signalling systems in use for international telephone services.

Pathfinder: An Experimental Telephone Exchange Using Stored-Program Control

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FOREWORD

Most of the work of the British Post Office (BPO) Research Department is carried out under laboratory conditions at the new Research Centre at Martlesham. However, in some cases, it is found desirable to expose the experimental equipment to the effects of service under field conditions.

An early example of this was the digital tandem exchange, Empress[1], which first carried live traffic in 1968. It was therefore appropriate that the new experimental stored-program-controlled (SPC) local exchange, Pathfinder, described in this article, carried its first calls on 16 February 1976, only a few months after the Empress exchange was withdrawn from service.

The formal opening of Pathfinder was performed at Martlesham in May 1976 by Dr. Ena Knight (Director, Eastern Telecommunications Region) and Mr. Charles May (Director of Research). The participation of Dr. Knight in the opening ceremony was particularly welcomed because the staff of the Eastern Telecommunications Region had contributed greatly to solving the many problems of interworking Pathfinder with the rest of the telephone network.

After 1 year of operation, Pathfinder has provided valuable data on the problems of commissioning, operating and maintaining an SPC local exchange. The result of all this operational experience is forming a valuable source of information to the joint BPO and industry development of the new series of exchange systems—System X.

C. J. HUGHES
Deputy Director of
Research Department

INTRODUCTION

Many administrations throughout the world have introduced telephone exchanges using stored-program control (SPC) into their networks[2]. The British Post Office (BPO) has adopted a cautious attitude because this world experience has shown that, until recently, the use of computers for the control of a telephone exchange has been economic for only the large exchange that represents a small proportion of the UK installations. Also, the costs involved in preparing the computer programs and the design of the interfaces to the existing network have been extremely high.

For several years, the Research Department of the BPO has, therefore, been developing methods of applying SPC to the very small exchange of only a few hundred customers, and studies on an experimental design have now shown the cost to be comparable with that of existing exchanges. The use of a high-level language[3] has also reduced the programming costs, so that processor-controlled* exchanges are now under development for the UK network.

An aspect of SPC exchanges of particular interest to the BPO is the different maintenance techniques that they require. The high operational speeds and concentrated form of the complex electronic circuitry would require expensive test equipment and prolonged faulting procedures by highly-trained staff. The processing power which is available in SPC systems means that immediate and detailed information on a fault, or possible fault, can be passed to a central processor and there correlated with other information to deduce the location and severity of the fault. The equipment may then

† Research Department, Telecommunications Headquarters

* The term processor is used in this article to mean computer-like equipment, which controls industrial processes or telephone call connexions where the control tasks have to be performed as events occur

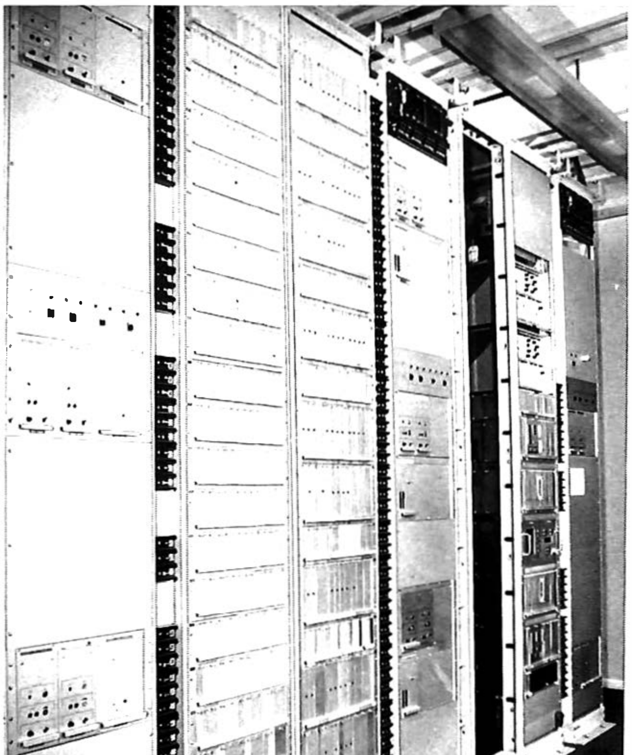

FIG. 1—A general view of the Pathfinder exchange equipment

be removed from service automatically and the information converted by the processor into a more readily understood man–machine language; this can be displayed on a visual display unit (VDU) or printer at a remote maintenance control centre. Using the man–machine language, the engineer can then interrogate the system for further information before initiating maintenance action.

To enable these principles to be tested in an operational environment, an experimental design of small local exchange has been installed at the Martlesham Research Centre (see Fig. 1) to serve 100 staff on the site. The exchange, which is known as *Pathfinder,* operates as a fully independent local exchange, with a dedicated national code and a range of junctions to and from the group switching centre (GSC) at Ipswich; it also has standard junctions to the TXE2 exchange[4] that serves the Research Centre. Most of the telephone instruments connected to Pathfinder are equipped with keypads and multi-frequency signalling, so that own-exchange calls are set up virtually instantaneously. For calls into the network, the exchange converts the multi-frequency signals into 10 pulses/s loop-disconnect signals; this causes a large post-dialling delay on long-distance connexions. Setting-up calls to the TXE2 exchange for access to the rest of the site is accelerated by making the Pathfinder numbering range part of the TXE2 exchange range, so that access digits are unnecessary.

If fully equipped, the Pathfinder design would be capable of serving up to 2000 subscribers, with a total traffic limit of about 100 erlangs.

EXCHANGE STRUCTURE

General Description

A block diagram of the Pathfinder exchange is shown in Fig. 2, which shows that the exchange can be divided into the following 4 areas.

(*a*) *Equipment allocated permanently to a given subscriber.* This consists of the line units, which monitor the loop resistance of a subscriber's line, and part of the scan-and-park stores (SPSs), which periodically interrogate the line units and store the busy/free/parked condition of each line.

(*b*) *The switchblock.* This concentrates the traffic from subscribers with a relatively low calling rate to the high-occupancy area of registers and supervisories.

(*c*) *Common equipment allocated exclusively to one call for part of its duration.* This comprises the registers, which receive the wanted number, and supervisory units, which provide an a.c.–d.c. split and monitor the line conditions on each side of it.

(*d*) *The processors and their associated control equipment.* These are time-shared among all subscribers and calls, and consist of the pre-processor utility (PPU), situated in the exchange building, and the processor utility (PU) at a remote location.

The major growth unit for subscribers' line units and the switchblock is a 10 erlang rack, which can accommodate up to 500 subscribers with an average originating traffic of 0·02 erlang each, or correspondingly fewer subscribers with higher originating traffic. One supervisory rack can handle the traffic from up to 4 switching racks, and one control rack serves all sizes of exchange up to more than 100 erlangs total traffic.

The control structure of Pathfinder is described in the next section.

Subscribers' Line Units

Each subscriber's line is monitored by a high-resistance (over 20 kΩ) loop detector, which can be permanently connected to the line without causing transmission impairment or interfering with d.c. signalling conditions. The outputs from up to 24 loop detectors are connected to a subscriber's SPS which monitors the state of each subscriber's line and flags significant changes to a block SPS. Each block SPS, which monitors 4 subscribers' SPSs, flags significant changes

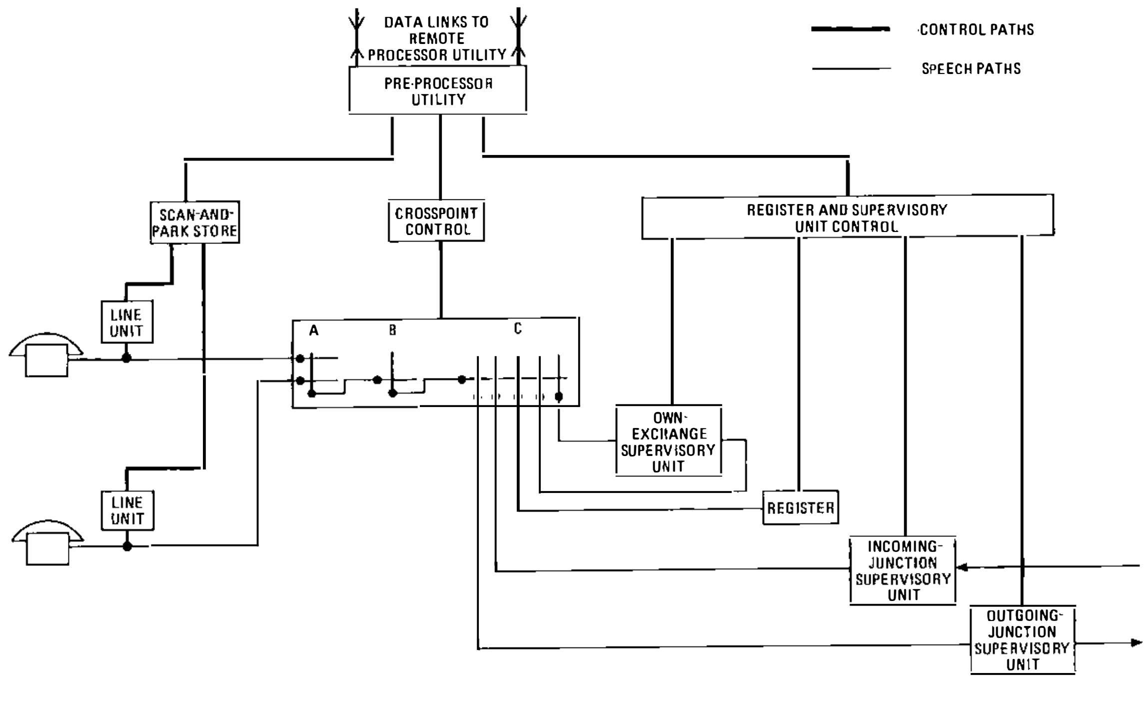

FIG. 2—Pathfinder block diagram

to the PPU. The subscribers' line units and their associated SPS are distributed between 3 security areas; each security area is fed from its own independent power supply, so that failure of one power supply cannot cause loss of service to more than one third of the subscribers connected to the exchange.

Switchblock

The basic building block for all switching stages in Pathfinder is effectively a 6 × 6 matrix of reed-relay crosspoints. The reed relays have 4 inserts. The reed contacts are used to switch only the speech path so that, as 2 inserts are required for each crosspoint, one relay can operate 2 crosspoints simultaneously. Two steering relays associated with each row of crosspoints in a switch select which of the 2 crosspoints in a relay is used. Each relay is controlled individually by a crosspoint control unit, which stores the state of each relay as 1 bit in its memory.

To reduce the number of relay drivers required, the relays are operated by co-ordinate pulses. Referring to Fig. 3, the drivers for rows 1–6 are fed with 6 phases of a pulse train having a duty ratio of 1 : 6 at a frequency of 16 kHz. To operate the relay at, for example, the intersection of row 4 and column 3, column driver 3 must be fed with a pulse train that is in phase with that from row driver 4. Relay (4,3), shown hatched, is then energized with a duty ratio of 1 : 6. A diode connected in parallel with each relay coil maintains the current in the coil when the drivers are turned off. The current in a relay coil when it is operated therefore consists of a steady component with a small superimposed 16 kHz ripple, and the relay remains operated as long as its row and column drivers are pulsed in synchronism.

The techniques of shared 4-insert relays and co-ordinate pulse operation will probably be replaced in the longer term by 2-insert reed relays driven by large-scale-integration (LSI) driver circuits with one latch per relay; a prototype has

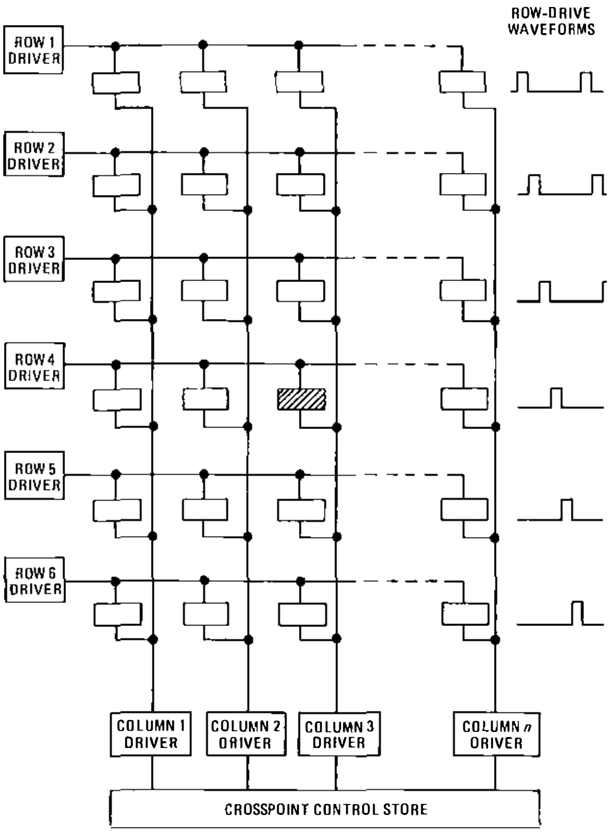

FIG. 3—Co-ordinate pulse operation of relays

been constructed with the driver integrated circuit (IC) and the relays mounted on one card.

There are 3 switching stages, A, B, and C, which concentrate the traffic from low-occupancy terminations (subscribers) to high-occupancy terminations (digit receivers and supervisory units), trunked in a similar way to TXE2 exchanges.[4] Pathfinder and TXE2 exchanges differ, however, in that Pathfinder does not use a D-switch to connect the incoming side of supervisory units to the C-switch. To reduce the probability of blocking on incoming-junction calls, each incoming-junction supervisory unit is connected to 2 C-switch terminals.

Registers

Pathfinder registers are controlled by microprocessors, as described later. This allows the details of supervision of a call during its setting-up phase, and the reception of each digit, to be carried out without reference to the PPU; the digits are transferred to the PPU, one at a time, as they are received. Changes in, for instance, subscribers' signalling systems can be handled by changing the program of the controlling microprocessor.

Three types of subscriber signalling are provided for Pathfinder:

(*a*) 10 pulses/s from a dial,
(*b*) Signalling System Multi-Frequency No. 4 (SSMF 4), and
(*c*) high-speed binary signalling.

Most of the telephones connected to Pathfinder have 12-button keypads used in conjunction with SSMF 4 signalling[5,6], which uses 2 voice-frequency tones to represent each digit. This provides for faster signalling from the subscriber to the exchange and, besides the digits 0–9, it offers 2 characters, * and #, that are used in activating supplementary services. Four other characters are available in the SSMF 4 for future use, but expansion beyond 16 characters is not possible.

Some terminals may eventually require a larger range of characters (for example, for a Viewdata[7] message transmission service, or for access to an automated directory-enquiry service), and a more extensible system has been developed using high-speed binary-coded signalling. This sends each character as a train of 8 loop-disconnect pulses at about 90 baud, using the same start-stop principle as the Telex system. The signalling speed, in characters per second, is as high as that for SSMF 4, and the code has capacity for a set of 64 characters. Some 12-button instruments using a subset of this range are connected to Pathfinder.

The register can discriminate between the 3 types of signalling by examining the line conditions. Reference to a *class-of-service* mark is unnecessary; therefore, a mixture of signalling systems can be used for a PBX or its extension telephones without difficulty, and any subscriber's telephone can be changed from one signalling system to another without needing to change any equipment or records in the exchange.

Supervisory Units

Pathfinder supervisory units are also controlled by microprocessors. Each supervisory unit consists of 2 half-sections, (own-exchange plus own-exchange, own-exchange plus outgoing-junction, or incoming-junction plus own-exchange), and one microprocessor controls a number of identical half-sections. Junction supervisory half-sections handle the details of reception or transmission of digits over the junction, so that a change from, for example, loop-disconnect to signalling systems AC 9 or MF 6 would not require any change of the program in the PPU.

Own-exchange supervisory half-sections can detect coin pulses and control the coin slots of pay-on-answer coin-collecting boxes, all the control logic being performed by the PPU. The only special arrangement necessary for a coin-box connexion is a mark in the class-of-service store.

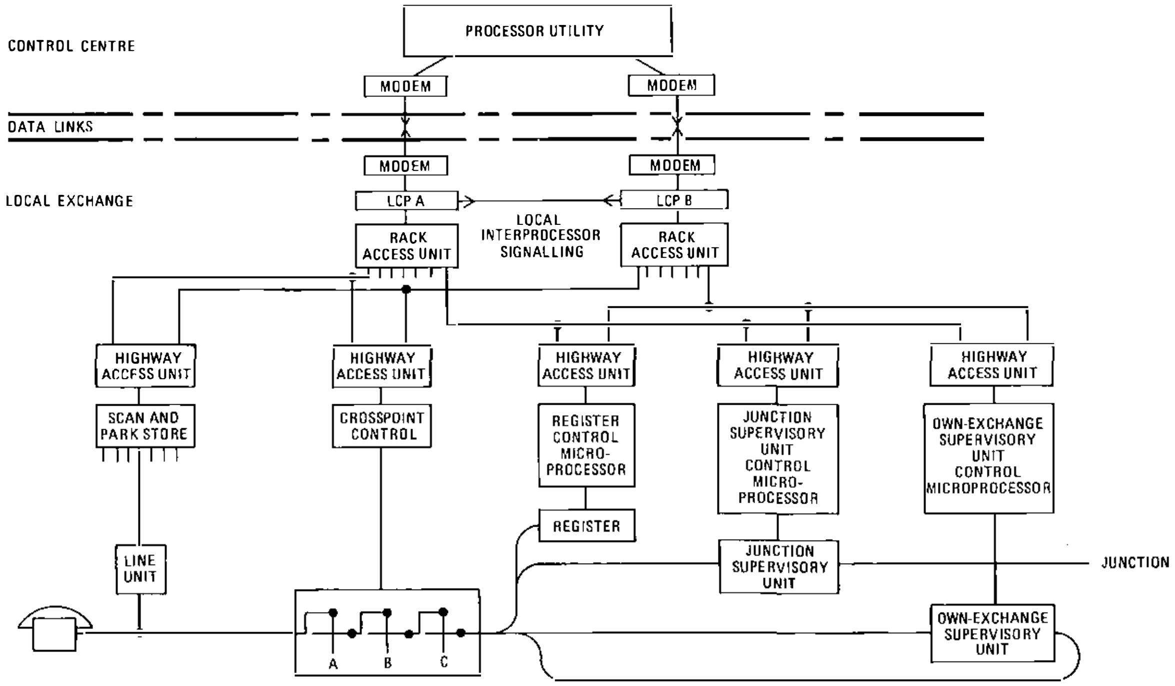

FIG. 4—Control structure

CONTROL STRUCTURE

General

Fig. 4 is a block diagram of the Pathfinder control system, and this shows that there is a 3-level hierarchy of control processors, consisting of

(*a*) the PU in a remote main control centre,

(*b*) 2 local control processors (LCPs) that together form the PPU, and

(*c*) a large number of microprocessors that control registers and supervisory units.

The Processor Utility

The PU is a large, powerful, reliable processor system, housed in a main control centre. Because of its large size and high reliability, the PU is relatively expensive and, to use it effectively, it is shared between a number of small remote exchanges such as Pathfinder. To achieve the high reliability and to allow smooth growth of the PU as its load increases, a multiprocessor system is used, permitting any of a number of processors to gain access to any of a number of store modules. This allows "graceful degradation" of the system if a processor or store module fails.

At present, the PU function for Pathfinder is fulfilled by a single Honeywell 516 computer, but it is intended that this will be replaced by a GEC Mark 2BL multi-processor system. The 516 software† has been structured to minimize the reprogramming needed for the change. The PU provides those functions that require large amounts of storage, are relatively infrequently required, or are most logically provided at a central point. Examples are fault diagnosis, supplementary services such as short-code dialling and subscriber-controlled transfer, billing, traffic analysis, and man–machine interaction. In particular, the comprehensive maintenance and diagnostic facilities designed into Pathfinder will rely heavily on correlation of fault reports in the PU.

† The programmed sequence of logical steps, which in combination make the processor perform a task, can easily be modified by changing electrical or magnetic conditions that define the binary digits in each step; they are therefore *soft*. The topology of the circuits which implement each logical step is not easily changed, and is therefore *hard*

The Message Transmission Subsystem

The PU will be linked to each of the local exchanges under its control by a message transmission subsystem (MTS). This consists of 2 data links, preferably over different routes, with their terminal equipments connected to ports of the PU at the control centre, and independently to each LCP at the local exchange. Each data link requires a 4 kHz bandwidth 4-wire circuit, which can use loaded junction pairs or frequency-division multiplex channels, one pair or channel for each direction of transmission. The data rate for the Pathfinder MTS[8] is 2·4 kbit/s; this is governed by the amount of time required to transmit a message and receive a reply, rather than by the long-term average data rate between the exchange and the PU. The Pathfinder MTS is 0·5 km in length, although lengths up to 100 km are feasible.

As the network evolves, and pulse-code-modulation (PCM) junctions become available between local exchanges and controlling PUs, the MTS will use a 64 kbit/s channel in the PCM primary multiplex; this will remove the need for modems and offer a much reduced time to transmit a message.

The Local Control Processor

The LCP, which is shown in Fig. 5, is a small processor[9] designed in Research Department for efficient control of telephone exchanges at a low capital cost. Each processor, with 16 000 words of program storage and 3000 words of data storage, occupies one shelf of a rack 533 mm wide. A fully-equipped exchange (100 erlangs) would require 12 000 words of data storage, although the LCP with its existing program storage could control an exchange carrying 500 erlangs of traffic.

Pathfinder uses 2 LCPs, working in a main and stand-by mode, to form a PPU with a mean time between failures of over 50 years. In normal operation, one LCP controls the exchange hardware, and sends information about the state of the hardware to the stand-by processor over a local interprocessor signalling link. If the main LCP fails, the stand-by can then take over control of the exchange with minimal disturbance of calls in progress. The interprocessor signalling link uses optical isolators so that there is no electrical connexion between the 2 LCPs; thus, a catastrophic fault (such as might result from inadvertent connexion of 240 V a.c.) in one processor cannot damage the other.

To ensure that an emergency change-over occurs only if the main LCP fails and the stand-by LCP is working correctly,

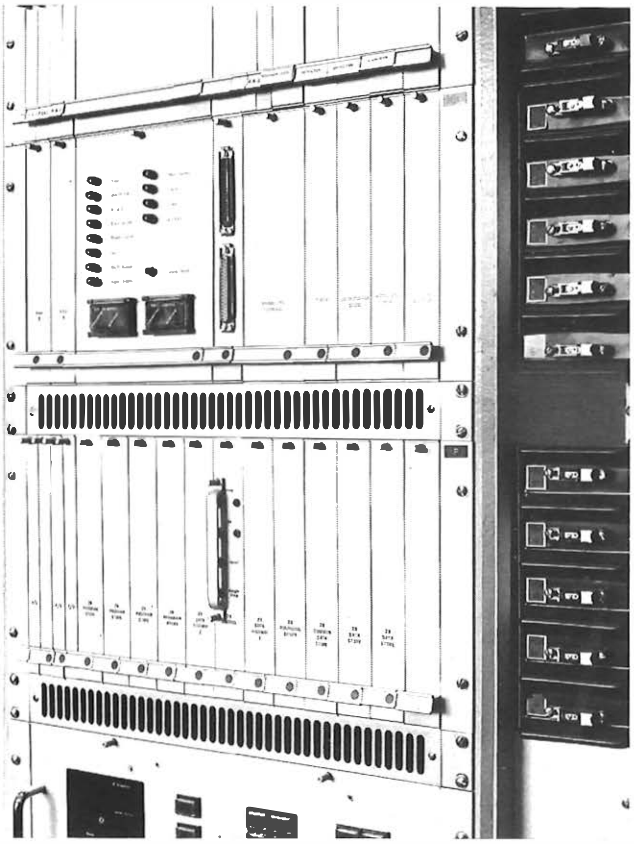

FIG. 5—A local control processor

a security scheme using a combination of hardware and software is necessary. Fig. 6 is a block diagram of the security hardware that controls access by each LCP to the exchange highways. The principal components of the security scheme are self-checking programs that are regularly run in both main and stand-by LCPs, and error-detection circuits known as *watchdogs*; 2 of these are associated with each LCP: one checks the other LCP and one checks the MTS link. The watchdogs include timing circuits that are continually reset to zero by the occurrence of events in their correct sequence. Should any event not occur in correct sequence, the watchdog is not reset and produces an alarm.

Every time an LCP enters a program segment, it sends a time code and a sequence code to its watchdog. The watchdog refers to a look-up table held in a read-only memory to find the next sequence code that it should receive. If this shows the sequence code to be incorrect, or if it is not received within the time specified by the time code, the watchdog signals a failure. The principle of the MTS watchdog is similar; the sequence codes are sent from the PU via the MTS, and a fixed maximum interval is allowed between code messages before an alarm occurs. Messages will normally be received in less than half this time.

A change-over can also be initiated from a control panel in the local exchange, or by a message from the PU. Before a controlled change-over takes place, all watchdogs are tested by generating codes that should cause them to fail, and monitoring their outputs. The change-over mechanism is tested at intervals of about 24 h by a simulated failure indication from the PU. These controlled change-overs do not affect service, but a genuine emergency change-over may affect calls being set up at the time.

A failure of both LCPs causes loss of service but, if the fault is transient, the system can recover by clearing all calls and initializing both LCPs. If the fault is persistent, recovery requires reloading of the control program into both LCPs. In Pathfinder at present, this requires manual intervention at the exchange but, eventually, the LCPs will be reloaded over the MTS under the control of the PU. The program to control communication with the MTS and reload the exchange control program will be held in a read-only memory to prevent corruption if the power supply fails.

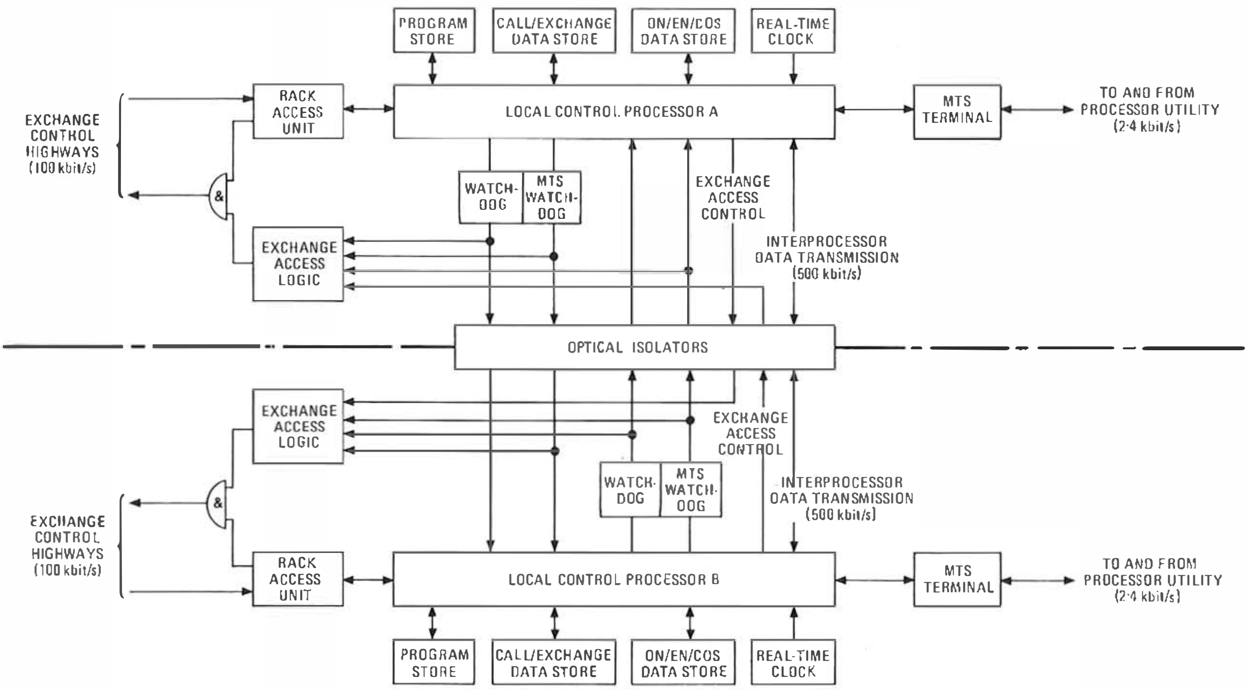

FIG. 6—LCP security block diagram

Exchange Highways

Each LCP communicates with the exchange over serial-data highways, with a data rate of 100 kbit/s. This data rate allows several metres of twisted pair to be driven by metal-oxide-silicon transistors that form part of an LSI circuit. Each highway consists of 4 twisted pairs: one pair carries data from the LCP to the exchange, another carries the associated clock signal, and the third and fourth pairs carry data and clock signals from the exchange to the LCP. The interface between the LCP and the highways is the rack access unit, which accepts data in 8 bit parallel form from the LCP and transmits it serially over the appropriate highway. In the reverse direction, serial data from the highways is received and passed in 8 bit parallel form to the LCP.

The interface between the exchange highways and the control units is the highway access unit (HAU), which can receive data from either LCP and pass it to its control unit in serial and/or parallel form as required by the control unit. There can be up to 64 HAUs on each highway. The messages from the LCP to the exchange include a 6 bit field that indicates the HAU for which the message is intended: only the HAU addressed by a message responds. The address of an HAU is determined by the wiring of the position into which the HAU is plugged, so that any HAU can be used in any position in the exchange. The current version of the HAU uses a number of transistor-transistor-logic ICs on a single printed-wiring board, but work by the Microelectronics Division of Research Department is well advanced on the production of a single-chip LSI version. The existing HAU and a prototype of the LSI chip are shown in Fig. 7; the chip will be mounted on the same board as its associated control unit.

Microprocessors

Supervisory units and registers in Pathfinder are controlled by identical microprocessors, with the software for the different tasks contained in associated read-only memory devices. The microprocessor is a single IC, mounted on a board with a number of other ICs that interface the microprocessor to the rest of the exchange. The hardware for the microprocessors controlling registers or supervisory units is thus standardized[10], resulting in potential cost savings from the ability to purchase in larger quantities and to reduce the number of spares. If a microprocessor fails, the registers or supervisory units controlled by it are inoperable. The failure of the microprocessor is, however, detected by the LCP, and traffic can be diverted from the registers or supervisory units. The effect on the exchange is to worsen the grade of service, but no subscriber suffers permanent loss of service.

EXCHANGE OPERATION

Own-Exchange Calls

A calling-subscriber's loop is detected by his line unit, which marks its inlet to an associated SPS. When the SPS detects

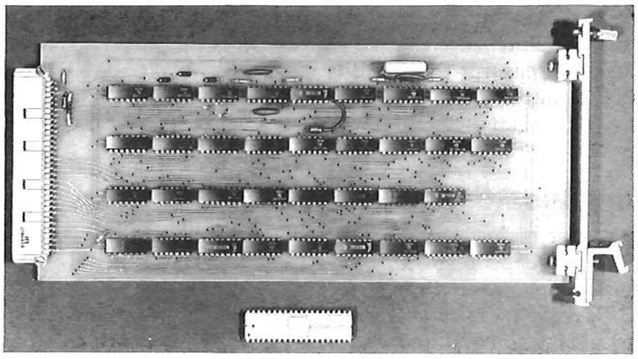

Fig. 7—The existing HAU with a prototype LSI replacement

the marked inlet, it stores the address and, in turn, marks its inlet to a block SPS; this again stores the address and sends a signal to the PPU. When the PPU recognizes this signal, a 2-stage sequential interrogation process identifies the calling line. This process takes between 2–30 ms, depending on the traffic carried. The PPU uses the calling A-switch equipment number to obtain the class of service (COS) from the COS store, which is a read/write memory connected as a peripheral to each LCP; if the subscriber is allowed to make outgoing calls, an attempt is made to connect a register. When a path has been set up to a register, a path-continuity test is made (as explained later) and, if this is successful, the register connects dial tone and line current to the calling line. If the path-continuity test fails, a path is set up to a second register: if the test from this register fails, equipment-engaged tone is connected to the subscriber. If there is no free path to a register, other registers are tested until a connexion can be made or until all 36 possibilities have been tried, in which case equipment-engaged tone is connected.

After receiving dial tone, the subscriber keys or dials digits, which are translated by the register to an internal code and signalled to the PPU as they are received.

When the PPU has received enough digits to identify the called subscriber, it releases the register and refers to the directory number–equipment number (DN–EN) translation table, which is held in the same peripheral read/write memory as the COS store, to find the called-subscriber's EN, and then to the COS store to find whether the called subscriber can receive incoming calls. If normal incoming calls are allowed, paths are set up from the calling and called subscribers to an own-exchange supervisory unit, and a path-continuity test is carried out on each path, as for connexion to a register. If this is successful, the own-exchange supervisory unit takes over supervision of the call, sending ringing tone to the calling subscriber and ringing current to the called subscriber.

When the called subscriber answers, the loop is detected by the supervisory unit, ringing tone and ringing current are removed, the speech path is connected, and line current is fed to both subscribers. The called-subscriber-answered condition is signalled to the PPU, which in turn signals to the PU so that charging for the call can be initiated.

Clearance by either subscriber is detected by the supervisory unit, and the release sequence follows standard practice. The clearance is signalled to the PU, so that the charging period can be terminated.

Outgoing-Junction Calls

Pathfinder has the normal complement of junctions to its parent GSC appropriate for a remote non-director exchange. There are also junctions to the co-located TXE2 exchange, which serves the Research Centre.

When the PPU determines from the initial digits sent by the subscriber that the call is to be routed to another exchange, an outgoing-junction supervisory unit in the appropriate group is seized. As the remaining digits are received by the PPU from the register, the PPU repeats them in the exchange's internal code to the outgoing-junction supervisory unit, which transmits the digits over the junction in the appropriate form; for example, using loop-disconnect, DC2, AC9, or MF6 systems. When the subscriber has finished signalling, the register is released and the subscriber is connected to the outgoing-junction supervisory unit, which supervises the remainder of the call. In the case of a local call, the times of called-subscriber-answer and call clearance are sent to the PU, which calculates the charge: in the case of a trunk call, the meter pulses from the GSC are detected by the supervisory unit and the information is passed via the PPU to the PU.

Incoming-Junction Calls

There are incoming junctions to Pathfinder from the parent

GSC (by local-access code) and from Martlesham Heath TXE2 exchange. On an incoming-junction call, digits are received over the junction by the incoming-junction supervisory unit and sent in the exchange's internal code to the PPU, which uses the digits to determine the called-subscriber's EN and COS in the same way as for an own-exchange call. If the called subscriber is free to receive normal calls, ringing tone is returned over the junction and ringing current is connected to the called subscriber in the normal way.

Supplementary Services

If a subscriber wishes to invoke a supplementary service, he must recall a register (if he is not already connected to one) by depressing a special button on his instrument; when he is connected to the register, he uses the * button on a keyphone to indicate that he requires a supplementary service. When the PPU recognizes this, it signals to the PU, which then takes over control of the call. Control of the call is also passed to the PU if the PPU finds from a called subscriber's COS that he has invoked a supplementary service; for example, transfer of incoming calls.

FAULT DIAGNOSIS AND MAINTENANCE

A major use of Pathfinder will be to study methods of locating exchange faults with diagnostic software, and to develop maintenance procedures for replacing the faulty equipment without significantly affecting service. To facilitate this work, Pathfinder maintenance is controlled by a small team of Research Department staff; they occupy an office equipped with a VDU to enable them to interact with the exchange via the PU, and a fault-reporting position to receive customers' complaints either directly or by means of an automatic answering service (see Fig. 8). This position also receives information from the Ipswich Repair Service Centre about complaints received from the public that may be attributable to Pathfinder.

Automated diagnosis of faults allows 2 substantial improvements over methods that rely on a manual response to alarm conditions. Firstly, a transient fault, although initially insignificant in its effect on service, may become sufficiently frequent to produce a recognizable degradation. The rate of occurrence of such faults can easily be monitored and a threshold set, which must be exceeded before maintenance action is initiated. This enables many faults to be corrected before they degrade service, but avoids an investigation by maintenance staff leading to a *fault-not-found* conclusion. Secondly, diagnostic software should enable a significant fault to be located rapidly and precisely, so that the faulty equipment can, if necessary, be removed from service automatically and the subsequent maintenance work accelerated.

Fig. 8—A member of the Pathfinder maintenance team dealing with a subscriber's fault report

To diagnose faults in the exchange, it is first necessary to generate indications of abnormal operation; these may arise as a result of applying test conditions, or by monitoring the pattern of use during normal operation. As an example of the first condition, Pathfinder checks each reed contact for both open-circuit and short-circuit faults as speech paths through the exchange are set up and cleared down. Each register and supervisory unit has a path-continuity tester (PCT) circuit associated with it which, whenever a path is set up to its C-switch terminal through the A-, B- and C-stages of the switchblock, applies a short burst of 80 V, 25 Hz signal between each leg and earth. This causes a detectable earth current to flow through each half of the high impedance of the subscriber's line unit, but does not ring the subscriber's bell. Each time a path is set up, all reeds are checked for closure and, each time a path is cleared, one of the relays, chosen at random, is released first and a check made for path discontinuity.

The monitoring of an operational pattern is exemplified by the message that is passed to the PU whenever a *calling-line-clearance* condition occurs during certain stages of setting up a call. Such conditions may occur as a result of premature clearance by the customer, even though the exchange responses are normal. Frequent occurrences, however, particularly if they all point to the same register or supervisory unit, indicate an equipment fault.

The location of the faulty unit is diagnosed, in the PU, to a particular slide-in unit where possible. In some cases, this is known from the origin of an alarm indication (for example, a fault in an LCP–highway interface unit can be identified from one message only) but, in most cases, several indications must be compared before a common factor emerges and a faulty unit is identified.

Diagnosis of a fault in a crosspoint control store is an example of this correlation process. The crosspoint control store in Pathfinder can control up to 156 relays which, for security reasons, are distributed over the switchblock. The control store itself has no fault-detection circuit because faulty operation causes misoperation of one or more relays and these can be located by the PCT. Any indications from the PCT of relay failure are thus stored in the PU diagnostic software as pointers to the control store and, if a number of apparent crosspoint failures have a common control store, the fault is deduced to lie there, rather than in the relays.

Once the PU has diagnosed a fault to a particular unit and passed the information to the VDU at the maintenance control position, the maintenance staff must replace the faulty unit by a spare. If the unit is in a common-equipment area, where the service to customers is not directly affected, the PU also sends a message to the PPU, so that the unit can be marked in the PPU store as unavailable. If the staff require further information, they can interrogate the PU from the VDU.

When in the exchange building, the maintenance staff can use a portable VDU to communicate with the PU, which can change the PPU records via the MTS. This enables the man–machine language, which resides in the PU, to be used, and also ensures that validity checks can be applied to keyboard entries before they are used to implement changes in the exchange: direct communication with the PPU is allowed only on rare occasions.

COMMISSIONING

Another major advantage of SPC exchanges is the ease with which the processors can be used to accelerate the commissioning work. Special programs can be loaded into the PPU, and these can rapidly apply a series of test conditions to each peripheral unit in turn by using the control signalling system and the fault-detection equipment built into the exchange. Pathfinder was commissioned in this way.

After the initial testing of the power distribution to all racks, Pathfinder was commissioned in 3 stages. It was first necessary to test the PPU to ensure that it was available as a tool. In common with all Pathfinder units, the individual slide-in units were first given brief checks to eliminate obvious errors, and the central processing unit, program and data store were then tested in isolation using self-checking software that generated comparable results by 2 processes. It was then possible to load special programs to check units that were closely associated with the PPU, such as the COS store and security hardware. Once confidence in the processor was established, it could be used for the second stage, which was to check the highways and then to test functionally each peripheral unit in the exchange.

The testing of the switchblock is a good example of the use of the PPU for automatic testing. The PCT in a unit associated with a C-switch terminal was first tested in isolation, and then the PPU was used to set up sequentially all possible paths through the switchblock from that C-switch terminal to each A-switch terminal in turn. As each path was set up, the PCT was used to test each reed for open-circuit and short-circuit faults and, in addition, with the aid of a simple test box containing a diode, for reversals and crossed-path conditions. The test box was applied to an A-switch terminal and moved manually as the processor completed each test. (For most of the work, the test box could have been associated with a C-switch terminal, and paths that had already been tested used to apply it to A-switch terminals under processor control; this would have reduced the period to test the switchblock from 30 min to a few minutes, but the increased complexity of the software could not be justified for Pathfinder.)

The third stage in the commissioning was an overall assessment of performance from outside the subscribers' line and junction interfaces. These tests were applied by an independent unit, which was developed in parallel with Pathfinder, and is known as a *Strowger interworking simulator for testing exchange responses* (SISTER). This unit, which is also controlled by a small processor, is able to set up a few simultaneous calls through Pathfinder, and to check that each simulated event produces the correct response from the exchange by monitoring both calling and called lines. The times at which the events in the different calls occur can be varied in either a random or predetermined manner, and the parameters of each call (for example, dial make–break ratio) can also be varied. Abnormal activities, such as premature clearance or multiple calling signals, are also generated. Such a test proves the ability of the common control to handle all events in any sequence.

SISTER was not designed to generate large numbers of calls, and the traffic capacity of Pathfinder was not measured during commissioning as it was known to be more than adequate. This would require an extention to SISTER, and would normally form a fourth and final commissioning stage.

Commissioning work on Pathfinder was started at the beginning of January 1976 and, on 16 February, SISTER was used to generate 1605 own-exchange calls, only 2 of which failed (99·875% successful). Customers were connected on 18 February and given a 2 d/week trial own-exchange service while the junctions were brought into use, and full continuous service was provided on 12 April 1976.

CONSTRUCTION

Pathfinder is mounted on 3 racks, each 533 mm wide by 3·2 m high. One rack houses the subscribers' line units and the switchblock, the second houses the registers and supervisory units, and the third houses the PPU and the associated modems for the MTS.

One of the factors governing the equipment practice used was that it should be possible to use an existing laboratory model as a test bed for the plug-in modules that are used in Pathfinder; the equipment practice is not, therefore, necessarily typical of a production exchange. All modules have 2-part plug-and-socket connexions. There are 2 sizes of printed-circuit board: 222 mm high by 252 mm long, using 2·54 mm pitch single-row connectors, and 133 mm high by 252 mm long, using 2·54 mm pitch double-row connectors. All boards use plated-through holes. The wiring between connectors uses wrapped joints.

Power for Pathfinder is derived from the −50 V supply for the co-located TXE2 exchange, using commercial d.c.–d.c. converters. Each equipment rack is divided into separate security zones; this allows the exchange to continue operation at a poorer grade of service if the power supply to any one zone fails.

CONCLUSIONS

The decision to construct Pathfinder was made in July 1974, and installation was completed by the end of 1975. Using the commissioning methods described, the exchange was brought into full operation to provide service by 12 April 1976 and was formally opened 1 month later.

During the first 6 months of service, there were several occasions on which one LCP failed and 2 occasions, one of 7 min and one of 3 s duration, when both LCPs failed simultaneously. These failures were caused by an operator error (at that time, the PU did not provide the necessary protection against erroneous keyboard entries), and high ambient temperature in the room (36°C) respectively. The general service to the customer has been excellent, however, and Pathfinder is now used regularly for outgoing and incoming calls; Pathfinder numbers are listed in the BPO internal directories and appear on both internal and external correspondence.

The methods that are being developed for maintaining Pathfinder and the experience of using them in a realistic environment are proving extremely valuable, and further uses for the exchange are being considered.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the efforts of the Pathfinder team and of Telecommunications Headquarters, Eastern Telecommunications Region and Colchester Telephone Area staff in bringing the exchange into operation, and also the contributions made by those staff to this article.

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The Evolution of the INTELSAT V System and Satellite

Part 2—Spacecraft Design

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The first part of this article described the general features of the INTELSAT V system. This concluding part describes the spacecraft aerial systems and communications equipment, and includes a simplified description of the satellite launching sequence.

INTRODUCTION

The communications traffic-carrying capacity of the INTELSAT V satellite will be almost double that of its predecessor, INTELSAT IVA. This will be achieved primarily by means of frequency re-use techniques made possible by the very advanced aerial system which will be used on INTELSAT V. However, the extra effective bandwidth made available in this way requires extra power if it is to be fully utilized. The extra power requirement has led to a body-stabilized design being chosen for the INTELSAT V satellite, rather than the spin-stabilized type previously used by the International Telecommunications Satellite Organization (INTELSAT).

Part 1 of this article[6] described the general features of the INTELSAT V system, including the use of hemi, zone, spot and global aerial beams. This concluding part gives a description of the aerial system, communications hardware and spacecraft design. An explanation of design features is given where appropriate.

AERIAL SYSTEMS

General Features of 6/4 GHz Aerials

To derive the transmit and receive, hemi and zone, coverage patterns, a large and complex aerial system will be provided on INTELSAT V, featuring

(*a*) low sidelobe levels,
(*b*) feed arrays, comprising 88 feeds each for receive and transmit aerials,
(*c*) offset geometry,
(*d*) low cross-polarization levels, and
(*e*) deployable paraboloid section reflectors, fabricated in graphite-fibre reinforced plastic (GFRP).

Over their specified coverage areas the hemi beams will have a minimum gain of about 22 dBi (gain relative to an isotropic radiator), and the zone beams, which have a smaller coverage, will have minimum gains of about 25 dBi.

Sidelobe Suppression

In order that the hemi and zone beams covering the western land masses can effectively re-use the same frequencies as their eastern counterparts, there must be excellent isolation between the east and west beams. This isolation is achieved by beam-shaping and sidelobe-cancellation techniques.

The shaped-beam coverages are, in essence, built-up of narrower beams, the response of these narrow beams falling off very sharply outside the coverage areas (see Fig. 8). Although this approach achieves a rapid rate of fall-off in response at the edge of the coverage areas, and allows the desired pattern to be accurately tailored, it does not by itself yield the very low overall sidelobe values that are required.

These low sidelobe values are achieved by choosing a critical combination of constituent beam sizes, feed sizes and feed spacings, that results in the sidelobe components of the constituent beams partially cancelling each other in the region of interest; that is, in the region of the other shaped beam. By using these beam-shaping and sidelobe-cancellation techniques, INTELSAT V should be able to achieve better than 30 dB isolation between the west and east beams over much of the coverage area. A minimum of 27 dB isolation is required.

Feed Arrangements

The 6 GHz receive aerial system and the 4 GHz transmit aerial system are, in principle, scaled versions of each other. To form the many constituent beams that merge to produce the shaped beam patterns of INTELSAT V, 88 feeds are required. Such a large array of feeds would cause substantial aperture blocking of the aerial dish if a front-fed system were to be used. In addition to the loss of efficiency that aperture blocking would cause, radiation scattered by the feed array and support structure would degrade both the side-

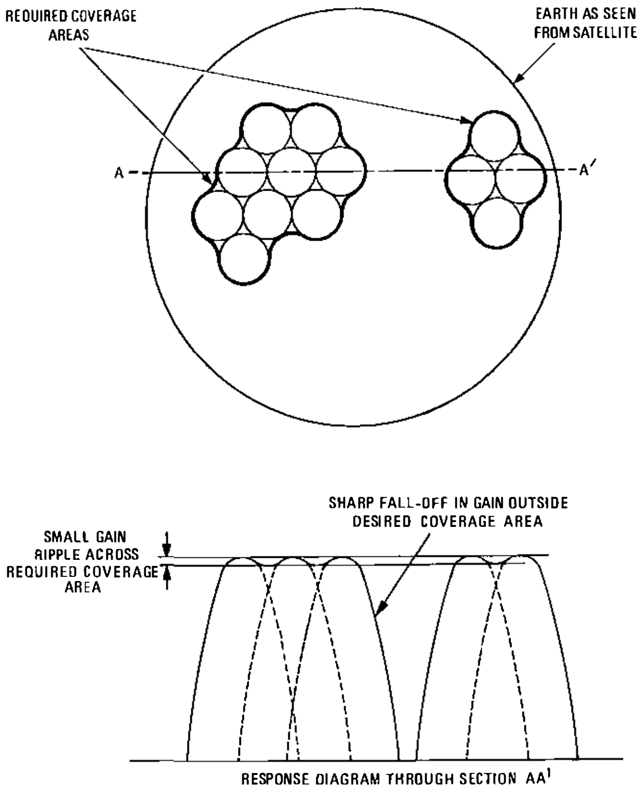

FIG. 8—Illustration of the generation of shaped aerial beams

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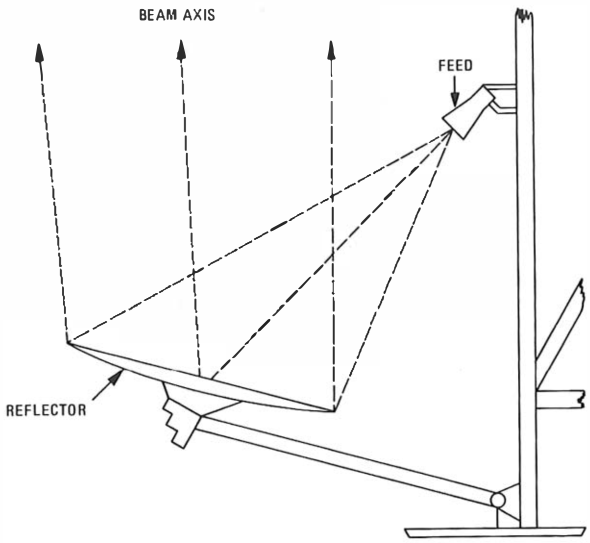

FIG. 9—Geometry of offset-fed paraboloid aerial system

lobe performance and the polarization purity. INTELSAT V, therefore, uses an offset-fed paraboloid aerial system, as shown in Fig. 9.

When used with circular polarization, as will be the case at 6/4 GHz, the offset geometry will assist in preserving the high polarization purity required for frequency re-use by means of opposite polarizations.[7]

Constructional Aspects

To generate the small constituent beams at 4 GHz, a large reflector aperture is required. INTELSAT V uses a 2·44 m diameter projected aperture, the long axis of the reflector being larger still because of the offset geometry. This large reflector, and the other smaller ones for the 6 GHz and 14/11 GHz aerials, are constructed from GFRP, which is substantially more rigid, weight for weight, than any of the aerospace metal alloys. However, in the context of the INTELSAT V design, the most important property of GFRP is its extremely low thermal expansion coefficient which enables the aerials to retain their contours with precision, despite the harsh thermal gradients occurring in orbit.

Offset-fed paraboloid geometry enables a compact stowing arrangement to be used, whereby the aerial reflector dishes are folded-in on the central mast structure that carries the feeds (see Fig. 10). In this way, the large aerial dishes can be accommodated within the confines of the launch shroud, to be deployed when the satellite is in orbit; the complex feed systems require no deployment, being fixed rigidly to the aerial-feed tower. The aerial-feed tower, like the reflector dishes, is made of GFRP for rigidity and thermal stability.

Global Horns

INTELSAT V provides for global coverage by means of conventional global-beam horns, operating only on a single polarization. To accommodate slight pointing offsets required for different longitudinal locations of the satellite, the global coverage horn-aerial system is steerable, so that it can always be aimed at the sub-satellite point. This enables an aerial having a beam edge gain of nearly 17 dBi to be used.

14/11 GHz Aerials

The 14/11 GHz spot aerials are single-feed offset types, capable of being redirected by ground command over a limited range of positions on the earth's surface. The east and west spot aerials use orthogonal linear polarizations to give additional isolation when the beams are operated at a small angular separation. The elliptical east spot beam is derived by

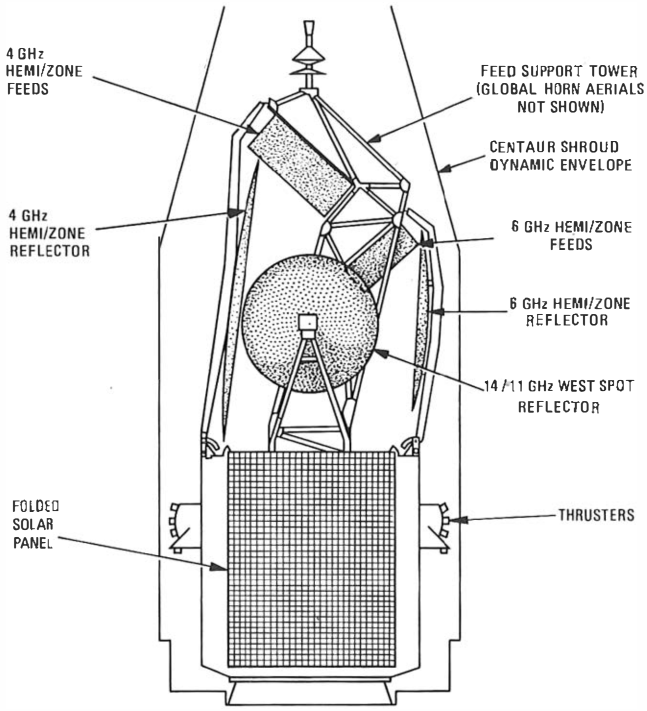

FIG. 10—Reflector stowing arrangements

means of a reflector dish whose projected shape is circular, but whose curvature is designed to give defocusing and beam spreading in the desired plane. A single aerial dish, used for both receive and transmit functions, is provided for each beam. The east spot beam will have a transmit gain of nearly 34 dBi, and the smaller west spot beam will have a transmit gain of about 37 dBi, these gains being achieved at the edge of the coverage areas.

COMMUNICATIONS EQUIPMENT

Receivers

The communications package of INTELSAT V will contain 11 similar 6/4 GHz receivers. Five of these are for operational use: one each for global, east and west hemi, and east and west zone receiving aerials; the remainder are used as stand-by units that can be brought into service in the event of a failure of an operational receiver. Each receiver includes a low-noise 6 GHz amplifier, a mixer to convert from the 6 GHz to the 4 GHz band, a 4 GHz pre-amplifier and a driver amplifier. The front-end amplification at 6 GHz is provided by 4 stages of silicon bipolar transistors. The attenuation/frequency response of each receiver is flat to within 0·25 dB over the total bandwidth of 500 MHz, and each receiver has a noise figure of about 5·5 dB. The mixer is of the low-noise double-balanced diode type, and has a conversion frequency of 2225 MHz, derived through a multiplier chain from a high-stability crystal-controlled local oscillator, operating at 23·2 MHz. Post-mixer amplification at 4 GHz is achieved by a 4-stage silicon bipolar transistor pre-amplifier having a gain of approximately 27 dB and a 5-stage 24 dB gain driver-amplifier that also uses silicon bi-polar transistors. A single-step gain adjustment of 7·5 dB is provided by a switched attenuator, controlled by command from the ground.

A further 4 receivers are provided for operation at 14/4 GHz, one operational receiver and one stand-by receiver for each of the 2 spot receiving aerials. These receivers have single-stage germanium tunnel diode front-ends, feeding directly into a single-balanced Schottky-diode mixer. The down-conversion frequency of 10·3 GHz is derived from a 26·8 MHz crystal-controlled local oscillator. Post-mixer amplification is similar to that provided for the 6 GHz receiver, except that a 5-stage pre-amplifier is used. The overall noise figure is expected to be better than 6·5 dB.

To reduce spacecraft mass and to improve reliability, microwave integrated circuit techniques will be used almost exclusively in both types of receiver.

Channel Input Multiplexing

Channel routing from the receiver outputs is achieved by a series of 8-pole elliptic-function filters ($Q \approx 10\,000$) constructed of GFRP and mounted on aluminium manifolds. The advantages of GFRP over alloys such as invar, used in earlier INTELSAT satellites, are substantial weight saving and an extremely low temperature coefficient. The weight-saving aspect is particularly important in the INTELSAT V design since a total of 60 such filters has to be accommodated in the satellite. However, the manufacturing processes are very exacting, requiring highly-accurate metal plating of the surfaces and a prolonged curing process to stabilize the filters against any long-term deformation. Very slight changes in shape can give rise to substantial changes in electrical performance at the high frequencies involved.

Transmitters

The output transponders all use travelling-wave amplifiers (TWAs) and are provided, for the most part, on a 3 for 2 redundancy basis, the exceptions being the global transponders and the 241 MHz spot transponders, which have a 1 for 1 stand-by provision. The spot transponders include individual up-converters operating with translation frequencies of 7·25 GHz for channels (1–2) and (5–6), and 7·5 GHz for channel (7–12), to convert the 4 GHz signals from the switching matrix to the two 250 MHz bandwidth down-path bands allocated at 10·95–11·2 GHz and 11·45–11·7 GHz. The other transponders provide amplification only, since their input signals are already located in the allocated down-path frequency bands, at 4 GHz. Single-step gain adjustments of 7·5 dB at 4 GHz and 5 dB at 11 GHz, are provided by switched-attenuators that are controllable from the ground.

The 4 GHz output TWAs will be single-collector types of flight-proven design. Two versions will be used, one of 8·5 W saturated output power for hemi and global use, and one of 4·5 W mainly for zone coverage. Each TWA will have its own electronic power conditioner (EPC).

The 11 GHz TWAs of 10 W saturated output power will probably be double-collector types. The double-collector design gives an improvement in efficiency and better thermal control, but at the expense of greater complexity in construction and more complicated EPCs.

Output Multiplexing

Channelling of the 4 GHz TWA outputs to the aerial feeds will be by means of GFRP filters in a contiguous multiplex arrangement. The use of this technique represents a significant advance from the INTELSAT IV and IVA multiplexing arrangements in which, to ease the filter design requirements, were separated into odd and even channel multiplexers associated with separate aerials. By the use of contiguous multiplexing techniques the number of aerials is reduced to one per coverage mode, and this results in a significant saving in overall mass of the spacecraft. However, the design of the contiguous filters will be a critical item in the INTELSAT V design because they have to be much sharper in their cut-off characteristics, and they are very sensitive to interactions from adjacent filters.

The operating bandwidths of the 11 GHz transponders are widely separated in frequency, so the output multiplexing requirements are less stringent.

Switching Equipment

The main channel switching matrix at 4 GHz will be built up from standard mechanical coaxial switches, of the double-change-over type. Sufficient redundancy will be provided to ensure that the failure of any one switch will not preclude the selection of any of the specified switching combinations.

Change-over to stand-by receivers and transponders will generally be by means of mechanical coaxial switches, with the exception of the 11 GHz transponders, which, because of the importance of very low loss in this application, will probably use mechanical waveguide switches. Another possibility being investigated for the 11 GHz transponder switching is the use of ferrite switches. Facilities will be provided for the remote control of all switch operations by the ground control stations while the satellite is in orbit, and indications of the state of each switch will be telemetered.

SPACECRAFT ASPECTS

INTELSAT V will be some 170 kg heavier than its immediate predecessor. However, due to progressive improvements achieved in the launcher payload capability, INTELSAT V will use the same type of launcher as the earlier INTELSAT IV and IVA satellites.

The configuration of the INTELSAT V satellite marks a radical departure for INTELSAT in that the spacecraft is body-stabilized about all 3 axes, and this factor explains the marked difference in appearance between INTELSAT V and the spin-stabilized INTELSAT IVA. A physical comparison of the INTELSAT V and IVA satellites is shown in Fig. 11.

Whereas INTELSAT IVA's stability is derived from its slowly-spinning cylindrical body, INTELSAT V uses an internal momentum wheel to provide its primary stabilization.

One important limitation of a spin-stabilized spacecraft is the inefficient use it makes of its solar cells, which are mounted on the spinning body. At any instant, half of the cells are in shadow, and many of those in sunlight are operating under oblique lighting conditions. A body-mounted solar array produces only one third of the power that it could produce if it were mounted on a flat panel, oriented perpendicular to the sun's rays. Since the 27 operating transponders of INTELSAT V require large (by satellite standards) amounts of d.c. power ($\approx$ 800 W), a spin-stabilized INTELSAT V would be in a very marginal situation with regard to available power. This arises because the size of the body drum is constrained by the limited amount of room available in the upper stage of the launch vehicle. Therefore, the size of the body drum cannot be increased to extend the area available for mounting solar cells.

INTELSAT V requires a large and complex array of aerials, and it will be appreciated that a physically compact spacecraft will leave more room for the aerial system than a bulky spacecraft. A spin-stabilized design of satellite capable of meeting the power requirements of INTELSAT V is necessarily bulky. A body-stabilized satellite has a significant advantage in this respect because the spacecraft body can be made quite compact, the large solar panels being folded against the sides of the spacecraft in the stowed configuration.

The inherently compact aspect of the body-stabilized design will be particularly important in the case of future launches by the National Aeronautics and Space Administration (NASA) space shuttle that will be able to launch several spacecraft in a single mission, thus sharing the launch costs between spacecraft operating bodies.

At first sight, it might appear that a body-stabilized spacecraft would be heavier than a spin-stabilized type, owing to the mass of the momentum wheel required in the former, compared with the free gyroscopic properties provided by the spinning body of the latter. However, the momentum wheel is not particularly heavy (about 15 kg, including one redundant wheel) and a variety of other factors combine to give the body-stabilized INTELSAT V an overall mass advantage over an equivalent spin-stabilized version.

Although a number of advantages are offered by body-

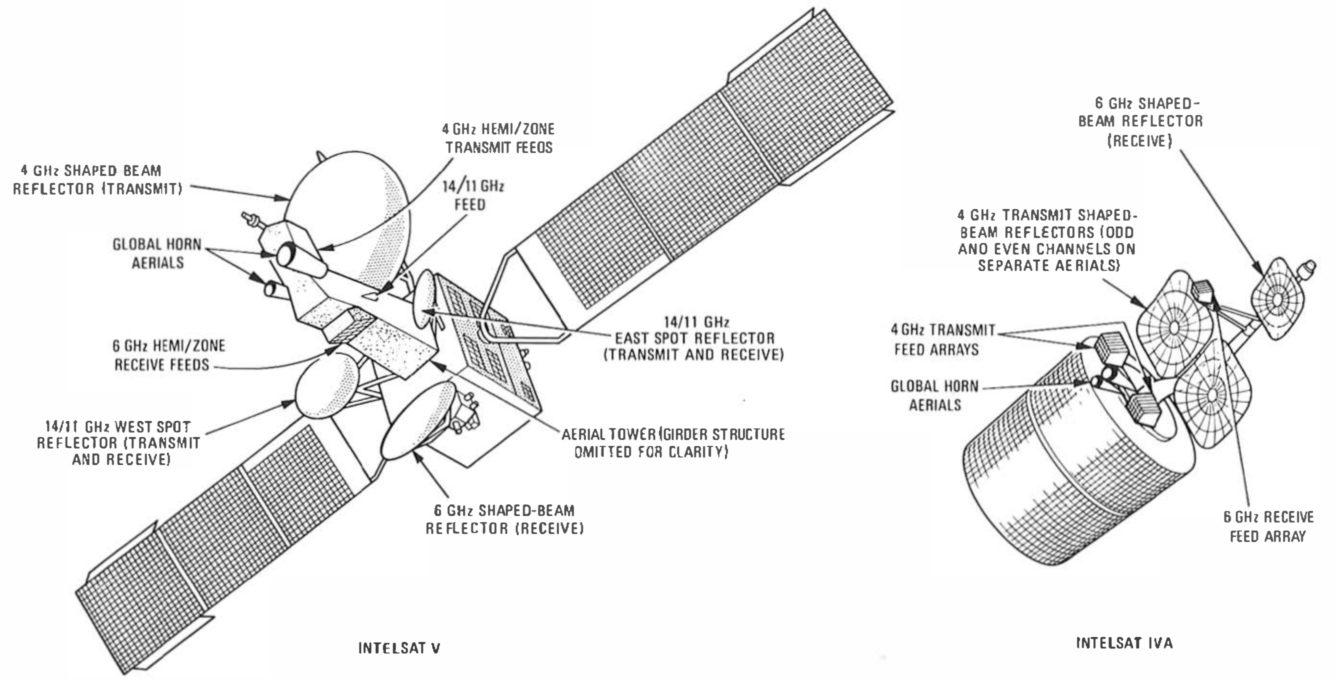

FIG. 11—Physical comparison of INTELSAT V and IVA

stabilization of the spacecraft, an element of risk is involved in providing a more sophisticated and complex attitude stabilization system, which is required to remain operational for the 7-year life of the satellite. Several body-stabilized spacecraft are now operational, but none have yet been in service for the time needed to demonstrate their ability to work satisfactorily for the lifetime required by INTELSAT. Nevertheless, there is no doubt that the required lifetime is well within the existing state-of-the-art, and the general configuration of the satellite is well suited to further development.

Attitude Control and Sensing

A single momentum wheel, spinning at approximately 3500 revolutions/min will be used to stabilize the spacecraft in the desired attitude. In essence, the rigidity imparted to the axis of the momentum wheel by its high rate of spin tends to hold the spacecraft stable in the roll and yaw axes (see Fig. 12). Control about the pitch axis is effected by increasing or decreasing the rotation speed of the momentum wheel by means of electric motors whose torque reacts back on the spacecraft. Control about the yaw and roll axes, is achieved by the use of gas jets that operate in pulses to produce a torque on the spacecraft, causing the momentum wheel axis to precess, taking the spacecraft with it.

The gas jets used for attitude control use liquid hydrazine fuel (N_2H_4), which is passed through a catalyst bed, causing its breakdown into ammonia, nitrogen and hydrogen, together with the release of heat. These gases then accelerate through a conventional rocket nozzle, providing a thrust reaction. Though catalytic-hydrazine thrusters are not the most efficient producers of thrust, they are fairly simple in design; consequently they are reliable and ideally suited to attitude control and station-keeping tasks which involve many restart cycles. Electrical heating is used to prevent freezing of the hydrazine, and this assists in obtaining the required operational reliability of the propellant valves.

The body-fixed momentum wheel, and the thrusters, are duplicated for reliability.

Attitude sensing in orbit is achieved by means of scanning infra-red sensors that sense the edge of the earth against the cold background of space. In this way, good accuracy ($\approx 0{\cdot}14°$) can be achieved in roll and pitch, but the earth sensors are unable to detect yaw errors directly. However, yaw at one part of the orbit becomes roll 90° further on and, in this way, yaw errors can be maintained to within $\pm 0{\cdot}4°$. These relatively large errors in yaw are fortunately not significant with regard to the required coverage areas of the earth-facing aerials.

Sun-sensors are used during the sequence of manoeuvres required to place the spacecraft in the geosynchronous orbit, thus enabling the spacecraft to be correctly oriented for firing its apogee motor.

STATION KEEPING

The geosynchronous orbit is not a stable orbit. Gravitational "wells" exist, attracting the spacecraft, eastward or westward, away from the intended longitudinal position. Also the gravitational pull of the sun and the moon combine to pull the orbital plane away from the equatorial plane, causing an increase in the orbital inclination. To keep the spacecraft over the desired longitude, periodic firings of the station-keeping hydrazine thrusters are required. Either frequent short bursts of thrust, or less-frequent longer bursts may be used, depending on how accurately the desired longitude needs to be maintained; approximately the same amount of fuel is used in either case, but frequent re-starts obviously pose reliability problems. INTELSAT usually maintains satellite longitude to within $\pm$ 0·1°, with station-keeping manoeuvres being necessary at about 2-monthly intervals. Over the INTELSAT V lifetime, 11·7 kg of fuel is allocated for longitudinal station keeping. Orbital inclination control

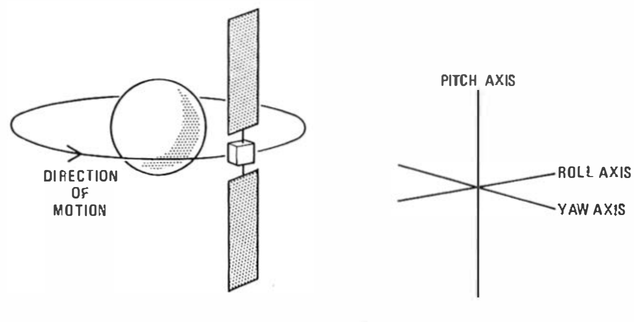

FIG. 12—Roll, pitch and yaw axes in the geostationary orbit

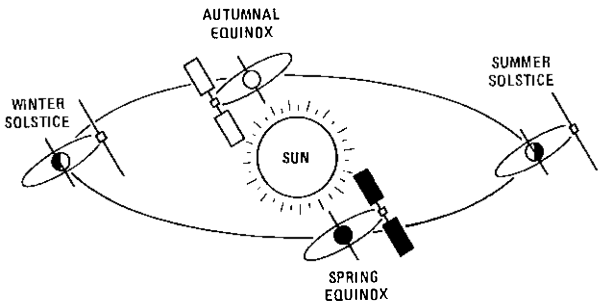

FIG. 13—Annual variation in illumination of solar panels

requires a far greater expenditure of fuel than longitudinal control (about 26 times as much, for example, in INTELSAT IVA) to the extent that a more fuel-efficient type of thruster has been selected for INTELSAT V. This thruster, known as the *electrothermal hydrazine thruster*, uses electrical heating to increase the exhaust velocity of the propellant gases, thereby increasing the thrust or thrust duration attainable for a given mass of hydrazine propellant.

An ion engine, which accelerates heavy positively-charged ions (for example mercury or caesium) electrostatically to form a very-high velocity exhaust stream, is even more efficient in the use of fuel. However, the ion engine is not yet sufficiently developed for station-keeping use on INTELSAT V, though it may be used in the INTELSAT VI era.

POWER SUBSYSTEM

INTELSAT V derives its electrical power from 17 400 solar cells mounted on 2 wing-like arrays of panels having a total span of over 15 m. The arrays are designed to generate 1·54 kW at the beginning of their life in orbit, but radiation damage, over the required 7-year lifetime, is expected to reduce their end-of-life output to 1·16 kW. The power values quoted are for the winter/summer solstice (worst case) conditions. The panels containing the solar cells are rotated to follow the sun but, since their axes are aligned north/south, they can be perfectly perpendicular to the sun's rays only at the equinoxes (see Fig. 13).

The power derived from the solar cells is fed to 2 batteries, each consisting of 28 series-connected 34 A h nickel-cadmium cells, which supply the spacecraft's power when the solar-panels are in the earth's shadow; that is, when the satellite is in eclipse. This eclipse condition occurs daily over a period of 45 d about each equinox (26 February–12 April and 30 August–14 October), building-up gradually to a maximum of 71 min at the Spring and Autumn equinoxes, and declining thereafter.

LAUNCH SEQUENCE

INTELSAT V will initially use the Atlas-Centaur launch vehicle (Atlas booster, plus Centaur upper-stage), as did its predecessors, INTELSAT IV and IVA. Later launches will probably use the NASA space shuttle, together with a simple spin-stabilized solid-fuel upper stage.

The Atlas booster is a kerosene liquid-oxygen fuelled "one-and-a-half-stage" rocket, whose central sustainer engine fires throughout the booster's powered flight, but whose outer engines fire only for the first 2·5 min of the flight, after which they, and their thrust structure, are jettisoned.

The fuel used for the Centaur stage of the launch vehicle is a combination of liquid-oxygen and liquid-hydrogen; these high-performance fuels are most effective in the upper stages of a launch vehicle.

The launch vehicle injects the spacecraft into an elliptical transfer orbit, whose apogee (highest point) is at geostationary altitude, and whose perigee (lowest point) is about 170 km above the surface of the earth. Thus, at apogee, the spacecraft is at the right altitude for the geosynchronous orbit, but is moving too slowly to stay in that orbit. By firing the apogee motor, the spacecraft is accelerated to the correct speed to circularize the orbit. The firing of the apogee motor normally occurs after several completions of the transfer orbit, when orbital parameters have been accurately established. This action not only circularizes the orbit, but also changes the orbital plane, thus ensuring that the final orbit is in the equatorial plane. The change of plane is required because the launch site (at Cape Canaveral, USA) is not on the equator, hence the transfer orbit is inclined to the equatorial plane by about 27°.

The satellite is spun-up to 45 revolutions/min for stabilization purposes after separation from the Centaur vehicle, and the subsequent apogee motor firing consumes about 860 kg of solid propellant, placing the spacecraft and apogee motor case (total weight 976 kg) in geostationary orbit. The spin axis is then reoriented, the spin rate is slowed, the momentum wheel is spun up, the solar panels are deployed, and a further momentum wheel speed change is made to achieve earth pointing. The aerial systems are then deployed, residual orbital inclination is removed, and the satellite is drifted into the correct longitudinal position. This greatly simplified picture of the launch sequence provides some insight into the complexities involved. Even so, in the series of 8 launches for INTELSAT IV, only one launch failure occurred.

Later launches will use the NASA manned space-shuttle launcher which will put a satellite and a spin-stabilized solid-fuelled rocket in low earth-orbit; the launcher will then return to earth. The spin-stabilized solid-fuelled rocket will inject the satellite into an elliptical transfer orbit, and the positioning sequence will thereafter be essentially the same as for an Atlas-Centaur launch. The use of the NASA space-shuttle should result in significant savings in launch costs.

REVIEW AND CONCLUSION

The INTELSAT V satellite represents a significant advance in design over the present generation of INTELSAT IVA satellites. It will use 3-axis body-stabilization, and thereby gain a considerable advantage in electrical power generation capability over previous INTELSAT satellites which have been spin-stabilized and it will have a complex aerial system, enabling more efficient use to be made of the limited bandwidth available at 4/6 GHz.

In addition to the frequency re-use technique already used by INTELSAT IVA, namely re-use by aerial-beam separation, INTELSAT V will achieve further frequency re-use by means of opposite circular polarizations, and will introduce INTELSAT to operations at 14/11 GHz in North America and several European countries. In short, INTELSAT V will employ most of the available technological options for coping with traffic growth. To this extent, the present INTELSAT V could, if it proves to be a sound design, provide the basic spacecraft from which later generations of INTELSAT satellites might be developed.

ACKNOWLEDGEMENTS

The authors would like to thank the Ford Aerospace and Communications Corporation and the Director General of INTELSAT for permission to make use of detailed INTELSAT V design material in the preparation of this article.

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The Development of International Telephone Switching Systems

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This article describes the relationship between major steps in the growth of international telephone services and the developments in transmission, signalling and switching that have made them possible. The international plans for achieving world-wide automatic access and the role of the new UK international switching centres, required to handle the rapid expansion of international direct dialling, are also described. This article provides the background to a series of articles on the new switching centres and the signalling sytems they use.

INTRODUCTION

International telephone services from the UK started in 1891 with a service to France. Two circuits only were provided, which constituted the full capacity of a cable, some 3 inches in diameter, that had been laid between St. Margaret's Bay in Kent and Sangatte. Initial growth of the service was slow; by 1914 the total number of international telephone circuits terminating in the UK was only 14.

Until 1927, telephone communication from the UK was possible to only a small number of countries that could be reached with satisfactory transmission through audio cable systems. In that year, a telephone service was opened between London and New York using a high-frequency (HF) radio link; this service was soon extended to connect calls between the UK and the USA, Canada and Cuba.

TRANSMISSION MILESTONES

A major landmark in the growth of the international telephone service was the opening of the first submarine coaxial-cable system, a 16-channel system to Holland, in 1937; in the same year, a 12-channel carrier system on balanced-pair cable was opened in the inland service. The first international cable using a submerged repeater was an Anglo-German coaxial submarine cable that entered service in 1946. During the late 1940s and early 1950s, more submarine cables were brought into service between the UK and the Continent, the additional circuits available making it possible to introduce a demand service to many European centres, starting with Paris in 1949.

Until 1956, longer distance intercontinental service was entirely dependent on HF radio, which suffers from the disadvantage that the available frequency spectrum is limited and has to be shared with other countries and between public telephones and other users. The transmission path of HF radio links makes use of ionospheric reflection which introduces variable loss and is, therefore, subject to fading. This impairment to transmission can be predicted and offset to some extent by choice of frequency; however, until recently, the service provided was of variable quality and had to be manually operated and monitored. Thus, by 1956, there were only about 70 of these circuits providing telephone service between the UK and the more distant parts of the world. The largest single group consisted of 14 circuits to the USA.

In 1956, the first intercontinental telephone cable (TAT 1) using submerged repeaters was opened between the UK and the USA.[1] TAT 1 provided, originally, 36 circuits of 4 kHz channel bandwidth. These circuits were of excellent transmission standard and stimulated the demand for long-distance international telephone services, which then entered an era where facilities were taken up almost as fast as they could be provided. In 1960, some relief was obtained by re-equipping the TAT 1 cable terminals to provide channels of 3 kHz bandwidth; this increased the number of circuits to 48. Also in 1960, time-assignment speech-interpolation equipment,[2] based on the principle that both participants in a conversation do not require a transmission path at the same time, was installed and virtually doubled the traffic-carrying capacity of the cable.

In 1962, a third technique for intercontinental telephony became possible when the first earth active communications satellite, TELSTAR,[3] was put into orbit, followed early in 1963 by the first geostationary earth satellite experiment.

Both cable and satellite techniques have since advanced very rapidly and the later additions to the international network have the high circuit capacities needed to meet a demand that has been stimulated by improvements in the quality and economy of the service. The latest intercontinental cable, TAT6, between Greenhill (USA) and St. Hilaire (France), which entered service in August 1976, has the capacity for carrying up to 4200 circuits of 3 kHz bandwidth. Circuits from this cable are extended to the UK on a special overland route that links the TAT6 cable terminal with the terminal of a new 25 MHz cable system which crosses the English Channel. A single INTELSAT IVA satellite has a capacity of some 5000 circuits and the INTELSAT V satellite,[4] now under development, offers a capacity of some 12 500 circuits.

HF radio circuits have been improved by better prediction and control methods, including automatic change-over to a more satisfactory frequency, and fading effects can now be largely overcome by the use of LINCOMPEX[5], which has been introduced progressively since 1965.

At present, the UK has about 2500 intercontinental public telephone circuits, of which 22 are HF radio circuits, the rest being divided almost equally between cable and satellite systems. However, the bulk of the UK international traffic is with continental countries, and this traffic is carried by some 7500 circuits in submarine cable systems and on microwave links across the English Channel.

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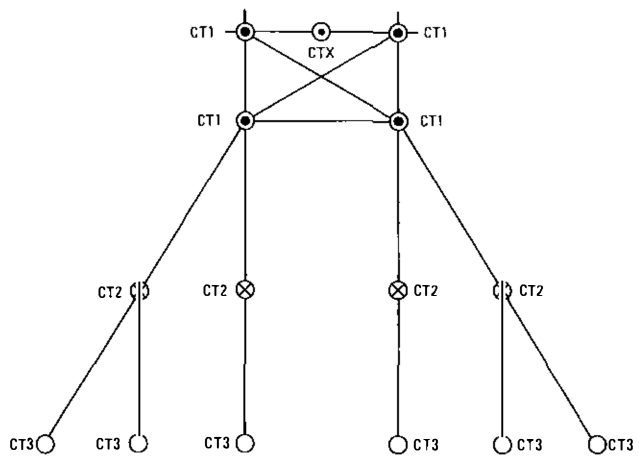


FIG. 1—Theoretical final route structure (backbone structure) of the international telephone network

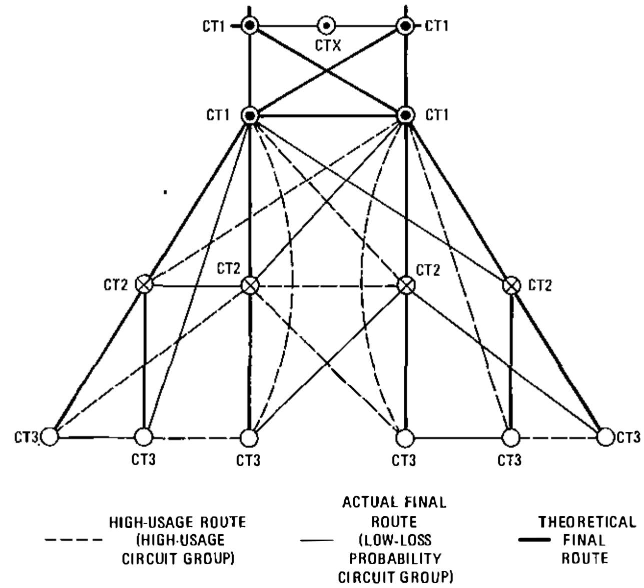


FIG. 2—Example of actual structure of the international telephone network

EVOLUTION OF THE INTERNATIONAL NETWORK

The use of modern technology has led to significant improvements in the field of transmission that have been matched by major advances in signalling and switching techniques. Operation of the international network has evolved along similar lines to those of many national networks in that the fully manual system of the early days was replaced by a semi-automatic system in a logical step towards the ultimate aim of a fully automatic system, with operator assistance only when required.

WORLD-WIDE CO-OPERATION

The introduction and extension of international telephone services requires agreement between nations. The principal forum for discussion is the International Telecommunication Union (ITU), supported by its consultative committees for radio communications (CCIR) and telegraphy and telephony (CCITT). There are other committees to meet the needs of regional and specialist interests. World-wide plans have been drawn up to ensure that ultimately it will be possible for a telephone call to be set up automatically between subscribers located anywhere in the world.

World Numbering Plan

The essential feature of a world-wide automatic system is that every subscriber should have a unique telephone number. To allow this, each country has been allotted a country code of 1, 2 or 3 digits. The first digit identifies one of 9 world zones. Zone 1 covers the North American continent and Caribbean Islands (in an integrated numbering area); zone 2 Africa, zones 3 and 4, most of Europe; zone 5 South America; zone 6 Australasia; zone 7 the USSR; zone 8, most of the Far East and zone 9 from Turkey and the Near East across India to Burma.

Large countries have single-digit country codes and small countries have 3-digit codes, the CCITT objective being that the number of digits in an international number should not exceed 12, excluding the international direct dialling (IDD) prefix digits, which signify an IDD call. The UK country code is 44 which, combined with the national number of a UK subscriber (minus the STD prefix digit 0), becomes an international number. The allocation of international prefix digits for access to the international service is a matter of choice for each national administration; the UK uses 010, but other countries use different prefix digits (for example, Switzerland uses 00, Sweden 009 and Belgium 91).

The numbering plan also covers semi-automatic operation, an important feature of which is the ability to signal the language which an assistance operator should speak when handling the call. The information is conveyed by means of a language digit that must immediately precede the national part of the international number. The CCITT has allocated the following language digits:

1	French	6	By agreement
2	English	7	By agreement
3	German	8	By agreement
4	Russian	9	Reserved
5	Spanish	0	Automatic (IDD)

It is the practice in all UK international switching centres (ISCs) for the language digit to be inserted automatically by the equipment processing an outgoing international call.

The national number consists of an area or trunk code, followed by the local exchange number. Thus, to call a number in New York, a UK subscriber would dial,

010	1	212	637 1212
International prefix	Country code	Area code for New York	New York local number

The call would be routed over a direct circuit to the USA, in which case the digits transmitted would be 0 212 637 1212, the initial digit 0 signifying that it is an IDD call.

If a call has to be routed via an international transit exchange, the country code digits have to be transmitted before the language digit; for example, on a call to Sydney 2076, Australia, assuming a direct route was not available, but a transit routing was available via Montreal, the UK subscriber would dial, 010 61 2 2076. The UK ISC sends 61 02 2076 to Montreal, and the Montreal equipment sends 02 2076 to Sydney.

World Routing Plan

The international routing plan provides for automatic and semi-automatic traffic, and is based on a hierarchical network of international transit switching centres, referred to as *centres du transit* (CTs). Fig. 1 represents the theoretical final-route structure or backbone network to provide satisfactory connexion between any 2 subscribers in the world (satisfactory in terms of transmission, grade of service and economic realities of efficient use of plant). The fundamental

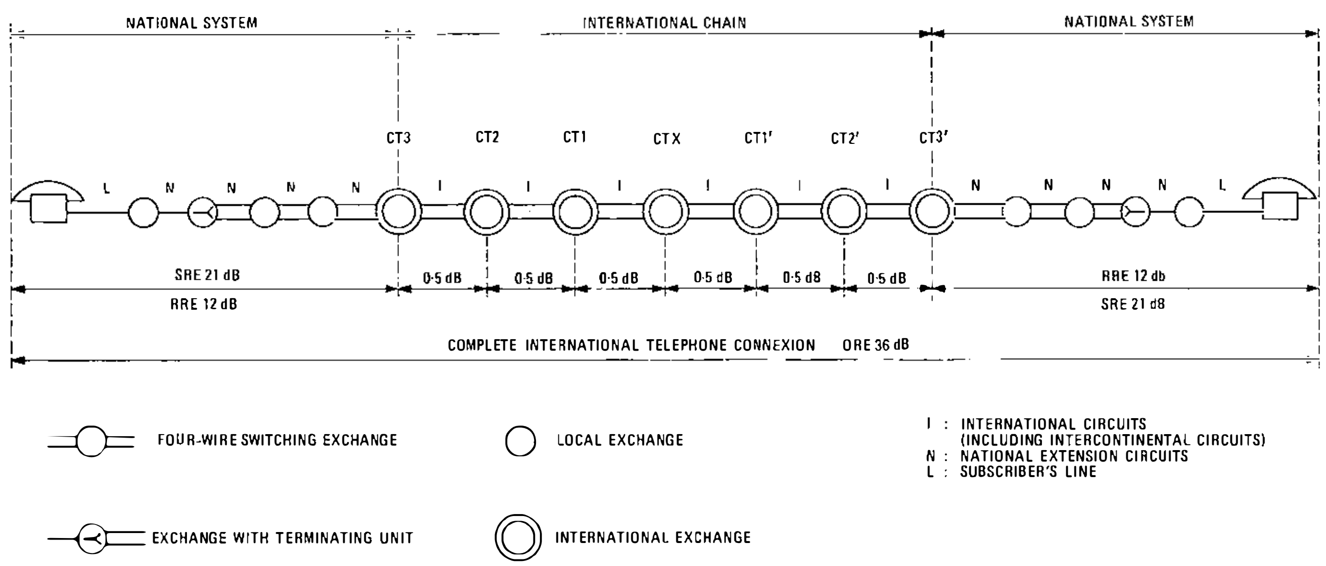


FIG. 3—A representative maximally adverse international telephone connexion

requirements of this plan are: that all CT1 exchanges shall be directly interconnected or, exceptionally, connected via not more than one intermediate international transit exchange (CTX); CT2s serve a defined part of a CT1 zone by providing transit access to the home CT1 for the CT3s in its zone; CT3s provide the interface between national networks and the international network.

In practice, the backbone network is supplemented by direct routings of the type shown in Fig. 2. The supplementary routings may be provided with the full number of circuits required to carry the traffic at an acceptable grade of service or they may be high-usage routes with overflow to the backbone routing, depending on the economics of the situation.

World Transmission Plan

The quality of transmission experienced on an international call depends on the quality of national as well as international networks, and so the CCITT transmission plan embraces both.

The CCITT recommendations for the maximum transmission loss of international connexions are stated in terms of *overall reference equivalent* (ORE), expressed in decibels relative to an internationally-agreed reference system. ORE includes the electro-acoustic properties of telephone instruments and the electrical properties of local lines (including the transmission bridge in the local exchange). The international transmission plan recognizes that each national administration must be free to allocate transmission losses in its own national system. Therefore, the maximum permitted losses of national systems are expressed in terms of *send reference equivalent* (SRE) and *receive reference equivalent* (RRE) referred to interface points (known as *virtual switching points*) on the international circuit in the CT3 exchange. The maximum loss recommended for SRE is 21 dB and for RRE 12 dB.

A maximally adverse international telephone connexion is shown in Fig. 3; the nominal transmission loss of each international circuit forming part of an international telephone connexion is 0·5 dB (at reference frequency 800 Hz). Other salient points of the transmission plan are: all ISCs use 4-wire switching; the maximum number of 4-wire switched circuits in a national network is 3 (exceptionally 4), and the terminal national transit exchange and the national local exchange may use 2-wire switching. This is the situation in the UK, where the interface between 4-wire and 2-wire switched networks is at a group switching centre (GSC) or equivalent exchange, connexion to the ISC being over a direct route or via the transit network, the choice depending on traffic and economic considerations.

INTERNATIONAL TELEPHONE TRAFFIC IN THE UK

All international telephone traffic in the UK is switched via dedicated international exchanges, calls requiring operator assistance being routed via an international control centre (ICC). At present, there are 16 switchrooms in the UK, 13 of these are located at 4 centres in London with others at Glasgow, Leicester and Brighton.

Outgoing operator traffic is separated into 4 streams depending on the destination country and whether the calls are to be routed

(*a*) over continental English-speaking routes,
(*b*) over continental French-speaking routes,
(*c*) on-demand over intercontinental routes, or
(*d*) over intercontinental routes not operated on-demand.

Dialling codes have been allocated for each type of traffic the codes used in London differing from those used in the provinces. In London, the director equipment can route the call from the local exchange to the appropriate international switchboard. Outside the London area, code-only relay-sets are being provided at GSCs; these relay-sets provide facilities that enable subscribers to dial standard codes and allow the 4 streams of traffic to be routed over a common group of circuits, using multi-frequency signalling system 2 (SSMF2) inter-register signalling to the remote ICC location, where the streams are separated. Until this method of working is provided, provincial subscribers have to dial 100 to obtain first an inland operator who connects the circuit to an ICC that has access to the required destination. To provide satisfactory transmission on the completed connexion, the ICC operator has to "revert" the call by recalling the provincial subscriber, thus eliminating the inland operator's 2-wire cord circuit from the speech path.

Incoming international traffic to ICCs consists of 5 basic types, listed below.

(*a*) Operator assistance is required to complete calls where incoming STD access is not available; such calls are identified by the code 11, following the language digit.

(*b*) Operator assistance is required to complete calls where STD access is available but difficulty is experienced with the routing, and for ordinary call-booking traffic. Both are identified by the code 12 following the language digit.

(*c*) Call-booking traffic associated with a particular country is routed to a particular group of positions according to the numerical digits following the code 12; for example, 2 12 7322. This is known as *code 12 country group traffic.*

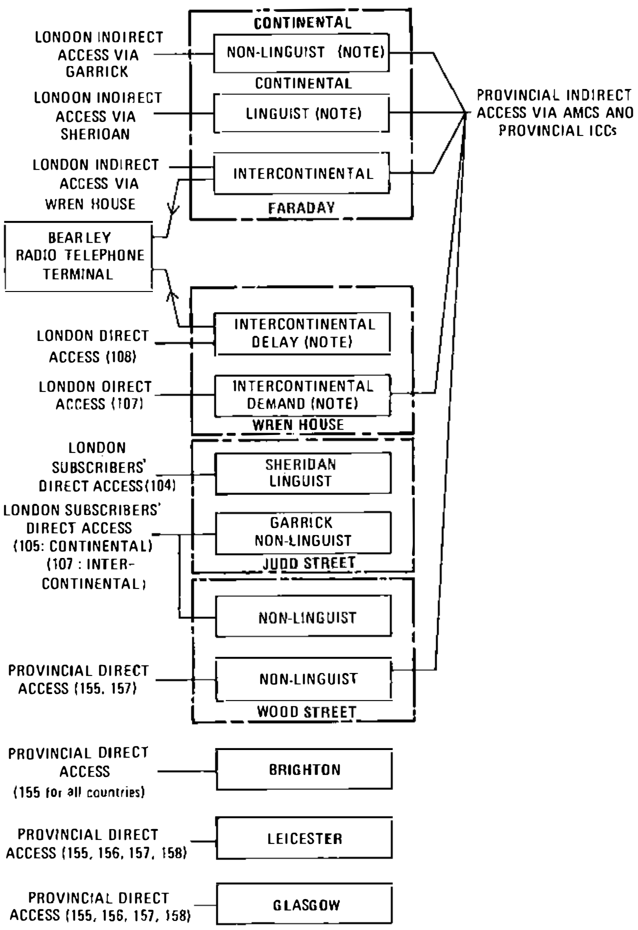
(*d*) Code-12 individual traffic requires connexion to a particular international operating position. Typically, this is used where an originating operator requires to be called back by an operator in the terminal country. Each operator's position is identifiable by an individual number within a linked numbering scheme covering all UK international switchrooms. The numbering scheme is also linked with item (*c*) above.

(*e*) Traffic incoming from international circuits that are operated manually terminates at ICCs.

The location and functions of the existing UK ICCs are shown in Fig. 4.

In addition to these basic types of operator-controlled traffic, a language-assistance facility is available on semi-automatic calls routed via certain of the UK ISCs. An originating operator experiencing difficulty on a connexion, can initiate the transmission of a *forward transfer* signal; receipt of this signal at the incoming ISC causes the connexion to be extended to an operator at an ICC.

All semi-automatic and IDD calls are routed via an ISC. The IDD prefix 010, dialled by a subscriber in a director area, causes the call to be routed to an outgoing trunk unit, either a central switching unit (CSU) or a sector switching centre (SSC), as appropriate. Examination of the digits 10, plus the country code, provides the charging rate information, and a translation to route the call to an ISC that has access to the required country.



Note: Two switchrooms are provided

FIG. 4—International control centres existing in 1977

In non-director areas, receipt of the IDD prefix digits 10 by the controlling register-translator results in the association of an international register,[6] a multi-frequency sender/receiver, and an international call-timer, to control call charging and to allow the call to be routed to the appropriate ISC, either direct or through the transit network.

For calls originating in either a director or non-director area, the international number is passed forward to a register in the ISC that controls further setting up of the call.

Although the charge to the subscriber is controlled from the CSU/SSC/GSC, it is necessary for details of all calls on the international routes to be recorded for the settlement of accounts with other countries. This is a function of the international accounting and traffic analysis equipment (IATAE)[7] or similar equipment, which is associated with every ISC.

SIGNALLING SYSTEMS

To interwork with the national and international networks the ISCs must provide appropriate signalling terminations. The signalling systems currently in use for international-

TABLE 1
National Signalling Systems

BPO Designation	Mode of Operation
Loop Disconnect	Pulsing at 10 pulses/s over a phantom circuit derived from a 4-wire speech path
Signalling System AC11[8]	Single-frequency (2280 Hz) line signalling system used in conjunction with a multi-frequency digital signalling system. A version providing a *forward transfer* signal is used on routes from remote ICCs to ISCs
Signalling System AC9	Single-frequency (2280 Hz) line signalling and digital signalling system, the latter signals being sent at 10 pulses/s. Superseded by SSAC11/MF2 for new routes
Signalling System DC2	A single-current, double-commutation system used for service traffic between ICCs. This system differs from the national SSDC2 system in that it provides for a *forward transfer* signal to summon operator assistance
Signalling System DC3[8]	The d.c. line signalling equivalent of SSAC11. Used in conjunction with SSMF2 on audio circuits where a continuous metallic path is provided between both signalling terminations. Also used over pulse-code-modulation links to Mollison and De Havilland ISCs
Signalling System DC4	The d.c. line signalling system used in conjunction with SSMF3 on routes from remote London ICCs to ISCs. The system provides a *proceed-to-send* signal, thereby enabling SSMF3 to use signals in the forward direction only
Signalling System MF2[8]	A multi-frequency inter-register signalling system in a 2-out-of-6 code, using 6 frequencies at 120 Hz spacing, 1380–1980 Hz in the forward direction, and 540–1140 Hz in the backward direction. The use of a guard signal between digits provides a good immunity to noise interference, but slows sending to approximately 3 digits/s
Signalling System MF3	A simplified version of SSMF2 using the forward frequencies only to convey digital signals from remote ICCs to ISCs. Used in conjunction with SSAC11 (forward transfer) or SSDC4

TABLE 2
International Signalling Systems

CCITT Designation	Mode of Operation
CCITT 1	Operating frequency 500/20 Hz; used on direct manually-operated circuits terminating at ICCs
CCITT 4 (BPO SSAC4)	A 2 voice-frequency system, using 2040 Hz and 2400 Hz for both line and inter-register signalling, the latter using serial binary code. CCITT4 is an end-to-end signalling system
CCITT 3 (BPO SSAC7)	Single-frequency (2280 Hz) line and inter-register signalling using a rhythmic (start-stop) code for digital signals. Used only at Faraday ISC on an incoming route from Paris
CCITT 5 (BPO SSAC10[9]/ SSMF1)	Two voice-frequencies of 2400 Hz and 2600 Hz are used for line signalling on a link-by-link basis. Six frequencies at 200 Hz spacing in the range 700–1700 Hz, are sent in a 2-out-of-6 code at 9 digits/s for inter-register signalling
CCITT R2† (Regional System No. 2)	Uses an outband within-channel continuous tone-on-idle state (3825 Hz) for line signalling, and in-band multi-frequency 2-out-of-6 compelled-code inter-register signalling on an end-to-end basis. First used in the UK on routes between Mollison ISC and the continent
CCITT 6[10]	All signalling information is removed from the speech paths and is carried over a separate signalling channel that is common to a large group of circuits. Data are transmitted at 2400 bit/s and the system operates on a link-by-link basis. The first UK application is expected to come into service in 1979

access circuits and international circuits are listed in Tables 1 and 2, including a brief description of the mode of operation.

FUNCTION AND EQUIPMENT OF UK ISCs

In a particular situation, the CT1, CT2 and CT3 switching functions need not necessarily be performed by physically separate exchanges. For example, until 1972, the UK had only one ISC, at Faraday. London is designated a CT1, therefore, Faraday fulfilled that function as well as the CT3 function of providing the interface between the UK national and international networks; it also fulfilled a hypothetical CT2 function.

The spectacular growth in demand for international services in the early 1970s meant that a large increase in switching capacity was urgently needed. The switching system at the Faraday ISC, which uses motor-uniselectors, was not suitable for the size of switching unit required. It was therefore decided to order a Plessey 5005 crossbar exchange for installation at Wood Street, London. The international exchange version of the Plessey 5005 system is known in the BPO as the *TXK2* system, and its application at Wood Street is described in an article in this *Journal*. The Wood Street ISC was put into service in 1972 and shared with the Faraday ISC joint CT1/CT3 status.

By 1972, it was clear that growth in demand was proceeding at such a rate that it could only be satisfied by a substantial increase in switching capacity. In planning for this very large increase in switching capacity, advantage was taken of the fact that most of the traffic makes use of only a limited number of the wide range of facilities available to international telephone services; for example, the demand for international transit routings or operator assistance on calls incoming to the UK is small in relation to the total traffic. In addition, some 80–85% of total UK international traffic is with 16 countries, and about 70% originates or terminates in the London charge group. It was therefore decided that the most effective way of handling international traffic was to segregate it into 2 streams, known as *major-route* and *minor-route* traffic. Major routes are defined as routes to those countries with whom the 16 or so largest traffic streams exist. A minor route is a route to any country other than those nominated as major-route countries.

It is intended that major-route traffic will be handled by large, limited-facility ISCs, while minor-route traffic, together with that traffic from major-route countries which requires the extra facilities, will be handled by a full-facility ISC.

The first limited-facility ISC to enter service was the Mollison ISC which was brought into service in November 1974 to handle major-route traffic between the UK and 4 intercontinental countries and 10 continental countries. L. M. Ericsson ARM 20 crossbar equipment, designated TXK5 by the BPO, provides two 4000 erlang unidirectional switching units for incoming and outgoing international traffic respectively. Mollison ISC, which will be the subject of an article in a later issue of the *Journal*, is located at Stag Lane, Edgware, some 19 km from Central London, on a site which also houses a TXK2 exchange known as the *De Havilland* ISC. This latter exchange provides full facilities and was brought into service in September 1975.

Two ISCs are currently being installed in Mondial House which is situated on the north bank of the river Thames in the City of London. The first is a full-facility TXK2 exchange, of a more advanced equipment design than that used at the Wood Street and De Havilland ISCs, and is named the *Mondial* ISC. The second exchange in Mondial House is another large limited-facility unit, which will be known as the *Thames* ISC. This ISC is being provided in 2 phases: phase 1 consists of separate incoming and outgoing units of TXK5 equipment; phase 2 is a bothway unit using L. M. Ericsson AKE 132 equipment, which is designated TXK6 by the BPO.

CONCLUSION

The progressive application of new technology and techniques in the transmission, signalling and switching fields has made the international telephone service more attractive to customers. Demand for this service in the last decade has increased at an annual rate of 20% and has necessitated the provision, in the UK, of large ISCs having high traffic-carrying capability. Details of these ISCs will be given in a series of articles to be published in this *Journal*; the first of these appears on p 86 of this issue.

† The BPO has given the designation SSMF6 to the national counterpart of CCITT R2, the 2 signalling systems being fully compatible for interworking on an end-to-end basis

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The TXK2 Switching System at Wood Street and De Havilland International Gateway Exchanges

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UDC 621.395.344.6: 654

This article describes the basic functions of the first British Post Office crossbar international telephone exchange which went into service in April 1971, at Wood Street, London. It also explains the changes made for the second application of this switching system at De Havilland international switching centre, which opened in September 1975.

WOOD STREET INTERNATIONAL TELEPHONE SERVICES CENTRE

Introduction

Until the opening of Wood Street international exchange in April 1971, all international calls to and from the UK were handled by Faraday international switching centre (ISC), in conjunction with the international control centres (ICCs). However, the switching equipment and the system architecture used at Faraday were considered unsuitable for further development to meet the growth of international direct dialling (IDD). It was therefore decided to install a crossbar system, which was then dimensioned to provide the maximum possible switching capacity within the floor space available.

The switching system used for Wood Street international telephone services centre (ITSC)[1] is an adaptation of the Plessey 5005T crossbar system, but unlike its national TXK1[2,3] counterpart, it provides facilities for switching 4-wire speech paths. It is designated *TXK2* by the British Post Office (BPO). The ITSC is situated in Wood Street, London, in a building that provides approximately 6500 m^2 of floor space, of which about 70% is used for switching equipment and associated services.

The Wood Street ITSC comprises

(*a*) the ISC,
(*b*) the ICC,
(*c*) the international maintenance centre (IMC), and
(*d*) the international accounting and traffic analysis equipment (IATAE).

ISC Signalling

The types of traffic for which the ISC provides automatic switching facilities are shown in Fig. 1.

Continental circuits are routed on submarine cables or cross-channel microwave links, with inland connexions being completed by conventional high-frequency (HF) transmission equipment. Since the route lengths are relatively short, propagation delays are short and echo suppressors are not normally necessary. Continental circuits terminating at Wood Street use the International Telegraph and Telephone Consultative Committee No. 4 (CCITT 4)[4] signalling system.

Intercontinental circuits, operating over long distances, have significant propagation delays and, consequently, are provided with echo suppressors. These circuits use CCITT 5[4] multi-frequency (MF) signalling. Many of the intercontinental circuits are operated in the bothway mode to take advantage of the non-coincidence of busy hours that arises when circuits terminate in different world time zones. Nevertheless, a unidirectional element is usually included in each of the routes.

Incoming circuits to the ISC from the national network use both a.c. and d.c. signalling. IDD traffic originating in the London director area uses loop-disconnect signalling, Signalling System AC No. 11 (SSAC 11) or SSDC 3, whereas similar traffic from provincial subscribers uses SSAC 11 only. The inter-register signalling for SSAC 11 and SSDC 3 is carried out in SSMF 2.

Operator-originated calls from the remote manual boards use a simplified form of fast signalling, known as *SSMF 3*, which employs MF signalling in the forward direction only. The associated line signalling system for SSMF 3 is SSAC 11 from provincial ICCs, and SSDC 4 from London ICCs. The SSAC 11 differs from the one used in the national trunk network in that it provides an additional signal, designated *forward transfer*, to call in a language assistance operator at the distant international exchange. Operator-originated calls from the Wood Street manual boards use d.c.-coded (DCC) signals from the operator's keyset; these signals are transmitted over the cord-circuit TIP and RING wires, via a common access relay-set, to an incoming register.

Outgoing routes from the ISC also use the standard national and international signalling systems, as used on the incoming routes; in addition, SSAC 9 is used on routes to those provincial group switching centres (GSCs) that at present cannot be reached directly, or via the national transit network

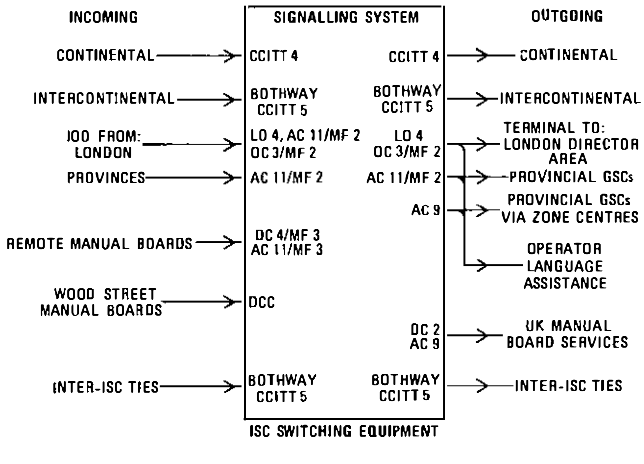

FIG. 1—Signalling systems used at Wood Street ISC

† Telecommunications Development Department, Telecommunications Headquarters

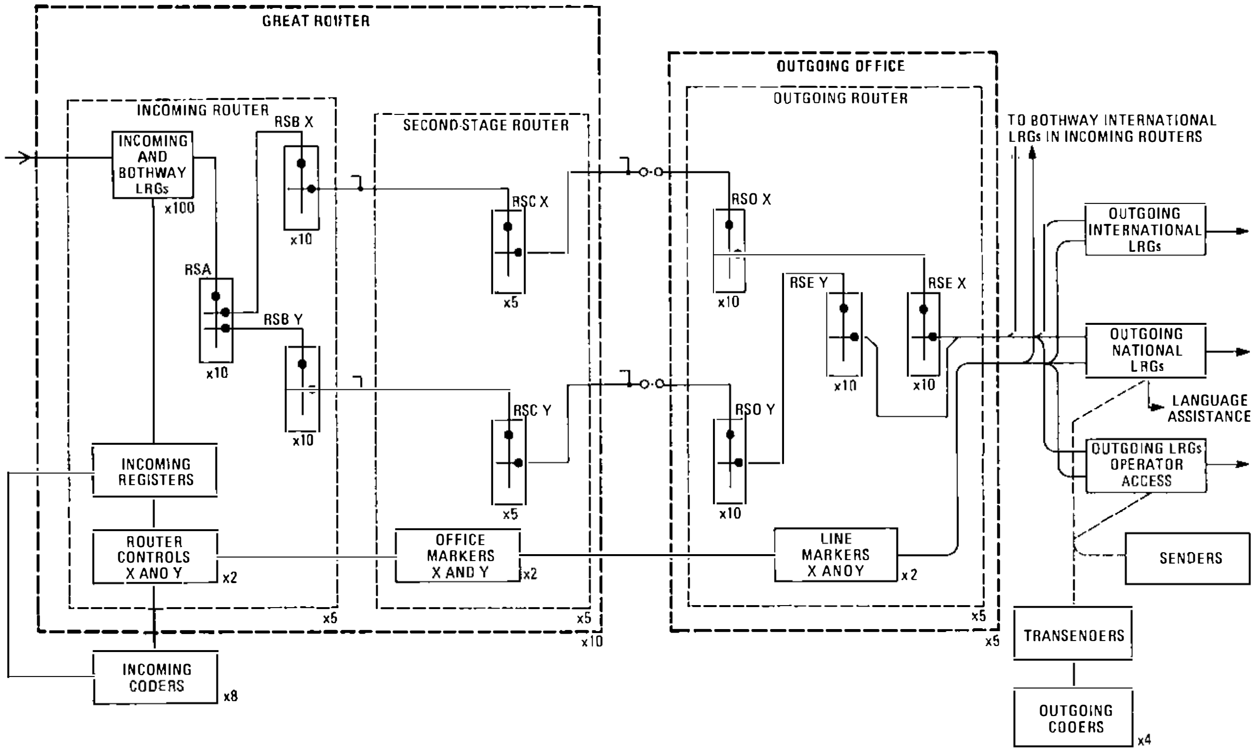

FIG. 2—Simplified trunking arrangements at Wood Street ISC

using SSMF 2 inter-register signalling. Tie circuits to other UK ISCs are provided to give access to countries that could not otherwise be reached from Wood Street ISC.

ISC Switchblock Design

The Wood Street ISC switchblock is designed to provide for up to 5000 incoming and 5000 outgoing circuits, with an estimated busy-hour load of 3000 erlangs. Five ranks of crossbar switches are used, each switch providing 10 inlets and 20 outlets of 5 wires (4 speech wires and 1 control wire). Calls are set up on the self-steering principle; backward marking signals from a selected outgoing circuit are steered through possible paths to the calling incoming circuit, a unique path is selected and is then established by the forward sequential closure of crosspoints at each switching stage.

A simplified trunking diagram is shown in Fig. 2. To enable a number of calls to be set up simultaneously, the crossbar switches and the control equipment are divided into sections comprising *great routers* on the incoming side and *offices* on the outgoing side of the exchange. These large formations of equipment are built up in the following way.

One hundred incoming line relay-groups (LRGs) with their associated registers, 10 route switches A (RSAs), 20 route switches B (RSBs), and router controls X and Y form an incoming router. The RSB outlets for 5 such incoming routers are spread over the inlets of 5 second-stage routers; each second-stage router consists of 10 route switches C (RSCs) and office markers X and Y. The grouping of 5 incoming routers and 5 second-stage routers forms a great router, and 10 of these are provided at Wood Street. The linking between RSB outlets and RSC inlets is such that each incoming router has access to all 5 second-stage routers within its own great router.

On the outgoing side of the exchange, 200 outgoing LRGs, a line marker X and a line marker Y, 20 route switches D (RSDs) and 20 route switches E (RSEs) form an outgoing

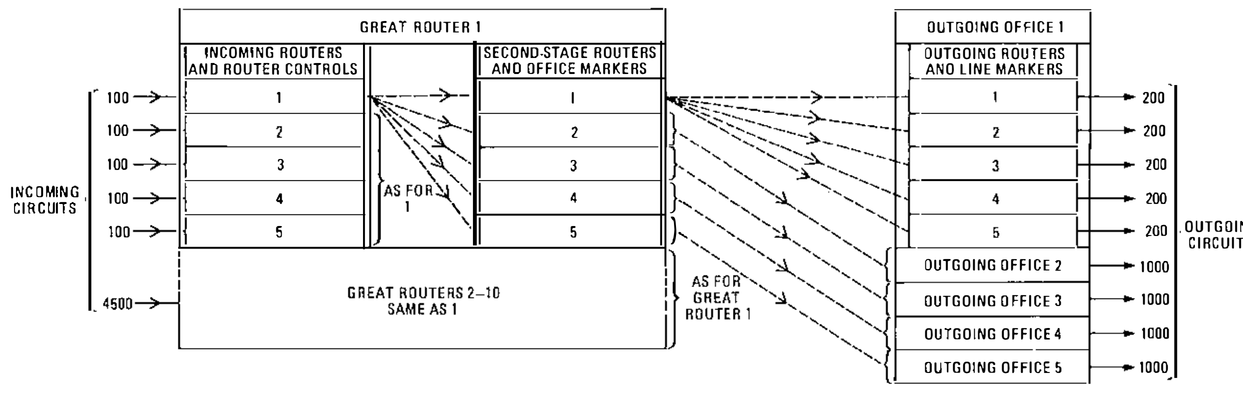

FIG. 3—Method of interconnecting the 3 router stages

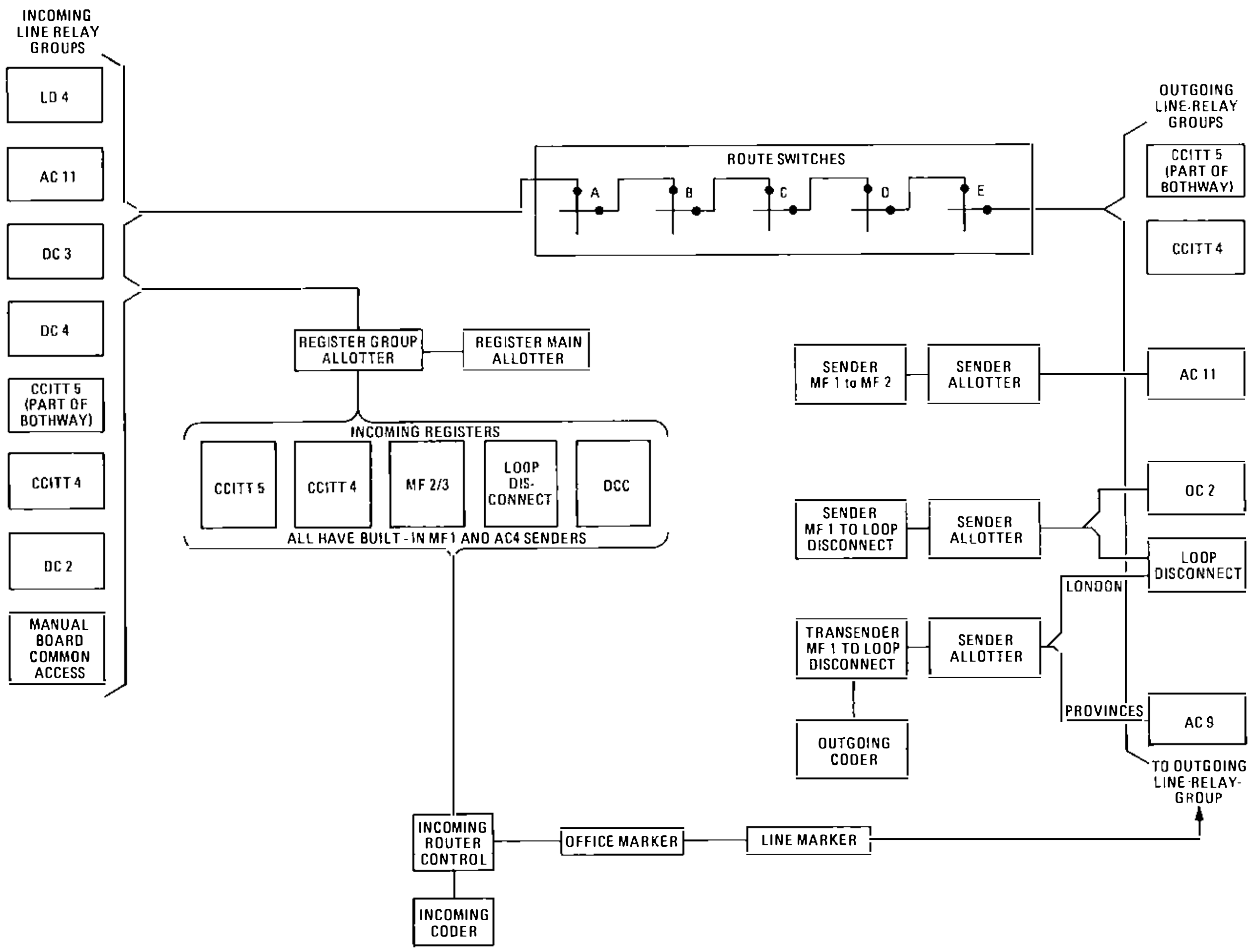

FIG. 4—Block diagram of Wood Street ISC main equipment

router. Five of these outgoing routers are combined to form an outgoing office of 1000 lines. Within a great router, a second-stage router is required for each outgoing office; hence, the linking between RSC outlets and RSD inlets is such that each of 5 second-stage routers has access to the corresponding outgoing office (see Fig. 3).

As shown in Fig. 2, the trunking between the RSA and RSE stages is divided into 2 equal parts, designated X and Y; the division extends across the whole switchblock so that, after the RSA inlets, there are 2 quite separate switching matrices that are commoned together again at the RSE outlets. Each half of the trunking normally carries half of the total exchange traffic. Also, if a second attempt to set up a connexion through the switchblock is necessary, it is normally made over the half of the exchange that was not used on the first attempt.

ISC Equipments

The various types of equipment and their method of interconnexion are shown in Fig. 4 and are described below.

Incoming Line Relay-Groups and Allotters

In general, a different type of incoming LRG and register is provided for each type of signalling system. The LRGs have access to a pool of registers, the register selection being controlled by a register allotter. The incoming LRGs send a discrimination signal to the register, hold the forward connexion, provide call-supervision facilities, and extend seizure, answer and release indications to the accounting equipment. The discrimination signals are pre-strapped in the LRG to indicate to the registers

(*a*) whether the call is originated by a subscriber or an operator,

(*b*) whether the call requires inland or international access, and

(*c*) if the incoming circuit is via a satellite, cable or an inter-ISC tie.

In addition, CCITT 4 and CCITT 5 incoming LRGs can return a voice-frequency *busy-flash* signal to the originating centre to enable the call to be dropped back to a local busy tone thus freeing the circuit for use on another call. Incoming LRGs serving manual-board routes can receive a *forward transfer* signal, which they extend to an outgoing LRG as a d.c. signal across the switchblock.

With the exception of the incoming loop-disconnect LRG, which has access to 3 registers, all other incoming LRGs have access to 4 incoming registers within a pool of 4–9 registers. A group allotter can serve up to 10 incoming LRGs. A main allotter, the function of which is to restrict the incoming LRGs' demands for a register to one at a time, serves up to 10 group allotters.

Incoming Registers

Five types of incoming register are provided. Their basic functions are to receive and store the incoming digits, forward up to 7 digits to the incoming coder when this is seized by the router control, and then to control the onward transmission of the digits in accordance with the sending instructions given by the coder.

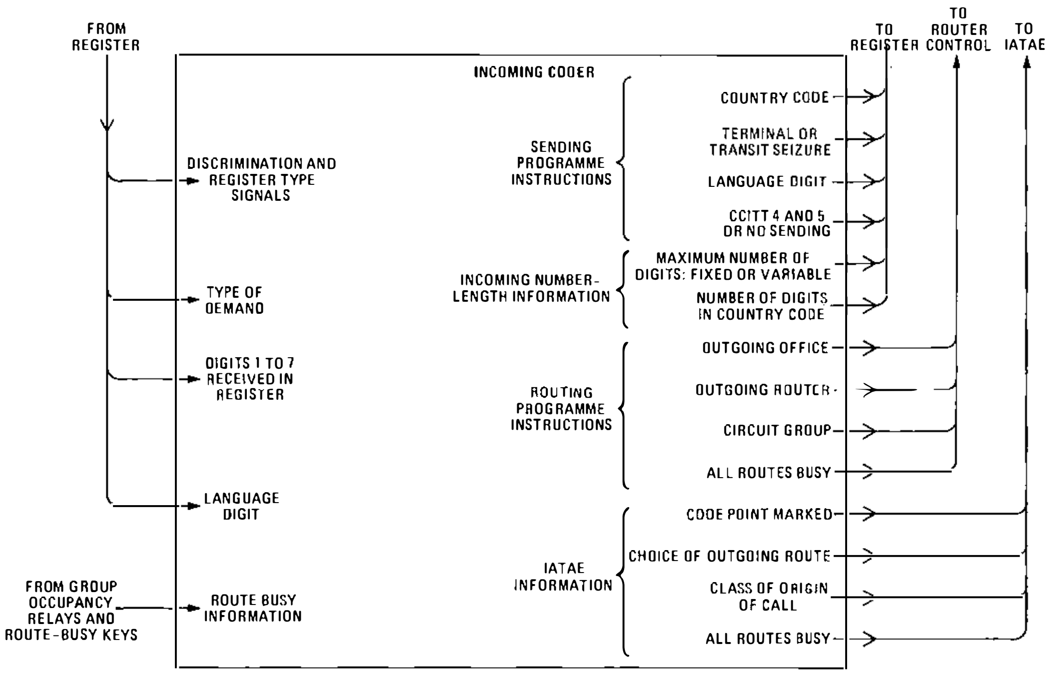

FIG. 5—Information transfer in incoming coder

Each of the incoming SSMF 2/3, CCITT 5 and DCC registers has a built-in signalling receiver. In the case of CCITT 4, however, in which the same 2 frequencies are used for both line signalling and inter-register signalling, the receiver is located in the incoming LRG, but the decoding of digital signals is carried out in the incoming register. Various timing controls and error-check circuits are also contained in the registers to supervise the register signalling processes. Under failure conditions, this enables the register to initiate a repeat attempt to set up the call or force release the connexion. Although the ISC must cater for 6 types of outgoing signalling (namely CCITT 4, CCITT 5, SSMF 2, loop-disconnect, SSAC 9 and SSDC 2), for economic reasons the register sending capabilities are limited to CCITT 4 and CCITT 5† MF signalling only. For calls terminating in the UK, the registers signal across the switchblock using their built-in CCITT 5 senders to signal to conversion equipment on the outgoing side of the exchange.

Router Control

The setting-up of a call path through the exchange is controlled by a router control, 2 of which are provided in each incoming router; one handles calls over the X paths and the other handles calls over the Y paths.

The router control is called in by an incoming register when a predetermined number of digits has been received. The router control seizes an incoming coder and also instructs the register to associate with that coder. Receipt of routing information from the coder identifies the office, outgoing router and the outgoing circuit group required; the router control then calls the relevant office marker and, via the latter, gains access to the required line marker. On instruction from the office marker, the router control closes the marking wires between the RSB outlets and the RSC inlets of the second-stage router serving that office. The router control also primes the RSA on which the calling LRG is terminated, to guard against intrusion by the partner router control and to ensure that only the relevant X or Y marking signals are accepted.

Marking is completed by the selection of one of the marking signals arriving at the RSA, whereupon the router control operates the RSA bridge magnet associated with the inlet to which the calling LRG is connected. This starts the sequential closing of crosspoints in the RSB–RSE stages and extends the transmit and receive pairs of wires to the outgoing LRG. The router control then applies a d.c. continuity test to these wires and, if the test is successful, it signals to the register that the switched path to the outgoing LRG has been proved.

The router control provides timed supervision of each stage in the call setting-up process; failure to complete any stage within approximately 1·5 s results in an equipment monitor being called to print out details of the equipment identities, and the register being instructed to make a repeat attempt to establish the call, provided it was not already a second attempt.

Incoming Coder

The incoming coder acts on information passed from the register to provide the routing instructions to the router control and sending instructions to the register. Each register and router control has access to 2 incoming coders and, as the holding time of this equipment is approximately 150 ms, only 8 are required to handle all the traffic carried by the Wood Street ITSC. The exchange of information that takes place between the incoming coder and other equipments is shown in Fig. 5.

On seizure by the router control, the incoming coder may need to receive up to 7 digits of the international number from the register. However, in most cases, digits representing the country code, which can be a maximum of 3, together with perhaps 1 or 2 digits of the area code are sufficient to enable the incoming coder to decide the routing and sending instructions.

On calls where the incoming signalling is such that an end-of-signalling indication is not received and routing is required to an outgoing CCITT 5 circuit, the incoming coder with-

† The register signalling part of CCITT 4 is known as *SSAC 4*, and CCITT 5 is known as *SSMF 1* in the BPO

holds routing instructions because it is a CCITT 5 signalling requirement that all digits be sent *en bloc*. For such calls, the initial seizure of the incoming coder is used to establish, firstly, that the outgoing signalling is CCITT 5 and, secondly, to provide the incoming number-length information. The latter is required so that the register can insert an *end-of-signalling* (*stop*) digit in its digit store. The incoming coder provides the necessary number-length indication in one of the following 2 forms.

(*a*) For calls to destination countries with fixed number-lengths, the incoming coder indicates to the register the actual number of digits to be expected from the originating centre. This enables the register to insert the *stop* digit as soon as the final digit is received.

(*b*) For calls to destination countries with variable number-lengths, the incoming coder signals to the register a *variable number-length*, together with the maximum number of digits that may be expected from the originating centre. The register then inserts the *stop* digit when no digit has been received for 5 s. However, if the maximum number-length is received, the *stop* digit is inserted immediately.

For calls to outgoing circuits using CCITT 5 signalling, a further application must be made to the incoming coder to obtain the required routing, and this is carried out when the register has established the *stop digit* condition, as set out above. However, when the call is terminated in the UK, a further application to the incoming coder is not necessary because the trans-exchange MF 1 signalling can be carried out on a digit-by-digit basis. This allows the outgoing national signalling from the signal-conversion equipment to overlap the incoming international signalling and thus minimize the post-dialling delays.

On receipt of certain types of discriminatory signals, indicated by the incoming LRG and stored by the register, the incoming coder may modify the outgoing routing or instruct the register to bar the call. The incoming coder constantly monitors the state of the outgoing routes and, if route-busy conditions pertain, it can automatically provide for up to 5 alternative routings.

During the seizure of the incoming coder on a routing demand, information relating to the class of incoming call (operator, subscriber or transit), the identity of the selected outgoing route and the call destination is passed to the IATAE so that the call can be accounted to the appropriate route-destination records.

Office Marker

The office marker provides access to the required line marker within the outgoing office and extends the outgoing-circuit-group information from the router control. Entry to the office marker is on a one-at-a-time basis and router relays, corresponding to the operated entry relay, close the appropriate marking leads between the incoming router and the second-stage router. Two office markers are associated with each second-stage router.

Line Marker

A pair of line markers is associated with each outgoing router. For route-identification purposes, 200 circuits in the outgoing router can be divided into a maximum of 20 groups, 10 high groups and 10 low groups. A high group caters for 17 circuits and can be extended in steps of 17 circuits by jumpering relief relays to a maximum of 102 circuits, but as large routes are normally spread over several outgoing routers for operational convenience, this limit is unlikely to be reached in practice. Each low group can use one of the relief relays and caters for 17 circuits only.

On seizure, the line marker extends a signal to the office marker to close the marking wires between the second-stage router and the outgoing office; that is, the RSC and RSD stages. The line marker then tests the circuits in the required route in a predetermined order, and the first free circuit is selected.

Outgoing LRGs and Associated Equipments

The outgoing LRGs control the sending and receipt of line signals. They also provide the necessary interface to convert the d.c. signals on the exchange side into line signals and vice versa. The exchange of line and supervisory signals between the incoming and outgoing LRGs is carried out over the 4-wire transmit and receive paths switched through the ISC.

On outgoing national calls, because the register trans-exchange signalling is in SSMF 1, the national outgoing LRGs require access to signal-conversion equipments called *MF 1/MF 2 senders* and *MF 1/loop-disconnect transenders.* The access function is fulfilled by sender allotters, which are similar in design to register allotters. To minimize the waiting period between the outgoing LRG accessing a sender or a transender and commencement of trans-exchange MF 1 signalling, preferential selection is given by the line marker to an outoing LRG with access to a free sender or a transender.

On outgoing loop-disconnect calls to the London director area routed via Faraday non-director incoming unit, and on outgoing SSAC 9 calls to provincial GSCs routed via an intermediate GSC, additional routing digits have to be provided. This is the function of the outgoing coder, which can provide up to a maximum of 6 routing digits. However, with the advent of sector switching centres[5,6,7] and transit switching centres,[8,9] the need to use outgoing coder facilities is diminishing.

Within the outgoing national LRGs, facilities also exist to call in assistance router equipment to connect incoming semi-automatic calls to UK assistance operator positions. This feature is required when the calls originated by overseas operators cannot be completed; for instance, due to language difficulties. In such cases, the overseas operator effects the transmission of a discrete *forward-transfer* signal. This is received by the outgoing LRG as a d.c. condition from the incoming LRG and, in conjunction with the language digit indication received from the sender or the transender, it enables the required linguist operator to be accessed via an assistance router (see Fig. 6). The linguist operator can act as an intermediary, but cannot control the routing of the call.

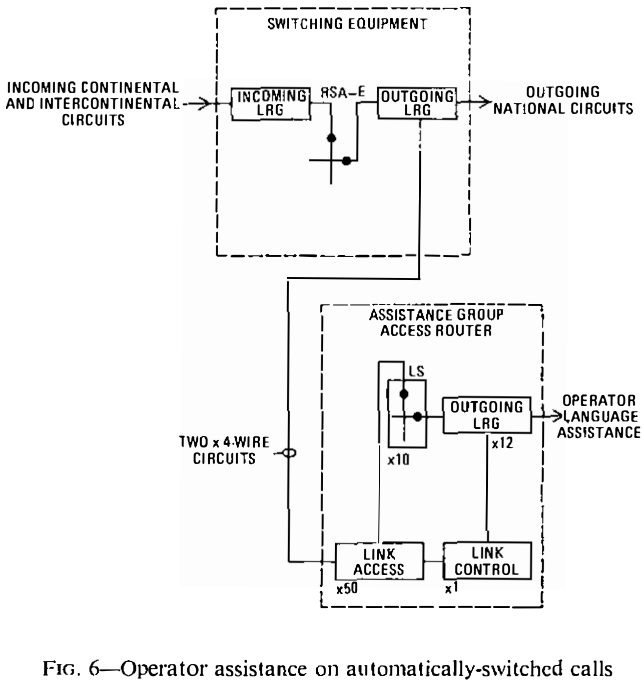

FIG. 6—Operator assistance on automatically-switched calls

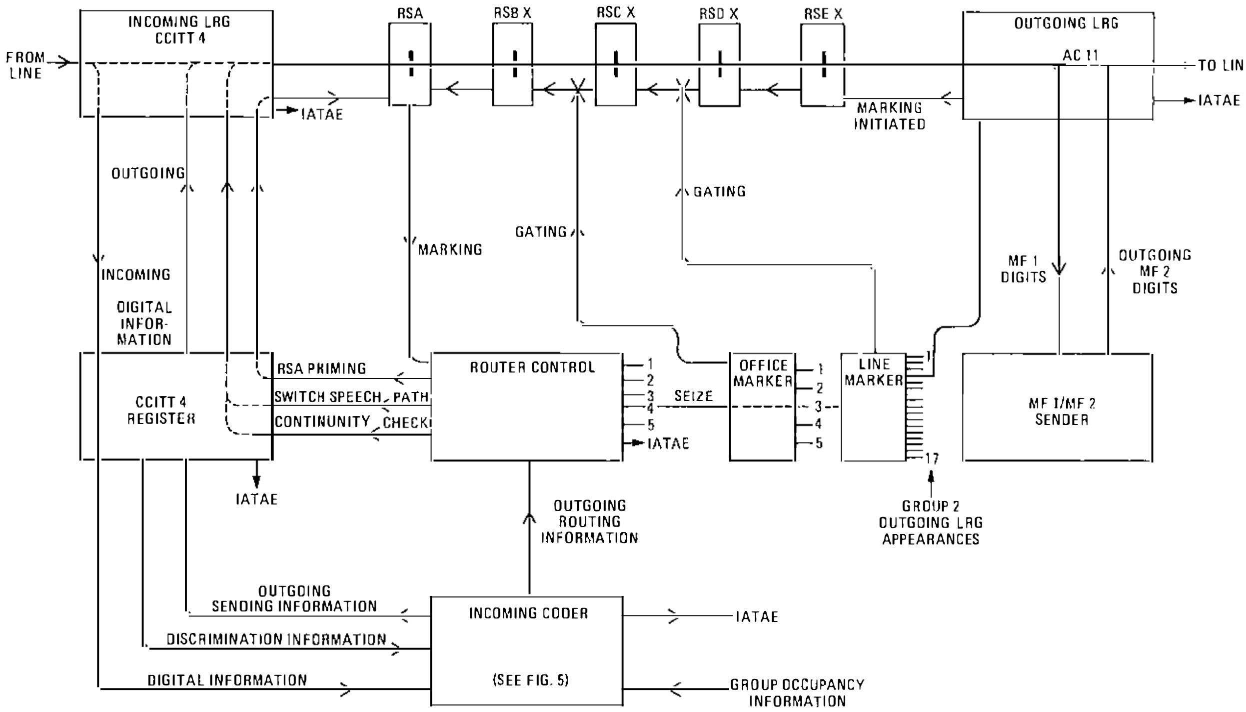

FIG. 7—Method of switching an incoming CCITT 4 to outgoing SSAC 11/MF 2 call

Selection and Marking

In the TXK2 system, selection of a free outgoing LRG by the line marker X or Y is on an individual basis and only the selected LRG originates marking signals through its associated RSE. The TXK1 technique of *mass marking* all free outgoing LRGs in the required route on the X or Y side of an exchange is not used at Wood Street. Individual marking enables a bothway circuit to be seized by the line marker and reduces the unguarded interval during which simultaneous seizure from both ends is possible.

The principles governing the steering of marking signals are the same as those used in the national TXK1 system, but as 5 stages of switching are used, it was considered desirable to provide fast marking. This is achieved by a slight change in the mode of operation of a basic 5005 crossbar switch involving earlier operation of the marking relay and resulting in reduced holding times for common equipments.

A Typical Call Through the ISC

Consider a subscriber-dialled incoming call using CCITT 4 signalling that requires connexion to a subscriber connected to a non-director GSC served by a route using SSAC 11/MF 2 signalling (see Fig. 7).

On receipt of a *terminal-seizure* signal, the incoming CCITT 4 LRG associates an incoming CCITT 4 register, returns a *proceed-to-send* signal to the originating ISC, and inter-register signalling then takes place. Typically, the register receives $(L)\ ABC\ N_1N_2N_3N_4N_5N_6$, where (L) is a language digit which, for an automatic call, is the digit 0. Since this is a subscriber-dialled terminal call, neither the UK country code (digits 44) nor an *end-of-signalling* digit (*stop* digit 15) is received. The storage of digits in the register starts at store position 3, missing out stores 1 and 2, which are used for country-code digits. When the sixth store is filled (digit C), the register applies to one of the 2 router controls available. If router control X is seized, all subsequent equipment seizures are on the X paths of the ISC.

On seizure of the incoming coder by the X router control, information highways are established. The register passes all stored digits to the incoming coder, including the language digit and a terminal CCITT 4 indication. Typically, the coder instructions to the register and the router control are as follows.

Sending Programme:

(*a*) send in CCITT 5 (SSMF 1),
(*b*) the incoming number-length is fixed, and
(*c*) the number of incoming digits, including the country code, is 12.

Routing Programme:

(*a*) the required route is in outgoing office No. 4,
(*b*) the required route is in outgoing router No. 3,
(*c*) the required route is in a low group, and
(*d*) the required route is in group No. 2.

When the register and router control have validated the instructions, the incoming coder is released; the router control then seizes the X office marker of second-stage router No. 4 and the X line marker of outgoing router No. 3 in outgoing office No. 4. The route group identity is passed on to the line marker and the RSA is primed.

The line marker selects one of the outgoing SSAC 11 LRGs in group 2 with access to a free SSMF 1/MF 2 sender. The RSE, an outlet of which is associated with the selected outgoing SSAC 11 LRG, initiates fast marking signals. These are steered across the switchblock via the contacts of the route relays (gating), operating the auxiliary and select magnets in the route switches.

When the marking signal is received in the router control, the control wire is earthed to operate the RSA bridge magnet and, thereby, start the sequential operation of the bridge magnets in the other route switches. The transmit and receive pairs, which are now extended to the outgoing LRG, are checked for continuity. Once the paths are proved, the router control releases, thereby releasing the office marker and the line marker. The forward connexion is then held by the register.

On release of the line marker, the outgoing SSAC 11 LRG associates an SSMF 1/MF 2 sender to which the transmit pair on the exchange side of the LRG is extended.

The outgoing LRG then sends a seize signal to line. The SSMF 1/MF 2 sender initiates the return of a d.c. *proceed-to-send* signal from the outgoing LRG to the register, which then commences the trans-exchange sending of the digits in SSMF 1 code.

Meanwhile, the register continues to receive the numerical information from the originating ISC. If the outgoing SSMF 1 sending catches up with the incoming digits, the register suspends sending and awaits receipt of a further incoming digit. When the final digit, N_6, is stored in the register, a *stop* digit is simulated and a CCITT 4 *number-received* signal is returned to the originating centre to cause the release of its control equipment. The SSMF 2 portion of the SSMF 1/MF 2 sender is activated after the receipt of the first 4 digits, 0 *ABC*. On receipt of the *proceed-to-send* signal from the GSC, it starts sending forward the stored digits. The language digit is not sent to the GSC; its use is confined to providing the language information to the outgoing LRG in case language assistance is required on incoming semi-automatic calls.

After the receipt of the final digit, N_6, the GSC returns an SSMF 2 *number-received* signal. This is conveyed by the sender in d.c. form to the outgoing LRG, which repeats the signal to the incoming register. The register and the sender then release and the connexion is held under the control of the incoming CCITT 4 LRG.

Since the release of the incoming register is delayed until after the receipt of SSMF 2 *number-received* signal, the SSMF 1/MF 2 sender can instruct the register to carry out a repeat attempt if an SSMF 2 signalling failure occurs.

Maintenance Equipment

Under call-failure conditions, one of 2 equipment monitors is seized to record the identities of the various equipments used in setting up the call. A teleprinter associated with the equipment monitor prints out the necessary information in a predetermined sequence.

Automatic routiners are provided to routine the registers, LRGs and sender/transenders. Testers are provided for the more complex equipments such as voice-frequency and MF receivers, and a recent addition is a BPO-designed 4-wire crossbar switch tester that assists maintenance staff to locate faults in route switches.

International Maintenance Centre

An IMC is provided at Wood Street to carry out monitoring and faulting of the national and international circuits and their associated signalling equipment. The IMC is also responsible for compiling circuit fault records, and liaising with other maintenance controls in the UK and abroad. There are some unique features in the IMC that are not encountered in the national network, and these will be described in a later article.

International Control Centre

Although an increasing proportion of traffic is dialled by subscribers, operators are still required to complete certain calls in the international and UK national networks. This function is carried out by the ICC equipment. Wood Street ICC is designed to handle the following types of incoming operator assistance traffic.

(*a*) Code 11 incoming traffic, where the originating operator cannot complete the call by semi-automatic means; on such calls, the ISC receives a *terminal-seizure* signal, a *language* digit, code 11, and a *stop* digit.

(*b*) Code 12 general call-booking traffic; this is identified in the ISC by receipt of a *terminal-seizure* signal, a *language* digit, code 12 and a *stop* digit.

(*c*) Code 12 country group traffic that requires call bookings to specific countries; this type of traffic is recognized in the ISC by examination of specific incoming digits—$N_1N_2N_3$ (plus *stop* digit), following the receipt of the *terminal-seizure* signal, *language* digit and code 12. The $N_1N_2N_3$ digits enable the ISC to route the calls via a code 12 position router to a specific group of operators who handle these call bookings.

(*d*) Code 12 individual traffic requiring routing via the code 12 position router to a specific operator's position; calls in this category need additional digits to the *terminal-seizure* signal, *language* digit and code 12 indication to define the specific operator position, the latter being a part of a linked numbering-scheme involving all ICCs' operator positions.

Incoming code 12 country group and code 12 individual traffic is routed to the operator's answering jack via the code 12 position router. This is a further stage of crossbar switching equipment having its own controls, which can distinguish between the 2 types of traffic.

The operators are also provided with an outgoing multiple, on which the inland and international common-access circuits are terminated. For outgoing calls to both UK and overseas subscribers, the outgoing connexion is via the ISC equipment, numerical signalling being in DCC digits from the 2-wire sleeve-control manual boards. To connect the calls via the operators' 2-wire cord circuit would degrade the standard of transmission. This limitation is overcome by the use of an auto-manual router (AMR), which provides a 4-wire path to bridge the operators' 2-wire cord circuits (see Fig. 8). Once the operator has set up the connexion, the auto-manual router receives a discrete signal over the cord circuit that enables it to identify the incoming and outgoing LRGs used in the connexion. On restoration of the operator's SPEAK key, the conversation is carried by the 4-wire path; the 2-wire jack provides monitoring.

International Accounting and Traffic Analysis Equipment

The charge for an IDD call is recorded on the subscriber's meter in the same way that STD call charges are recorded, the tariff equipments for both services being located at the originating GSCs, SSCs or central switching units. However, the charge to be credited to the administration in the country of destination of the IDD call needs to be determined by other means and this is the function of the IATAE.

Information to an on-line computer is provided by reed-relay interface equipment, which signals the following events for incoming LRGs: seizure, address and route information available in the coder, called-subscriber answer, and clear. Each event is temporarily stored with the identity of the incoming LRG and the time of occurrence. The interval between answer and clear is calculated and added to the relevant route destination totals store.

To provide further information for exchange and network management, event recorders are also equipped for outgoing international LRGs, while exchange common equipment is scanned by the IATAE at appropriate rates to record total seizures and holding times.

A fuller description of the IATAE equipment was given in an earlier article in the *Journal*.[10]

DE HAVILLAND ISC

The second TXK2 ISC, which went into service in September 1975, is situated at Stag Lane, Edgware, in North London, on a site that also contains Mollison TXK5 ISC, which will be the subject of a later article.

De Havilland ISC is a full-facility unit which was originally intended to be the initial installation for the Mondial ISC, but was reconfigured and located at Stag Lane due to building delay at Mondial House. The switchblock is designed to provide for up to 5000 incoming and 5000 outgoing circuits,

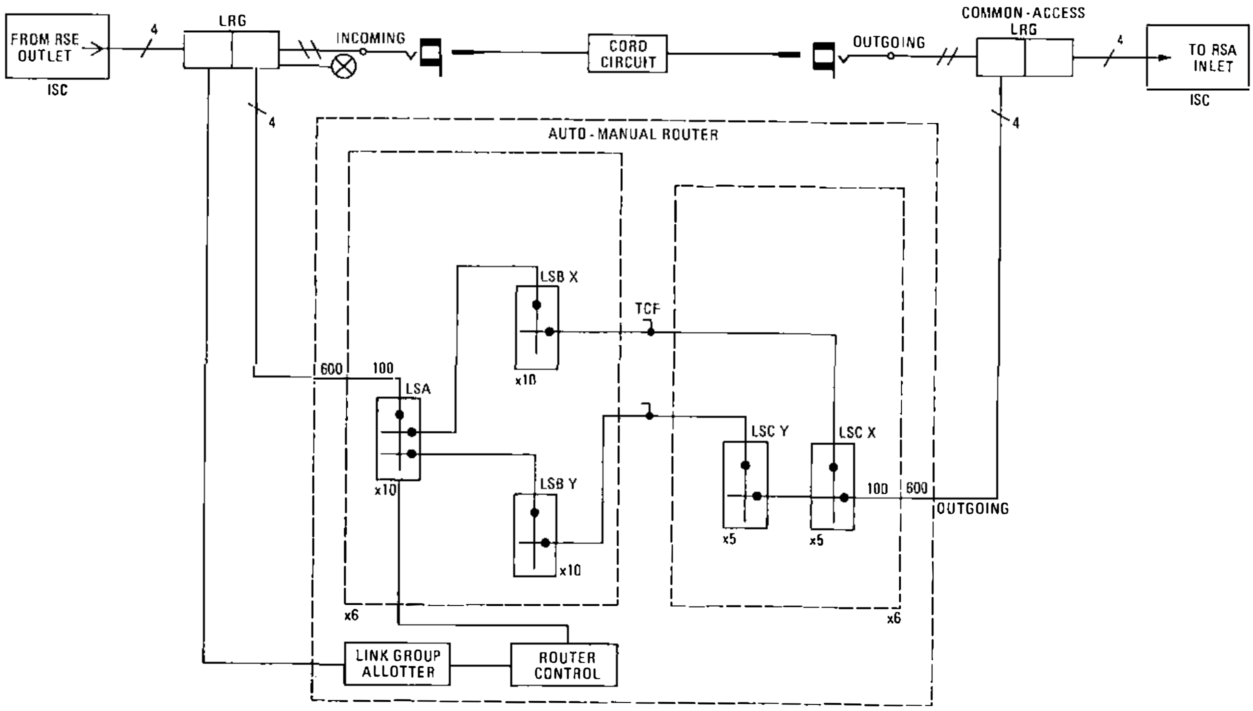

FIG. 8—Four-wire auto-manual router

with an estimated busy-hour load of 3000 erlangs. Although it has no directly-associated manual boards, it does provide access to and from remote ICCs to enable them to control national and international semi-automatic calls.

The equipment design is basically the same as that used for Wood Street ISC, but it incorporates the following improvements.

(*a*) To provide for shorter call holding times and consequently higher demands on common equipments, larger pools of registers, incoming coders, outgoing senders and transenders have been provided.

(*b*) The number of registers to which an incoming SSAC 11 or SSDC 3 LRG has access has been increased from 4 to 6.

(*c*) To give greater reliability, CCITT 4 receivers using discrete silicon transistors have been provided instead of the electronic-tube type used at Wood Street.

(*d*) More space has been made available on the coder connecting frame for the tag-block wiring associated with the code-digits expansion field.

(*e*) A more advanced IATAE is provided giving additional facilities for norm testing.

Significant changes were made to improve the installation and commissioning procedures. Equipment was delivered to site in the form of fully-equipped racks that had been tested in the factory; in addition, computer-controlled installation test equipment was provided on site to speed up the testing and commissioning.

CONCLUSION

TXK2 equipment has played a prominent part in providing international gateway exchanges with the necessary modern facilities and additional switching capacity to match the growth in international traffic as the IDD service is extended to the whole of the UK.

The early performance of Wood Street ISC was adversely affected by the exchange being called upon to handle traffic far in excess of its designed busy-hour capacity. Since the opening of Mollison and De Havilland ISCs, traffic has been redistributed, with the result that Wood Street ISC is now meeting its design objectives.

ACKNOWLEDGEMENTS

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Dual Polarization Technology

Part 1—Principles of Dual Polarization Microwave Transmission

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Plans are being made to increase the traffic-carrying capacity of the international satellite telecommunications system by exploiting the polarization properties of radio waves. Part 1 of this article describes the principles of dual-polarization operation and the extra requirements that it places on aerial design. Part 2 will describe the practical implementation of dual-polarization equipment, and Part 3 will discuss problems associated with propagation through the atmosphere and ionosphere.

INTRODUCTION

The development of communication satellite systems over the last decade has stimulated a dramatic increase in international telephone and data traffic. This has led to a rapid growth of satellite systems to the point where the frequency bandwidth available is becoming a severe limitation on the circuit capacity of each satellite.

This problem of providing more circuit capacity could be alleviated by placing more satellites in orbit, or making use of higher frequencies. However, there are operational, economic and technical problems associated with these solutions. Another approach is to transmit 2 signals on the same frequency through each satellite. One method of preventing the signals interfering with one another is to use highly-directional aerials on the satellite, directed at different parts of the earth's surface; a second method exploits the polarization properties of radio waves. This series of articles is concerned with the feasibility of the latter technique, known as *frequency re-use by dual polarization*. The feasibility of dual-polarization operation for future satellite systems has now been verified and demonstrated.

DUAL POLARIZATION TRANSMISSION

The principle of polarization discrimination can be demonstrated using visible light. Most sources of visible light radiate a mixture of polarized waves in which the direction of oscillation of the electric field varies rapidly and randomly A polarized filter, such as the lens of a pair of Polaroid sun-glasses, can be used to select waves in which the electric field oscillates in one direction only. If 2 light sources are placed side-by-side, as shown in Fig. 1, but with polarized filters oriented at right angles to one another, the radiation from either light source may be selected using a third polarized filter.

The same principles are applied to enable the transmission of 2 independent microwave carriers using the same frequency over the same earth–satellite link. However, unlike a light source, a microwave aerial naturally transmits or receives waves of a specific polarization, so there is no need for separate polarized filters.

The principles of dual polarization operation are illustrated by a simple microwave aerial comprising a length of circular waveguide, flared out at one end to form a horn (see Fig. 2(*a*)). This aerial can be used to transmit 2 cross-polarized signals simultaneously. The polarization of each signal is governed by the coupling of the circular waveguide to the 2 signal paths in an *orthomode junction*. The

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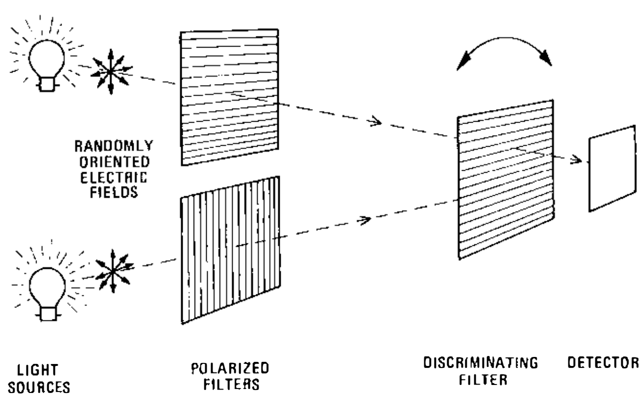
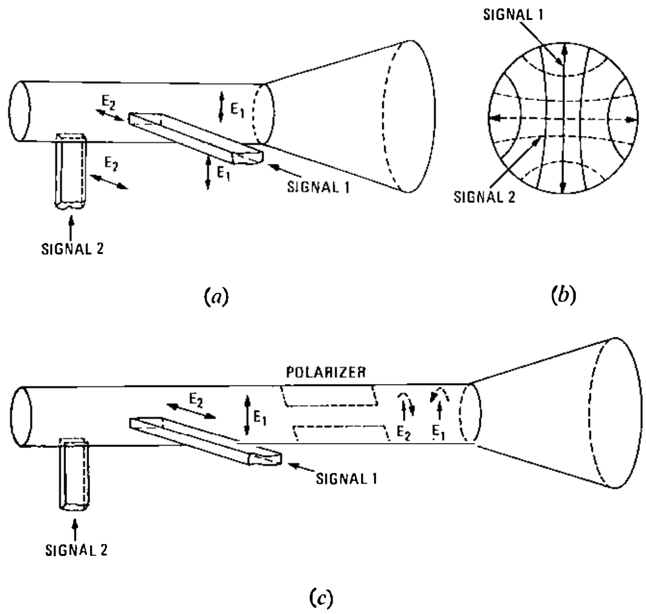


FIG. 1—An optical model of polarization discrimination



(*a*) Horn and circular waveguide with orthomode junction
(*b*) Electric fields within circular waveguide (TE_{11} mode)
(*c*) Horn aerial with quarter-wave polarizer

FIG. 2—Microwave horn aerials for dual polarization

electric fields in each of the rectangular waveguides are oriented as shown by the arrows E_1 and E_2 in Fig. 2(*a*) and excite electric fields in the corresponding directions in the circular waveguide (Fig. 2(*b*)). A similar horn may be used for reception so that, ideally, the signal present at each output port of the receiving horn arises solely from the respective input port of the transmitting horn. In practice, there will be a degree of crosstalk between the 2 signal paths arising from inaccurate construction of the horns or inaccurate alignment.

In a practical satellite link, more complex horns are used in conjunction with large focusing reflectors. The effects of these components are considered in later sections of this article, following a closer examination of the concept of wave polarization.

THEORY OF WAVE POLARIZATION

Only the case of linearly-polarized waves, in which the electric field oscillates in magnitude but retains the same direction in space, has been considered so far. It is natural to choose "horizontal" and "vertical" as reference directions, but any pair of directions at right angles to one another could be chosen to give 2 independent signal paths. Other orientations of the electric-field vector can, in fact, be considered as combinations of vertically and horizontally polarized waves. Fig. 3(*a*) shows how diagonally-polarized waves can be constructed by adding or subtracting a pair of vertically and horizontally polarized waves, oscillating in phase with one another.

If vertically and horizontally polarized waves are combined out of phase, the resultant electric-field vector never decreases to zero but rotates in space. Fig. 3(*b*) shows the particular example of 2 linearly-polarized waves in phase quadrature, which can be combined to give either right-hand or left-hand circularly-polarized waves. Fig. 3(*b*) also shows that they may be combined to give a more general intermediate form of polarization, in which the electric field rotates and also oscillates in magnitude, known as *elliptical polarization*.

It is possible to choose a large number of pairs of polarization states that could be used to provide 2 independent communication channels. The example of a pair of perpendicular linear polarizations has been described, but it is also possible to use the 2 hands of circular polarization, or even pairs of elliptical polarizations. For example, the next generation of INTELSAT satellites (INTELSAT V) is planned for use with dual circular polarizations.

The simple aerial of Fig. 2(*a*) can be adapted to transmit and receive circular polarization by the addition of a quarter-wave polarizer, as shown in Fig. 2(*c*). A polarizer is a length of waveguide modified so that propagation in one plane of polarization, the active plane, is delayed by a quarter of a wavelength in relation to that in the plane at right angles; that is, there is a relative phase shift of 90°. Thus, if a wave arrives at the polarizer linearly polarized at 45° to the active plane of the polarizer, the wave has equal components parallel and perpendicular to the active plane (see Fig. 3(*a*)). On leaving the polarizer, one component is delayed by a quarter wavelength so that the 2 components form a circularly-polarized wave (Fig. 3(*b*)). If 2 orthogonal linear polarizations are applied to the polarizer in this way then the 2 opposite hands of circular polarization will be obtained. Conversely, the application of 2 oppositely circularly-polarized waves will generate 2 orthogonal linearly-polarized waves.

In a practical system, the wave arriving at an aerial will be imperfectly polarized, and this polarization may be changing with time. It is then possible to use a pair of rotatable polarizers, perhaps controlled by a suitable servo system, to convert the incoming polarizations to 2 linear polarizations which can be separated at the orthomode junction. A full mathematical analysis of this process is cumbersome and very difficult to visualize. The latter problem at least can be largely overcome by using an imaginary sphere to represent the different polarization states.[1] This representation, first suggested by the French mathematician Henri Poincaré,[2] is mathematically exact, but also provides a useful qualitative understanding of the relationship between different polarization states and of the effects of polarizers.

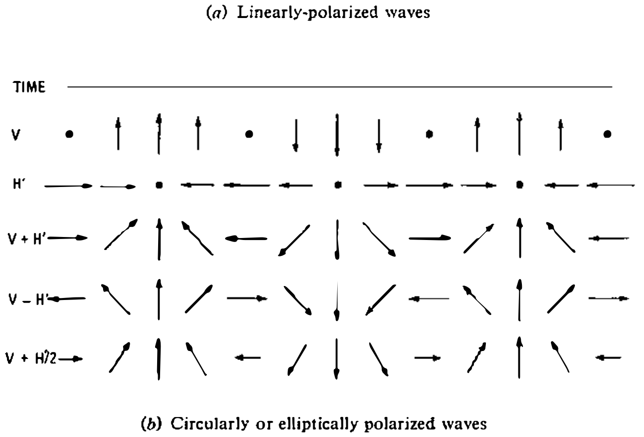
Poincaré Sphere

In Poincaré's representation each point on the surface of an imaginary sphere corresponds to a particular polarization, linear, circular or elliptical (Fig. 4). Using geographical terminology, the north and south poles of the sphere represent left-hand and right-hand circularly-polarized waves respectively (L and R on Fig. 4). Points on the equator represent linear polarization, the longitude of the point being twice the orientation angle of the polarization vector; that is, zero longitude represents horizontally-polarized waves (H on Fig. 4), 180° longitude represents vertically-polarized waves (V on Fig. 4) (orientation angle = 90°), 90° and 270° longitude represent 45° and 135° diagonally-polarized waves (D_1, and D_2, on Fig. 4), and so on.

Points on the sphere lying between the equator and the poles represent elliptical polarizations. The longitude of the point is twice the orientation angle of the major axis of the ellipse. The latitude is related to the axial ratio, which is the ratio of the minor to major axes. Points in the northern hemisphere represent left-hand elliptically-polarized waves, while those in the southern hemisphere represent right-hand polarized waves.

Thus, in Fig. 4, all points lying on the longitude passing through Q_1 have major axes inclined at an angle β to the horizontal, but the axial ratio increases from the equator (linear polarization) through points Q_2 and Q_3 to the pole.

A particularly useful feature of the Poincaré sphere is that the difference between 2 polarized waves is indicated quantitatively by the angular separation of the corresponding points on the sphere. If, for example, one point represents the polarization of a wave and another the polarization of a receiving aerial, then the separation of the 2 points on the sphere is a measure of the efficiency with which the aerial will



(*a*) Linearly-polarized waves

(*b*) Circularly or elliptically polarized waves

FIG. 3—Combination of orthogonal linearly polarized waves

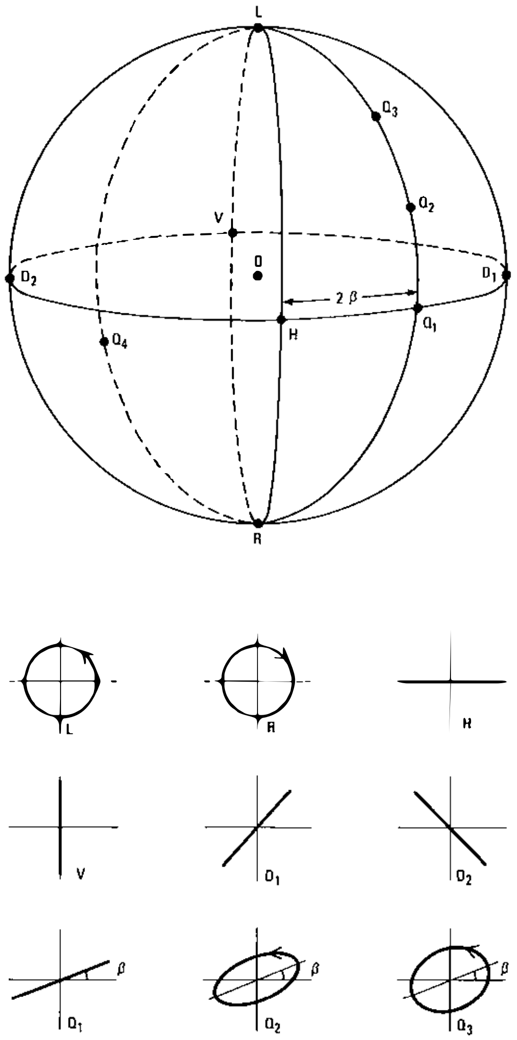


FIG. 4—The Poincaré sphere

receive the wave. In particular, the wave will not be received at all if the points are diametrically opposite. Examples, from Fig. 4, are left-hand and right-hand circular polarization (L and R), crossed linearly-polarized waves (H and V or D_1 and D_2), and the pair of elliptical polarizations Q_2 and Q_4. Such pairs of polarizations are commonly referred to as being *orthogonal*.

Polarizers

The function of a polarizer is to delay the component of linear polarization in its active plane by a phase angle, ϕ, in relation to the component in the perpendicular plane. In the Poincaré sphere representation, this is equivalent to rotating the sphere by the same angle ϕ about an axis lying across the equator of the sphere; the longitude of this axis corresponds to the inclination of the active plane of the polarizer. Two cases of particular importance are the half-wave (180°) and quarter-wave (90°) polarizers, which have already been mentioned.

A half-wave polarizer has the effect of rotating the Poincaré sphere by 180° about an axis lying in the equator (Fig. 5(*a*)). Thus the axial ratio of any polarization state, such as Q_1 in Fig. 5(*a*), is unchanged in magnitude but reversed in sign (left-hand rotation becomes right-hand and vice versa), while the polarization ellipse is "reflected" in the active plane of the polarizer. The half-wave polarizer is often used with a linearly-polarized incident wave, for example S_1 of Fig. 5 (*a*), when it has the effect of rotating the plane of polarization (S_2). If the polarizer itself is rotated, the resultant wave is rotated through twice the angle.

The effect of a quarter-wave polarizer is more complex as it rotates the Poincaré sphere through only 90°; its most common application is to convert between linear and circular polarizations. For example, the polarizer illustrated in Fig. 5(*b*) will transform points L_1 and R_1 to L_2 and R_2 respectively; that is, left-hand and right-hand circular polarizations are converted to 2 orthogonal linear polarizations, each at 45° to the active plane of the polarizer. Conversely, the linear polarizations at R_2 and L_2 would be converted to circular polarizations at L_1 and R_1 respectively. A quarter-wave polarizer can also be used to convert a general elliptically-polarized wave (S_1) to linear polarization (S_2) if the active plane of the polarizer is made to coincide with one of the principal axes of the polarization ellipse.

It can now be seen how the combination of 2 rotatable polarizers can be used to convert any polarization state to the required linear polarizations for an orthomode junction. For example, a quarter-wave polarizer can first convert the incoming polarization (usually nearly-circular or nearly-linear) to a linear polarization, while a half-wave polarizer rotates the plane of linear polarization to match the orientation of the orthomode junction.

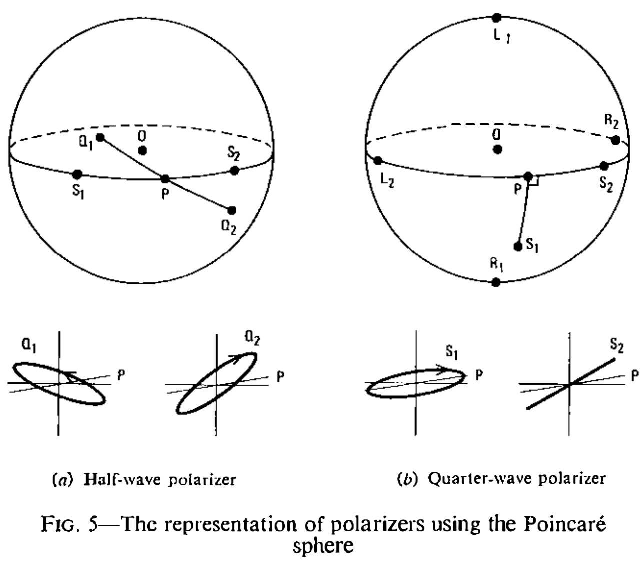
Rotation of the Poincaré sphere cannot alter the angular distance between points on the sphere. Thus, if the incident polarizations are not orthogonal at the input they cannot be made orthogonal, although they can be adjusted to produce a best compromise for separating them at the orthomode junction.

AERIAL DESIGN

Although the performance requirements and construction of satellite aerials and earth-station aerials differ in some respects, the requirements for dual polarization operation are similar, and the same design principles apply to both cases.

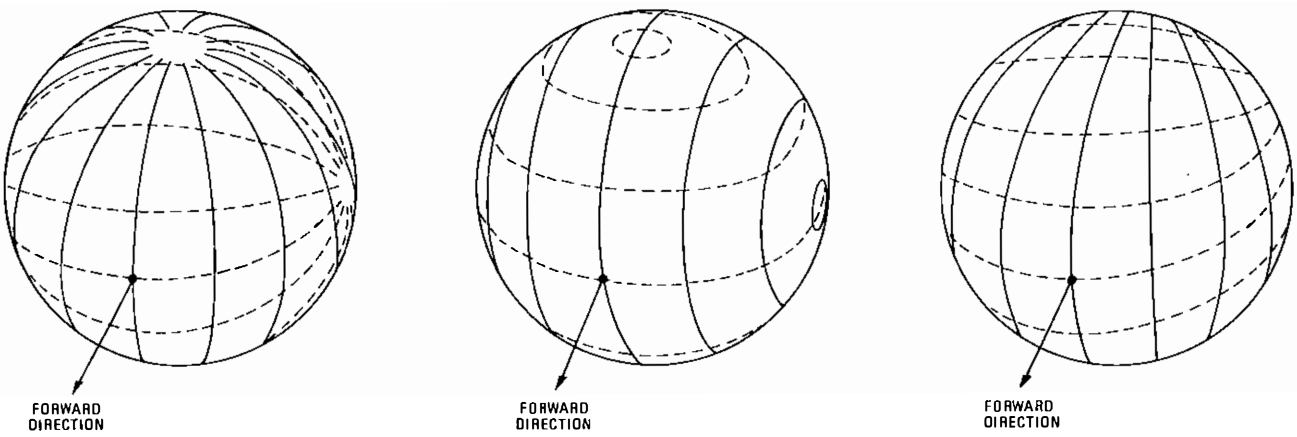
Satellite aerials are generally required to illuminate a substantial part of the earth's surface; this is usually achieved by designing the satellite beams to fall in gain by about 3 dB from the beam centre to the edge of the required coverage area. The satellite aerial is, therefore, required to have good polarization characteristics over a large part of its main beam. An earth-station aerial usually tracks a satellite, so the polarization properties of the aerial are generally important only near the beam centre, where the gain is within about 0·5 dB of its peak value.

The polarization properties of reflector aerials, used at earth stations and on many satellites, depend on both the feed horn at the reflector focus and on the curved reflectors. The considerations applicable to feed horns are equally applicable to horns used as satellite aerials in their own right.



(*a*) Half-wave polarizer (*b*) Quarter-wave polarizer

FIG. 5—The representation of polarizers using the Poincaré sphere



(*a*) Electric-dipole source (*b*) Magnetic-dipole source (*c*) Huygens source

Note: The source is at the centre of the sphere on which the directions of the electric fields in the waves are marked. The dotted lines show the field lines for the same source rotated through 90°

Fig. 6—Polarization patterns of electromagnetic radiators

Polarization Properties of Horns

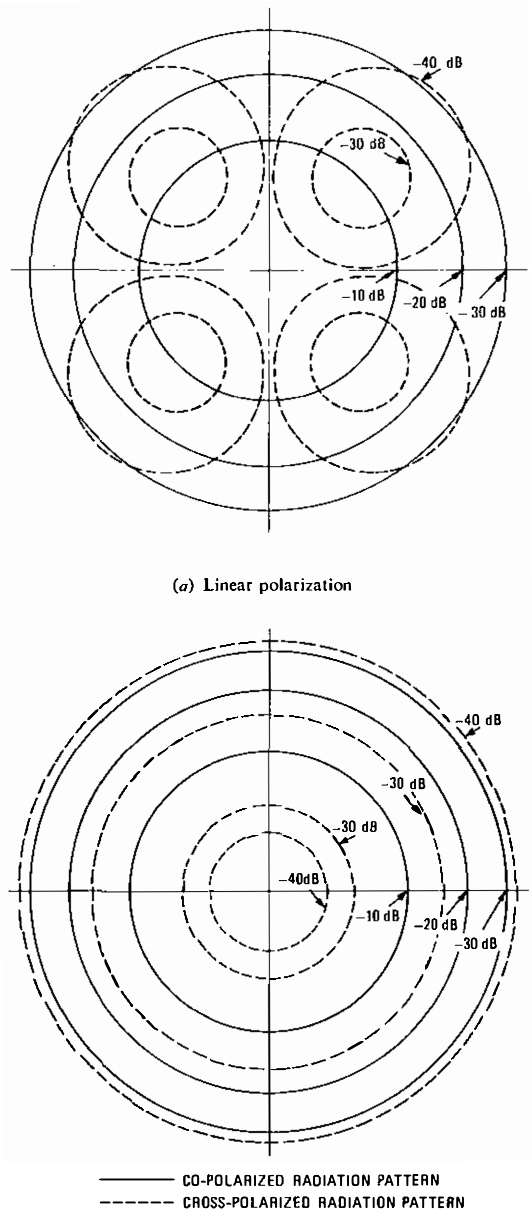
Electromagnetic energy is radiated by a horn as a result of the oscillating electric and magnetic fields in the horn aperture; these electric and magnetic fields give rise to distinctive polarization patterns which must be combined to produce a pattern suitable for a dual polarization horn.

The radiation pattern of an electric field alone is given by that of a short electric dipole. Fig. 6(*a*) shows the lines of electric field induced on the surface of a large imaginary sphere by a short electric dipole at its centre. The dashed lines show the field due to a similar dipole rotated through 90°. Similarly, Fig. 6(*b*) shows the radiation pattern of an elementary small magnetic dipole. In both cases, a pair of orthogonal dipoles gives rise to a pair of radiated fields which are not orthogonal in all directions.

A combination of electric and magnetic dipoles of equal strengths gives rise to the radiated field shown in Fig. 6(*c*) and is known as a *Huygens source*. A pair of orthogonally polarized Huygens sources gives rise to a pair of radiated field patterns that are orthogonal in every direction. An ideal horn design should, therefore, radiate waves whose electric field pattern is the same as that of a Huygens source in all directions. Practical horns, such as that of Fig. 2, fall short of this ideal. Measurement of the cross-polarized radiation results in a pattern similar to that shown in Fig. 7(*a*); this pattern has 4 characteristic *Condon lobes* with no cross-polarization in the principal planes.

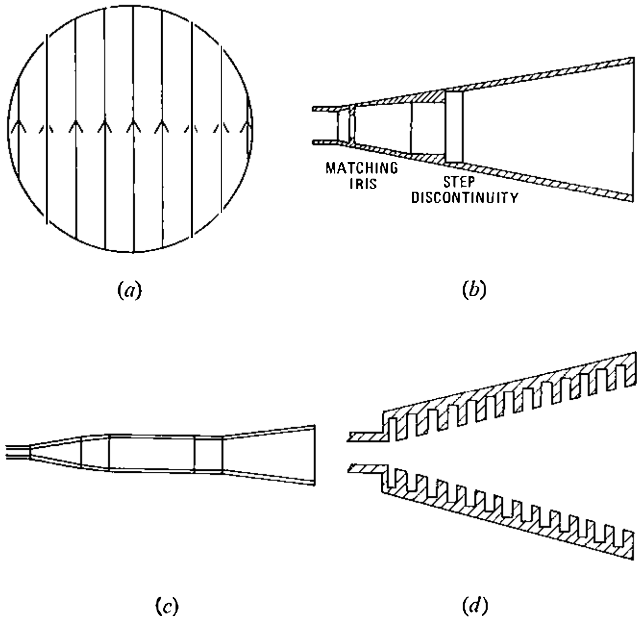
The field distributions leading to non-Huygens source radiation patterns also cause the radiated beam to be slightly elliptical in shape. When the horn is used with circularly-polarized radiation, this asymmetry of the beam results in cross-polarized radiation in the principal planes. The magnitude of this cross-polarization is the same as that of the Condon lobes in the 45° planes so that the cross-polarized radiation pattern for circular polarization has a circularly symmetrical cross-polarized lobe (Fig. 7(*b*)).

The radiation of a horn will correspond closely to that of a Huygens source if the aperture electric field has the form shown in Fig. 8(*a*). Ideally this field should also taper from the centre to the edge of the aperture in such a way as to minimize unwanted side-lobe radiation. Two approaches have been used to provide an aperture field which satisfies these requirements; in practice, it is found that with both approaches the requirements of low cross-polarization, high beam symmetry and low sidelobes tend to be satisfied simultaneously.



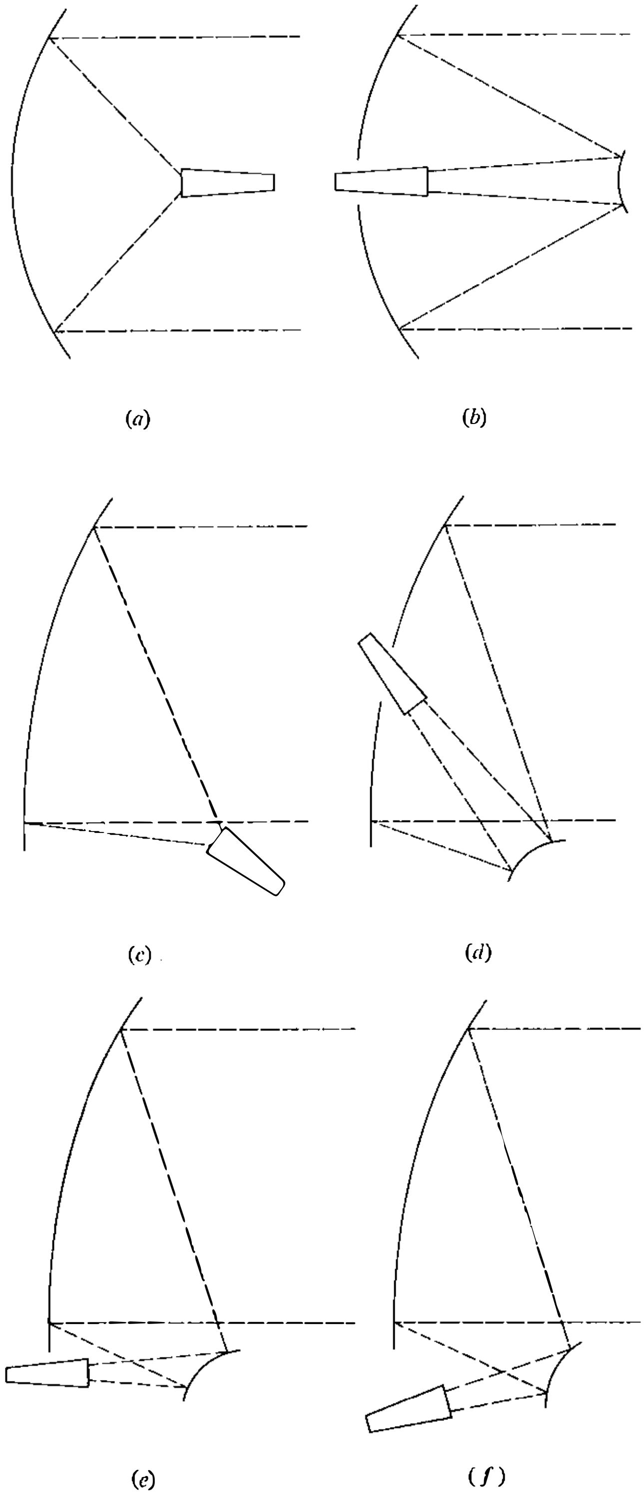
(*b*) Circular polarization

Fig. 7—Radiation patterns of a typical horn aerial



(*a*) Required aperture field
(*b*) Two-mode Potter horn (circular section)
(*c*) Three-mode multiflare horn (square section)
(*d*) Corrugated horn (circular section)

FIG. 8—Horn designs for high beam symmetry and polarization purity



(*a*) Front-fed symmetrical reflector
(*b*) Symmetrical Cassegrain
(*c*) Single-offset reflector
(*d*) Open Cassegrain
(*e*) Offset Cassegrain
(*f*) Modified offset-Cassegrain

FIG. 9—Possible configurations for reflector aerials

Horn Designs

The first approach, originally proposed by Potter,[3] is to introduce deliberately a higher-order mode into the horn. The higher mode chosen, the transverse magnetic (TM_{11}) mode in circular waveguide, has a cross-polarized radiation pattern which cancels that of the fundamental TE_{11} mode and a co-polarized pattern that improves the beam symmetry. The required amount of TM_{11} mode energy is excited at a step discontinuity in the horn (Fig. 8(*b*)); the length of horn following the step must then be adjusted so that the 2 modes are in the correct phase relationship at the horn aperture. Since the relative amplitude and phase of the 2 modes are frequency-dependent, the useful bandwidth of horns designed using this technique is limited. The design shown in Fig. 8(*c*) has obtained some improvement in bandwidth by exciting the higher mode at a number of flare-angle discontinuities, rather than at a single step discontinuity.

The alternative approach exploits the properties of *hybrid modes*, whose electric-field distributions resemble combinations of TE and TM waveguide modes. These modes cannot propagate along conventional smooth-walled waveguides or horns, but require corrugated or dielectric-lined walls. Fig. 8(*d*) shows a section of a corrugated horn in whose walls are machined a series of circumferential slots; this structure effectively allows electric fields parallel to the horn axis to enter the horn walls, but prevents circumferential fields from doing so. The exact form of the hybrid modes depends on the radius and depth of the slots in relation to the wavelength, and in a given geometry the electric field distribution will change with frequency.

Corrugated-horn feeds have been designed to propagate the fundamental HE_{11} mode whose electric-field pattern is very similar to that shown in Fig. 8(*a*) over a wide frequency band. Typically, the cross-polarized lobes are at least 35 dB below the co-polar peak over the required bandwidth. The performance of these horns is superior to that of multimode smooth-walled horns, but they suffer the disadvantages of higher weight and cost.

The Effect of Reflectors on Polarization

Most high-gain microwave aerials use one or more curved reflectors to focus the radiation from the feed horn. In single-reflector designs (Fig. 9(*a*) and Fig. 9(*c*)), the reflector is required to change the spherical wave spreading from the feed horn into a plane wave, and must therefore be a portion of a paraboloid. In the dual-reflector Cassegrain configurations (Figs. 9(*b*), (*d*), (*e*) and (*f*)), the appropriate reflecting surfaces are sections of a paraboloid for the main reflector and of a hyperboloid for the sub-reflector. In practice, these reflectors are often shaped slightly to increase the aerial gain by improving the distribution of radiated energy from the feed horn over the main reflector, and by reducing spill-over from the feed horn past the sub-reflector.

Symmetrical Reflectors

The cross-polarized radiation patterns of symmetrical reflector aerials (Figs. (9*a*) and (*b*)) generally display the same form as those of their feed horns. Confusion between 2 different analyses of this cross-polarization has created some misunderstanding of how it arises. One analysis has assumed the feed to have the radiation pattern of an electric dipole (Fig. 6(*a*)). An aerial with an electric dipole feed is known to have significant cross-polarized lobes in its radiation pattern and, in the case of a front-fed aerial (Fig. 9(*a*)), these increase with the depth of the main reflector. In the case of unshaped Cassegrain aerials (Fig. 9(*b*)), the cross-polarized lobes are lower. In general, it is found that the magnitude of the lobes depends on the angle subtended at the feed by the main reflector or sub-reflector. This cross-polarization, since it increases away from the centre of the reflector and is greater is the case of more deeply curved reflectors, has commonly been blamed on the curvature of the reflectors themselves. The improvement gained by Cassegrain configurations is sometimes attributed to cancellation between the opposing curvatures of the 2 reflectors.

The alternative analysis is based on the fact that a Huygens source feed is required to minimize the cross-polarization in the radiated beam of a reflector aerial. The presence of significant cross-polarization is therefore ascribed to failure of practical feeds to match the properties of a Huygens source. This use of the Huygens source as the reference radiation pattern, against which the performance of practical feeds is measured, is more satisfactory in view of its properties described above in relation to a pair of orthogonally polarized radiators. It also has the advantage that reflection of radiation from a Huygens source by a paraboloid or hyperboloid results in a radiation pattern that also appears to have originated from a Huygens source. This analysis also indicates how a suitable feed should be designed for a reflector of any depth of curvature, whereas the earlier analysis failed to provide very useful guidelines for feed design, but postulated a false advantage for shallow, less curved reflectors. Using the second approach, the cross-polarization of a reflector with an electric dipole feed is seen to result from the unsuitability of the electric dipole for this purpose, this unsuitability increasing with the angular width of the feed's radiation pattern.

Front-fed and unshaped Cassegrain aerials are generally designed so that only the part of the feed radiation within about the −10 dB to −12 dB contour of the co-polarized beam is intercepted by the reflectors. Since the cross-polarized energy is radiated at greater angles from the feed axis than the co-polarized energy, a greater proportion of the cross-polarized energy spills past the reflectors. The cross-polarized lobes of the aerial are, therefore, some 4–6 dB lower in relation to the main lobe than those of the aerial's feed.[4] Shaped Cassegrain aerials, on the other hand, are designed to make efficient use of the wider-angle radiation from the feed horn out to the −15 dB or − 20 dB contour. The cross-polarized lobes of these aerials are expected to be reduced by a smaller amount.

The surfaces of large reflectors deviate from their ideal design shapes by small fractions of a wavelength due to wind and gravitational forces, and because of errors in measurement and construction. These profile errors do not increase the total amount of cross-polarization in the aerial beam, but they distort and spread the energy in the cross-polarized lobes so that there is a finite level of cross-polarization at the centre of the beam. Scattering of radiation from feed or sub-reflector support struts has a similar effect.

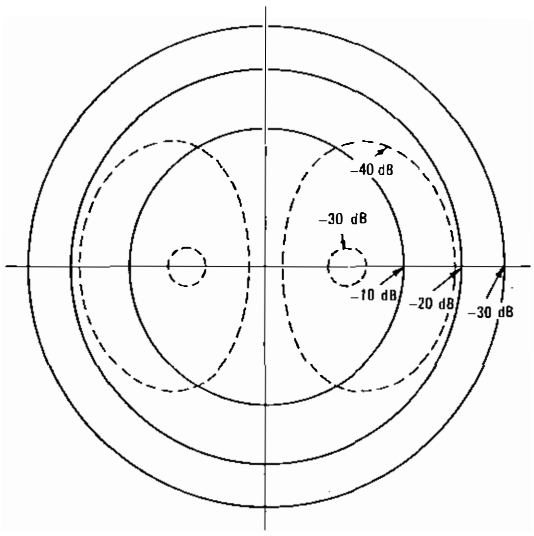


FIG. 10—Radiation patterns of offset reflector with Huygens source feed

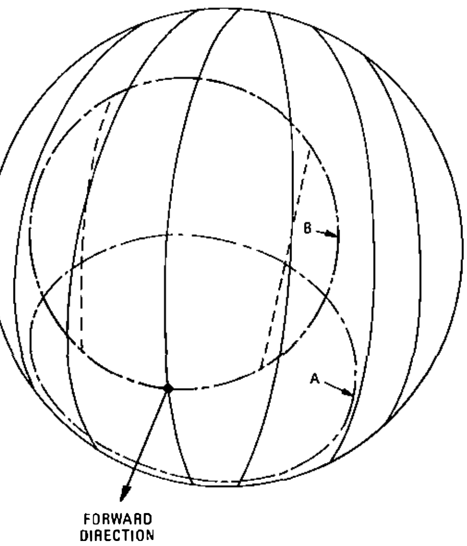
Offset Reflectors

Offset reflector configurations (Figs. 9(*c*)–(*f*)) offer advantages of decreased blockage and scatter, and of greater control of spill-over radiation. It is therefore important to examine their polarization properties. Single offset reflectors are used on the INTELSAT IV and IVA satellites, and will also be used on the INTELSAT V satellite.

If an offset reflector is illuminated by a linearly-polarized feed designed for a symmetrical reflector, the cross-polarized radiation pattern will be dominated by a pair of lobes on either side of the axis of symmetry, as shown in Fig. 10. These lobes lie nearer to the centre of the beam than the 4 Condon lobes of a horn or symmetrical reflector. There is no inherent cross-polarization with circular polarization, but there is an angular shift of the radiated beam whose direction depends on the hand of polarization. For example, if a Huygens feed is used in the configuration shown in Fig. 9(*c*), with linear polarization the cross-polarized lobes will peak 20 dB below the level of the co-polarized peak, while with circular polarization the beam will shift sideways by a tenth of a beamwidth.

The cause of these lobes can be seen by reference to Fig. 11, which shows the electric-field lines of a Huygens source drawn on the surface of a sphere. A symmetrical reflector intercepts that part of the radiation pattern bounded by a circle such as that marked A. To minimize cross-polarization, an offset reflector should intercept an offset portion of the radiation pattern such as that marked by circle B. In practice, however, a symmetrical feed-horn, radiating the pattern within circle A, is usually tilted to illuminate the offset reflector with the field pattern shown by the dashed lines within circle B. The 2 cross-polarized lobes result from the inclination of these lines to the required field lines on either side of the axis of symmetry.

It has recently been shown that feed horns can be designed to radiate a field pattern appropriate to an offset reflector.[5] These feeds also provide a more uniform distribution of energy over the reflector surface, compensating for the fact that one side of an offset reflector is much further from the



Note: Circle A encloses the part of the pattern intercepted by a symmetrical reflector, circle B encloses the part which should be intercepted by an offset reflector. The dashed lines within B show the form of the electric vectors within A, transposed to the position of B

FIG. 11—Radiated Field of a Huygens source

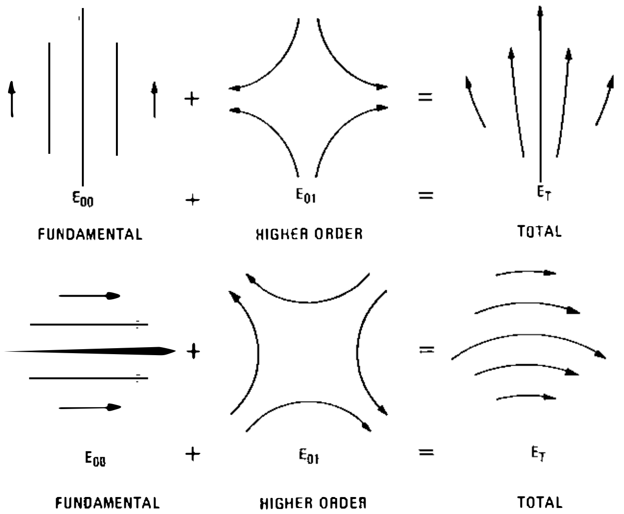


FIG. 12—Addition of fundamental and higher-order Gaussian modes to represent the effect of reflection from an offset curved surface

feed than the other. These feed horns use the technique described earlier, of generating a higher mode within the feed horn, except that the mode used in this case, TE_{21} in smooth-walled circular horns or HE_{21} in corrugated horns, has to be generated at an asymmetrical discontinuity in the guide.

A number of aerials, including the 6 m experimental aerial of the British Post Office Research Department at Martlesham Heath, use the aerial configuration shown in Fig. 9(*d*) with an offset main reflector and a symmetrical sub-reflector. A conventional feed would give rise to the same cross-polarization and squint properties in this configuration as in the front-fed offset design (Fig. 9(*c*)), but the same technique of horn design could be used to overcome these problems.

Fig. 9(*e*) shows an alternative dual-reflector offset aerial configuration which has been proposed to improve the cross-polarization performance while retaining a conventional symmetrical feed horn.[6] This improvement can be ascribed to cancellation between the effects of the 2 oppositely curved reflectors.

GAUSSIAN MODE THEORY

Recent theoretical developments have provided a simple method for estimating the cross-polarization of offset reflectors, either singly or in combination.

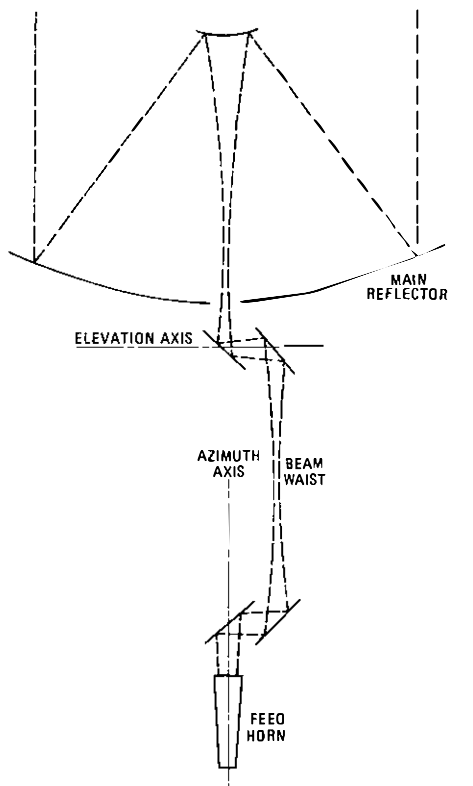
The electric-field pattern in a beam of microwave radiation can be described by combining a number of modes in free space in the same way as the fields within a waveguide or horn can be described as the superposition of a series of waveguide modes. In free space the appropriate modes are known as *Gaussian modes*, whose variation in intensity across the beam follows the Gaussian curve (the *normal* distribution of statistics). Approximate analysis of many of the problems of reflector aerial design is relatively straightforward because the radiation from a good multi-mode or corrugated horn approximates closely to the fundamental Gaussian mode in free space, and because the effects of offset curved reflectors can be described relatively accurately by the introduction of a single higher mode.[7] The theory is limited, however, to the extent that it assumes the reflectors to be very large relative to the width of the Gaussian beam. This does not significantly affect the results obtained provided the actual reflectors extend to at least about the −15 dB or −20 dB contour of the beam, but corrections are required for calculations on reflectors with edge tapers of only −10 dB or −12 dB.[7]

In the fundamental E_{00} Gaussian mode the electric field lies in a single direction in space; this mode therefore corresponds to the HE_{11} mode of corrugated waveguide and has no cross-polarization. Reflection by a curved offset reflector has the effect of converting part of the fundamental mode energy into the higher E_{01} mode. Fig. 12 illustrates how, for the 2 principal polarizations of the incident radiation, superposition of the E_{00} and E_{01} modes represents the form of the electric-field lines after reflection. The generation of the single higher mode on reflection accounts for both the cross-polarized lobes in the one principal plane and the amplitude asymmetry in the other plane.

The fraction of E_{00} mode energy converted to the E_{01} mode is proportional to the width of the Gaussian beam at the point of reflection, the curvature of the reflector and the angle of incidence. Thus, the amount of cross-polarization is greater for large beam widths, more curved, more sharply-focusing reflectors and for large angles of offset. It is interesting that, at least to a first order of accuracy, the cross-polarization does not depend on the exact shape of the reflector, whether it is a paraboloid, hyperboloid or ellipsoid for example, but only on its curvature over the central region where the majority of the radiated energy is concentrated.

In the reflector configurations of Fig. 9(*e*) and Fig. 9(*f*) the 2 reflectors have opposite curvatures and, therefore, convert energy into the higher mode in opposite phases. The contributions of the 2 reflectors will therefore tend to cancel one another. In the configuration of Fig. 9(*e*), however, the cancellation is incomplete. This can be compensated by increasing the angle of incidence at the sub-reflector as shown in Fig. 9(*f*). Calculations of the required tilt angle made on the basis of Gaussian mode theory have been compared with results obtained by computer integration over the reflector surfaces for a particular configuration,[8] and agree within 6%.

Although Gaussian mode theory has been applied successfully to configurations employing paraboloids, ellipsoids and hyperboloids, it cannot be expected to yield accurate results for shaped reflectors that deliberately distort the radiated beam from a Gaussian-like to a more uniform energy distribution.



Note: The dashed lines indicate the form of the microwave beam

FIG. 13—Outline of Cassegrain aerial with a beam-waveguide feed

BEAM WAVEGUIDES

The designs of symmetrical earth-station aerial discussed so far suffer from the practical disadvantage that the feed horn is situated at the focus or vertex of the main reflector where it is remote and relatively inaccessible. Recent designs have used a beam waveguide to convey the transmitted and received beams between the main reflector vertex and the feed horn, which is fixed near ground level (Fig. 13). The beam waveguide comprises a series of 4 reflectors acting as a kind of periscope to guide the beam through the aerial rotation axes. The entire system, with the exception of the feed horn, rotates with the main reflector around the vertical azimuth axis, while just one of the beam-waveguide reflectors rotates in elevation.

In most beam-waveguide designs, 2 of the reflectors are curved to refocus the beam as it propagates through the system. Since these reflectors are both curved and offset, they introduce a pair of cross-polarized lobes into the radiation pattern (Fig. 10). The relative orientation of the 2 reflectors is such that their contributions to the cross-polarized radiation pattern tend to cancel. The principal limitation on the extent to which this can take place is the phase shift between the fundamental and higher modes as they propagate between the curved reflectors.[9] This phase shift increases with the distance between the reflectors, but also depends on the width of the beam at its waist (Fig. 13). Most beam waveguides that have been constructed maintain a broad beam between the 2 curved reflectors, and the resulting phase shift can be as small as 20°. Designs have been proposed, however, which focus the beam to a narrow waist between the reflectors, so that the phase shift approaches 180°. In this case, the contributions of the reflectors tend to reinforce rather than cancel one another.

A number of beam-waveguide designs have been analysed by computer evaluation of the diffraction integrals over the reflector surfaces.[10] These computations showed that beam waveguides could readily be designed with cross-polarized lobes 35–40 dB below the co-polarized peak. Analysis of a design with a very narrow beam waist between the curved reflectors of the beam waveguide showed that the cross-polarized peaks could then be as high as −14 dB. These configurations have also been analysed by Gaussian mode theory and very close agreement was obtained.[11] This agreement confirms the value of the theory for assessing the behaviour of practical beam waveguides despite the approximations that have to be made, and shows that the performance of particular beam-waveguide designs can be predicted without expensive computer analysis.

A surprising conclusion from the computer study was that the cross-polarization performance of beam waveguides is relatively insensitive to mechanical displacements of the reflectors; this feature has also been confirmed by the Gaussian mode analysis of beam-waveguide propagation.

CONCLUSION

The impending introduction of frequency re-use by dual polarization has stimulated study of the polarization properties of different aerial designs. The effects of feed horns and reflectors, including beam waveguides, are now understood more clearly, and a technique has been developed for the quantitative analysis of offset reflectors. The cross-polarization contributions of these components can be kept to a low level by careful design so that the system performance will be limited by the other elements in the transmission path. The aerial feed components and the effects of the propagation paths will be discussed in later parts of this article.

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Teletraffic Aspects of Digital Switching

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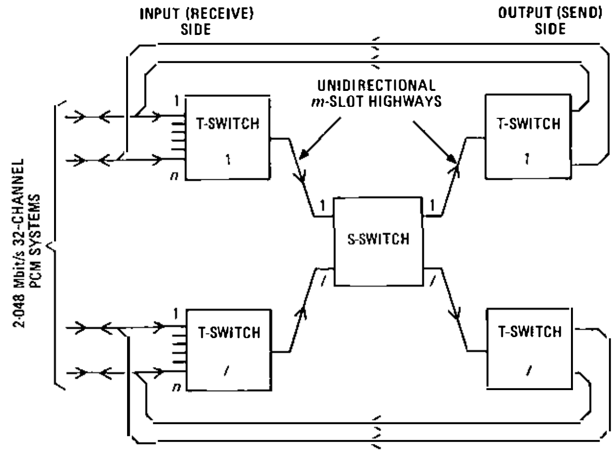
The teletraffic characteristics of a digital switching unit having a time–space–time structure are considered in this article. The results are described of a study of the effects on the grade of service of different methods of path selection, and of repeat-attempt facilities. Finally, a discussion is given on improving grades of service by the technique of rearrangement, in which connexion paths through the unit are instantaneously reorganized to overcome blocking.

INTRODUCTION

With the increasing use of digital transmission systems, several countries have devoted effort to the development of digital exchanges. A previous article[1] in this *Journal* described 2 successful field trials in the UK of digital tandem exchanges switching traffic on pulse-code-modulation (PCM) transmission systems: the British Post Office (BPO) Empress (West Kensington) exchange experiment, and the experimental exchange built at Moorgate by Standard Telephones and Cables Ltd.

A feature common to many of the more recent designs proposed for digital main-network exchanges is the use of relatively few internal switching stages, each capable of connecting an inlet to a very large number of outlets—over 1000 in some designs[2]. Such structures have teletraffic characteristics different from those of the majority of conventional electromechanical or semi-electronic switching systems, and the purpose of this article is to describe and discuss some of those characteristics.



Note: Typically, $m = 512$ and $n = 16$; l is the number of T-switches

FIG. 1—Basic components of a T–S–T digital switch

TYPICAL DIGITAL SWITCH

It is expected that the basic role of a digital switching system in the BPO network will be to interconnect 2·048 Mbit/s European Conference of Posts and Telecommunications Administrations (CEPT) standard transmission systems, although these systems may be further multiplexed (for example, to 120 Mbit/s) for transmission purposes[3]. Each CEPT system contains 32 time slots, of which 30 are normally used to carry speech channels. A digital switch thus has to perform 2 basic functions: interconnecting physically different line systems, and interconnecting different time slots. The switch must therefore contain at least one time (T) switching stage, and normally at least one space (S) switching stage. (If the number of PCM line systems to be terminated is fairly small, it may be possible to connect them all to a single high-capacity T-switch, thus avoiding the need for a separate S-switch.) Using an S-and-T notation, Empress exchange can be described as having an S–T–S structure, and the Moorgate experimental exchange an S–S–T–S–S structure.

Following the Empress experiment, the BPO Research Department constructed a laboratory model of a more advanced design of digital switch[4] using a T–S–T structure. The teletraffic properties of such a design are considered in this article, the T–S–T structure being typical of current designs of digital switch.

The essential features of a T–S–T switch are shown in Fig. 1. Several 32-channel PCM systems are connected to each T-switch, and any time slot in any of these systems can be connected to any of the 512 internal time slots in the highway from the T-switch to the S-switch. The S-switch can connect any of the 512 internal time slots to the same time slot on any of the output highways.

Growth is catered for by adding extra T-switches to accommodate more PCM systems, and adding the appropriate extra rows and columns to the S-switch matrix. If each external circuit carries an average of 0·75 erlang, then a 20 × 20 S-switch matrix corresponds to an exchange traffic capacity of about 3800 erlangs.

PRELIMINARY TRAFFIC STUDIES

From the teletraffic point of view, the T–S–T digital switch shown in Fig. 1 is equivalent to the 3-stage link-trunking system shown in Fig. 2. Since the S-switch interconnects internal highways that are time-divided into 512 slots, its equivalent in the link system is 512 switches, each of size $l \times l$.

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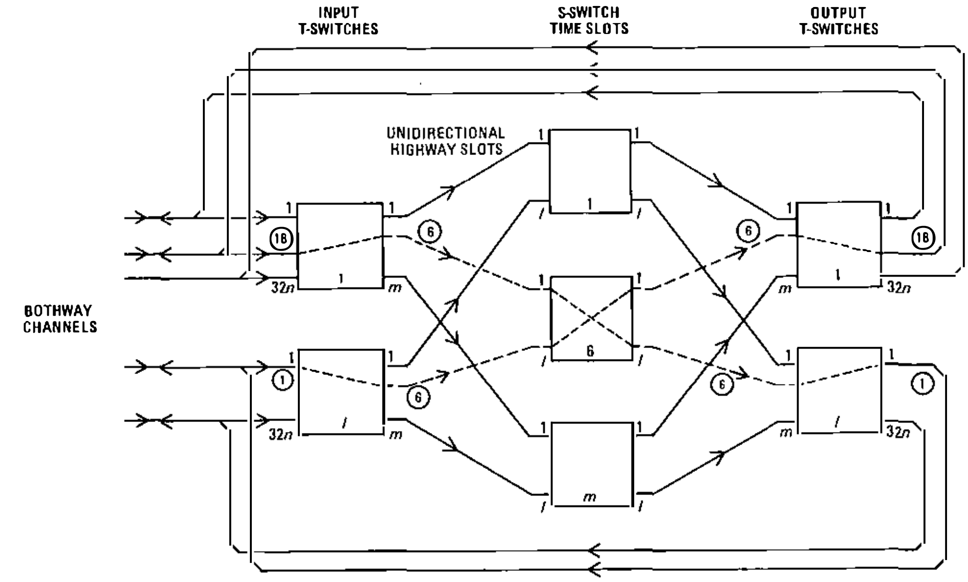


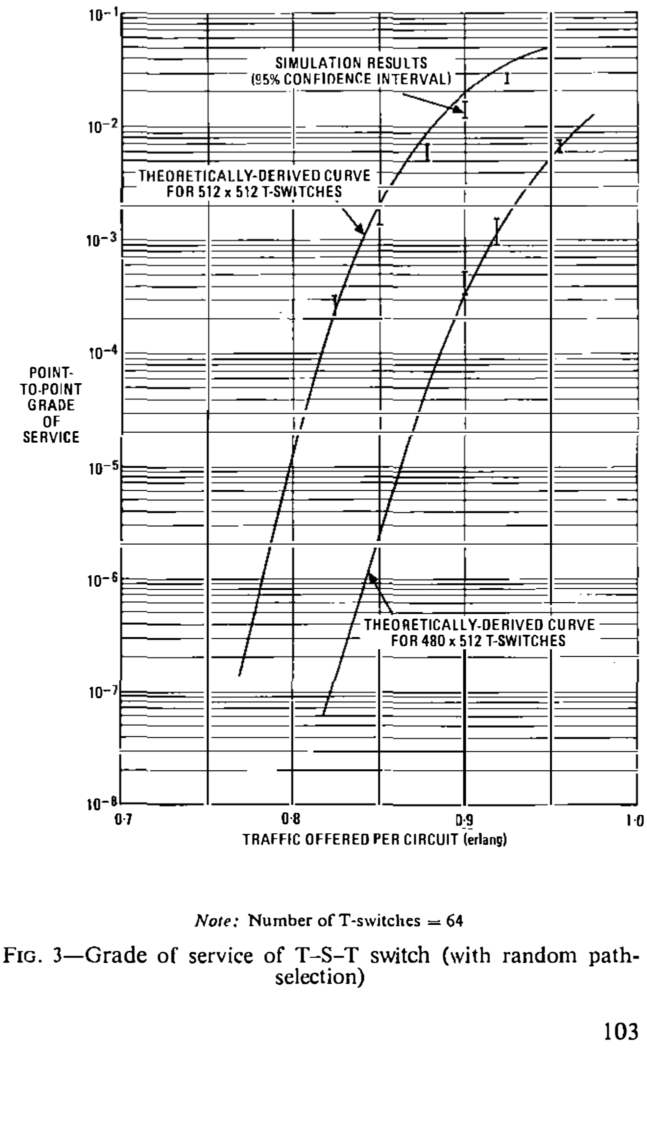
Notes: *1* Typically, *m* = 512 and *n* = 16; *l* is the number of T-switches
2 The dashed lines show the connexion of a call between time-slot 18 (shown circled) of a PCM system on T-switch 1 and time-slot 1 of a PCM system on T-switch *l*, using internal time-slot 6

FIG. 2—Space-division analogue of T–S–T switch, showing the connexion of an inter-T-switch call

Also shown (dashed lines) are the 2 paths through the switch that are needed to provide a bi-directional speech connexion. In principle, the 2 paths can be established independently, but it is technically convenient for them to be set up in internal time slots bearing some simple relationship to each other. In this study, it is assumed that they are both established in the same time slot.

Special rules must be formulated to control the choice of the second path for calls where the circuits to be connected together are on the same T-switch. It can be shown that, provided the number of circuits connected to each T-switch is less than or equal to the number of internal time slots, such calls are non-blocking. A more general discussion of non-blocking networks is given in the classic paper by Clos.[5]

By making certain simplifying assumptions, it is possible to use standard teletraffic techniques, applicable to the analysis of link systems, to derive a formula which estimates the point-to-point grade of service of the T–S–T switch. Details of the derivation are given in the Appendix, and results obtained from the formula are shown by the curves in Fig. 3. The grades of service measured, as a function of traffic offered, in a simulation experiment are plotted for comparison, the 95% confidence interval being shown for each simulation result. The simulation program, which enables some of the assumptions made by the analytical model to be relaxed, uses conventional event-by-event simulation techniques, and runs on the BPO's IBM 370/168 computer. For simplicity of presentation, it is assumed that all 32 channels on each 2·048 Mbit/s system are routed through the switch, although there is no difficulty in modifying the calculations to distinguish between channels carrying conversational traffic and those carrying signalling or synchronization information. With this simplification, connecting 15 PCM systems to each T-switch yields a 480 × 512 T-switch size (that is, 480 external circuits offer traffic to 512 internal time slots on the highway to the S-switch), while connecting 16 systems per T-switch gives a 512 × 512 T-switch size.



Note: Number of T-switches = 64

FIG. 3—Grade of service of T–S–T switch (with random path-selection)

The agreement between the simulation results and those obtained from the theoretical method is quite good, confirming that, in the case of the T–S–T structure, theoretical formulae can safely be used readily to provide estimates of performance to system designers, without recourse to the expensive and time-consuming use of simulation techniques. However, at grades of service worse than about 0·01, the assumptions on which the theory is based begin to break down, and formulae of this type are therefore not generally used beyond this point.

The theoretical formula does not take into account the limited size of the S-switch; the simulation results in Fig. 3 are for a fairly large system, having 64 T-switches. More detailed simulation study shows that, as the system size falls, the grade of service initially worsens gradually, but then improves again for very small systems. In the limit of a 1 × 1 S-switch, the trunking is non-blocking. The point of inflexion appears to lie around 5 T-switches, but is dependent on, for example, the rule used to select the time slot occupied by the second path.

The grade of service worsens with increased traffic offered much more rapidly than is the case with most conventional (for example, Strowger or crossbar) switching systems. This is a consequence of the very large size of the basic 512 × 512 switching module, which digital technology makes economically feasible. One implication of this sensitivity to the level of traffic offered is that the grade-of-service requirement under traffic-overload conditions will probably provide the dominant dimensioning criterion for switches of this type. A second consequence is that the marginal cost of improving the grade of service by (say) a factor of 5 is proportionately much lower for digital switches than for analogue ones, and it may be economically desirable to provide these switches to very good grades of service.

STUDY OF CONTROL METHODS

When a call is offered to a link system, there are generally several alternative paths available through the switch, and various rules can be devised for choosing which of the possible paths should be taken into use. If a particular call encounters blocking (that is, no free path is immediately available between the required pair of inlets and outlets), then the call may be rejected immediately, or some more elaborate control procedure may be invoked in an attempt to find a path for the call. In the theoretical model described above, it is assumed that the free path chosen is selected at random from those available, and that blocked calls are rejected immediately. The effects on the teletraffic characteristics of a T–S–T switch of applying more sophisticated control methods are considered below.

Path-Selection Methods

Provided that the number of external circuits connected to each T-switch is less than or equal to the number of internal time slots between each T-switch and the S-switch, the problem of finding a path between 2 marked external circuits is equivalent to the problem of finding a free internal time slot that can be used to interconnect the 2 T-switches on which the circuits are terminated. This is because each T-switch is non-blocking, provided that it has at least as many outlets as it has inlets. Thus, in a T–S–T digital switch, the path-selection process consists of examining the internal time slots until one is found that is free in both of the highways connecting the required pair of T-switches to the S-switch.

For simplicity, the theoretical formula derived in the Appendix assumes that the examination of internal time slots is conducted in a random sequence, and the simulation results in Fig. 3 are also based on this assumption for the purposes of comparison. In practice, it is unlikely that a system designer would find it convenient to implement a genuinely random path-selection process. The grade-of-service results for random selection are, however, quite useful, since one of the easiest selection rules to implement is a non-homing cyclic sequential scan of the internal time slots. The grade of service obtained when this selection rule is used is very similar to that obtained with genuinely random path-selection.

An alternative selection procedure uses a sequential scan, but commences the search at the same point each time; for example, at internal time slot 1. This provides a form of *call-packing* since, on average, more calls are set up in the lower-numbered time slots than in the higher-numbered time slots. In several types of link-trunking scheme, call-packing has been found to improve the point-to-point grade of service, and it can be seen from Table 1 that this is the case for the T–S–T structure.

The logical extension of call-packing is to attempt to set up each new call in whichever time slot is instantaneously carrying the greatest amount of traffic. This option can easily be investigated by simulation, though it is relatively difficult to implement in a practical switching system. The results for this *busiest-slot-search* method are also shown in Table 1, and it can be seen that there is some further improvement in the grade of service. The relative improvement over sequential searching of busiest-slot searching is illustrated in Table 1, together with the relative improvements of each over random searching.

On balance, it may he concluded that the benefits derived from busiest-slot searching are outweighed by the complexity of the control algorithm required to implement it. However, the simpler form of call-packing achieved by using a simple sequential scan with a fixed starting point gives a useful improvement in the grade of service, in addition to other technical advantages.

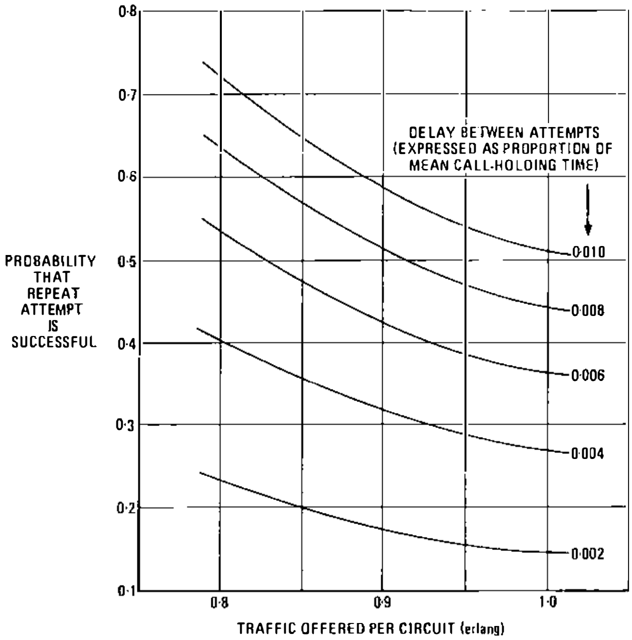
Repeat-Attempt Facilities

In digital exchanges, the path-selection mechanism will usually be arranged to examine all possible paths between the 2 circuits to be interconnected. If no free path is found, nothing

TABLE 1

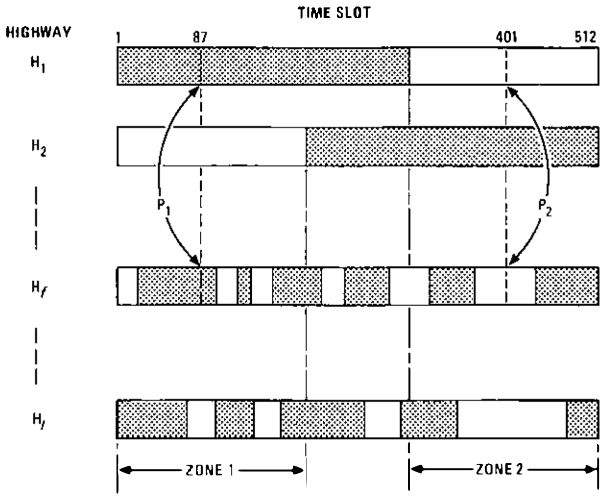
Effect of Path-Selection Rules on Grade of Service of T–S–T Switch

Traffic Offered per Circuit (erlang)	Grade of Service			Relative Improvement		
	Random Searching	Sequential Searching (Fixed Start)	Busiest-Slot Searching	Sequential / Random	Busiest-Slot / Random	Busiest-Slot / Sequential
0·952	$4{\cdot}54 \times 10^{-2}$	$4{\cdot}13 \times 10^{-2}$	$3{\cdot}91 \times 10^{-2}$	0·91	0·86	0·95
0·902	$1{\cdot}38 \times 10^{-2}$	$1{\cdot}25 \times 10^{-2}$	$1{\cdot}16 \times 10^{-2}$	0·91	0·84	0·93
0·850	$1{\cdot}65 \times 10^{-3}$	$9{\cdot}09 \times 10^{-4}$	$8{\cdot}16 \times 10^{-4}$	0·55	0·49	0·90
0·825	$2{\cdot}52 \times 10^{-4}$	$1{\cdot}46 \times 10^{-4}$	$1{\cdot}19 \times 10^{-4}$	0·58	0·47	0·82



Note: T-switch size = 480 × 512 (with random path-selection)

FIG. 4—Effect of delayed repeat-attempt facility in a T–S–T switch



Note: Shading denotes busy time slots

FIG. 5—Principle of rearrangement

is gained by immediately initiating a second attempt. However, if the control processor can be arranged to make a further (repeat) attempt after a short interval, the distribution of busy and free time slots on the 2 highways concerned may have changed, and it may therefore be possible to establish the call.

The possibility of using this form of repeat-attempt facility to improve the performance of the T–S–T structure has been examined using both analytical and simulation techniques. Fig. 4 shows results from the theoretical method; simulation results have confirmed the general shape of the curves but suggest that the theory slightly underestimates the improvement in the point-to-point grade of service provided by the repeat-attempt facility. Fig. 4 shows that, if the mean traffic offered to each external circuit is 0·8 erlang, then the probability of successfully establishing the call by a repeat attempt initiated after a delay of 0·006 mean call-holding times (that is, after about 1 s, assuming a mean call-holding time of 3 min) is slightly more than 50%.

In a modern stored-program-controlled system, there is no technical difficulty in implementing a repeat-attempt facility of this type. Unfortunately, the facility gives a worthwhile improvement in the grade of service at the expense of extending the post-dialling delay of the small minority of calls for which the facility has to be invoked. The usefulness of the technique therefore depends on the relative importance of the loss and delay standards that the digital exchange is required to meet.

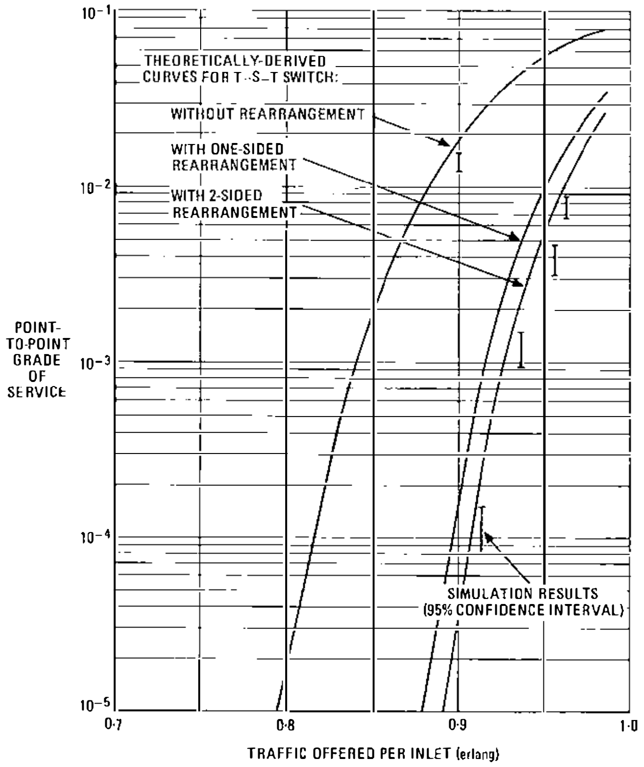
Rearrangement

It has been known for many years that, if an initial attempt to establish a connexion through a link-trunking scheme fails, it is in principle possible to rearrange the paths of some of the existing connexions so as to increase the probability of establishing the new connexion. This principle has not yet been applied in a practical switching system, partly because of the complexity of the control mechanism needed to implement the rearrangement algorithm, but also because of the difficulty of disconnecting and re-establishing existing speech connexions without giving offence to subscribers in an analogue switching system. In a time-division-multiplex switching system, the latter problem is substantially alleviated, and the use of processor-control techniques makes it possible to consider the adoption of relatively complex control procedures. It is, therefore, of interest to quantify the benefits that could be obtained by applying rearrangement to a digital switching system. Akiyama has shown[6] that good results are achieved by applying rearrangement to a 2-stage network having 24 internal time slots.

The principle of rearrangement can be explained by reference to Fig. 5. Each of T-switches 1–l is connected to the S-switch by a 512 time-slot highway, the highways being labelled H_1–H_l. Suppose that a call is to be set up between T-switches 1 and 2, and that, at the instant under consideration, the busy time slots in highways H_1 and H_2 are shown by the shaded portions of the diagram. There is no time slot which is free in both highways, and the call cannot be established. (Note that, since the numbering of the internal slots is essentially arbitrary, slots can be renumbered to give the simple situation shown in Fig. 5 without any loss of generality.) The time slots shown in zone 1 are free on highway H_2 but busy on highway H_1. If a call can be found in zone 1 between highway H_1 and some other T-switch (say, that connected to highway H_f) which could alternatively be connected on a time slot lying in zone 2, then the time slot consequently freed on highway H_1 in zone 1 can be used to establish the new call between highways H_1 and H_2. For example, call P_1, shown in time slot 87 between highways H_1 and H_f, could be moved to position P_2 (time slot 401), thus allowing time slot 87 to be used for the new call between highways H_1 and H_2.

Examining all the time slots in zone 1 to find a suitable call for rearrangement is called *one-sided rearrangement.* If the time slots in zone 2 are also searched, the procedure is called *2-sided rearrangement.* More complicated possibilities can be envisaged, where 2 or more existing calls are moved to make room for the new one, but these are not considered here.

The performance of a T–S–T switch with and without rearrangement is illustrated in Fig. 6. In each case, the curves are derived from theoretical formulae. Simulation results for a switch without rearrangement, and with 2-sided rearrangement, are plotted for comparison, and random path-selection is assumed. It can be seen that rearrangement greatly improves the grade of service, or, alternatively, at a constant grade of service, the traffic offered can be significantly increased.



Notes: 1 T-switch size = 512 × 512 (with random path-selection)
2 Simulation results shown only for T–S–T switch without rearrangement and with 2-sided rearrangement

FIG. 6—Effect of applying rearrangement to a T–S–T switch

CONCLUSIONS

The analysis described in this paper has investigated the unusual teletraffic behaviour of digital switching systems, with particular reference to the T–S–T structure. Similar analyses have also been made of several other possible designs of digital main-network switch. It has been shown that path-selection procedures, repeat-attempt facilities and rearrangement have a significant effect on the grade of service of the switching unit. Use of the appropriate teletraffic analysis methods at an early stage of the design process enables the teletraffic engineer to quantify the benefits of sophisticated techniques, such as rearrangement. The system designer can then compare these benefits with the control problems that they must to some extent create, and decide whether or not to include the techniques in the final design selected for development. In this way, the designer can ensure that his design will have satisfactory teletraffic characteristics before detailed development work is started.

ACKNOWLEDGEMENTS

The authors wish to thank their colleagues in Telecommunications Headquarters who contributed to the study described, especially Messrs. R. R. Hull and J. W. Roberts, who respectively derived the theoretical formulae for rearrangement and repeat attempts.

APPENDIX

In this Appendix, formulae are derived for the point-to-point grade of service of a 3-stage link system, of which the T–S–T digital switch is an example. The grade of service is defined as the conditional probability of loss in the switch, given that a call has seized a free inlet and a free outlet.

The analysis follows the method due to Jacobaeus[7] for the analysis of link systems, with a slight modification described by Huber[8].

Notation and Assumptions

Let

N be the number of external circuits connected to each T-switch,
m be the number of internal time slots on the highways interconnecting the T- and S-switches,
B be the point-to-point internal blocking probability (grade of service), as defined above,
A_0 be the traffic offered to each T-switch, and
A_F be a fictitious offered traffic, used for the calculation of B.

To derive a formula for the blocking probability, it is necessary to assume that

(*a*) the distributions of busy and free time slots on the 2 sets of internal highways (i.e., the receive T-switch to S-switch and S-switch to send T-switch highways) are statistically independent,
(*b*) each path is chosen at random from the free time slots,
(*c*) the number of busy time slots in each highway follows the Erlang distribution; that is, the probability that p links are busy out of a group of n, when the offered traffic is A erlangs, is given by

$$E_n(p, A) = \frac{\frac{A^p}{p!}}{\sum_{j=0}^{n} \frac{A^j}{j!}},$$

(*d*) only one direction of the bi-directional speech path is considered, since the second direction can be shown to be non-blocking for the selection rules used, and
(*e*) for simplicity of presentation, only the case when $N \leqslant m$ (that is, there is no concentration across the T-switch) is considered; the rearrangement of the formulae to cater for the case of $N > m$ is straightforward.

Method

It can be seen from Figs. 1 and 2 that the probability of a free path being found for a call between a given pair of T-switches is dependent only on the instantaneous status of the 2 highways from the T-switches to the S-switch. Let these highways be designated H_1 and H_2, and let the number of slots currently busy in each be p and q respectively. Given that each highway is offered A erlangs of traffic, the probability distributions of p and q are denoted by $G(p, A)$ and $G(q, A)$ respectively.

Since each highway contains m slots, then, for all states† characterized by a pair of values of p and q such that $(p + q) < m$, there is always at least one free slot in each highway, and the call will be successful.

However, for states where $(p + q) \geqslant m$, blocking can occur, depending on the way in which busy slots p and q are distributed over the m possible positions. Fig. 7 shows 2 possible states for the case where $m = 6$, $p = 3$ and $q = 4$. In Fig. 7(*a*), none of the free slots in highway H_1 matches any of those in highway H_2, and blocking will occur. In Fig. 7(*b*), however, a free slot is common to both highways.

† Patterns of busy/free slots on the 2 highways

TIME SLOT	(a) HIGHWAY H_1	(a) HIGHWAY H_2	(b) HIGHWAY H_1	(b) HIGHWAY H_2
1	●	o	●	o
2	●	o	●	●
3	●	●	●	●
4	o	●	o	●
5	o	●	o	●
$m = 6$	o	●	o	o
	$p = 3$	$q = 4$	$p = 3$	$q = 4$

● BUSY TIME SLOT
o FREE TIME SLOT

(*a*) Blocking state
(*b*) Non-blocking state

FIG. 7—Illustration of blocking and non-blocking states in a 3-stage link-trunking system

The number of ways in which q busy slots can be arranged on highway H_2 is given by the binomial coefficient $\binom{m}{q}$.† Similarly, the number of arrangements of p busy slots on highway H_1 that would make busy those $m - q$ slots coinciding with the free slots on highway H_2 is given by $\binom{p}{m-q}$. Since p and q are independent variables (assumption (a)), and all of these states are equally likely to occur (assumption (b)), the probability of blocking for any pair of values (p, q) is given by

$$P(p, q) = \frac{\binom{p}{m-q}}{\binom{m}{q}}.$$

Summing the probabilities for all possible pairs of values of p and q gives the total blocking probability as

$$B = \sum_{p=0}^{\min(N-1, m)} G(p, A) \sum_{q=m-p}^{\min(N-1, m)} G(q, A)\, P(p, q).*$$

The lower limit on the second summation reflects the fact that blocking cannot occur for states where $(p + q) < m$. The upper limit on both summations is set by the consideration that neither p nor q can exceed the smaller of m (the number of slots in the highway) or $N - 1$ (since, for the call to arrive, there must be at least one free external circuit on both T-switches).

Using assumptions (c) and (e), a more explicit formula for the blocking is

$$B = \sum_{p=0}^{N-1} E_{N-1}(p, A) \sum_{q=m-p}^{N-1} E_{N-1}(q, A) \frac{\binom{p}{m-q}}{\binom{m}{q}}. \quad \ldots\ldots(1)$$

† The binomial coefficient $\binom{a}{b}$ is defined as $\binom{a}{b} = \frac{a!}{b!(a-b)!}$

* The value of the expression min (a, b) is equal to the value of the smaller of the 2 variables a and b

The simplest method of evaluating this equation is to substitute the offered traffic, A_0, in place of A. When the blocking probability is low, this method gives acceptable results. As the intensity of offered traffic (and hence the blocking) increases, it is found that more accurate results are obtained by using a value for A that is related to the carried traffic rather than the offered traffic. This can be achieved by the following heuristic procedure.

(a) A value, Y, is specified for the traffic assumed to be carried by the T-switch highway.

(b) A value for the fictitious offered traffic, A_F, which would give the carried traffic, Y, is estimated from the equation

$$Y = A_F\{1 - E_N(N, A_F)\}. \quad \ldots\ldots (2)$$

(Since equation (2) has no exact analytical inverse, the value of A_F corresponding to Y must be found by an iterative method.)

(c) The fictitious offered traffic, A_F, is substituted for A in equation (1), and hence the grade of service corresponding to the traffic carried, Y, is determined.

(d) Finally, the level of offered traffic, A_0, corresponding to B and Y, is determined from the basic relationship

$$Y = A_0(1 - B).$$

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Book Reviews

Digital Transmission Systems. P. Bylanski, B.SC.(ENG.), PH.D., D.I.C., C.ENG., F.I.E.E., and D. G. W. Ingram, B.SC.(ENG.), M.A., C.ENG., F.I.E.E. Peter Peregrinus Ltd. (IEE Telecommunications Series). xii + 356 pp. 146 ills. UK: £13·80; overseas (excluding the Americas): £16·00.

This book, the authors of which both have wide experience in telecommunications research and development, represents a valuable contribution to the art of digital transmission, particularly at a time when there is a marked growth in the introduction of such systems while, paradoxically, there is a dearth of pertinent text books. A worthy complement to Professor Cattermole's *Pulse-Code Modulation*, it brings together and explores much material that has hitherto been available only through papers published by professional bodies, technical societies, commercial organizations and the CCITT.

Examining the work in depth, one senses the authors' inevitable dilemma of how much should be allocated to the sections on planning, multiplexing and transmission. Relating the actual allocation to the title, the balance seems good, although the absence of any analysis of microwave radio-relay and satellite systems is regrettable.

Moreover, at this point in time, it would have been useful to have included more than a passing reference to the increasingly important media: waveguide and optical fibre. The latter in particular merits substantially greater attention than a mere half page.

On a point of detail, the omission of codes 3B2T and 6B4T in the "Bibliography of some transmission codes" is surprising, since the former is referred to on p. 272 and the latter was extensively explored in papers presented to the 1975 IEE Conference on Telecommunication Transmission.

The authors are objective, in that the book is admittedly oriented towards the post-graduate reader and, although this is undoubtedly true, it should commend itself to all involved in both the study and research and development of digital transmission systems, with the wealth of references being a most valuable complement to the text.

G. H. B.

Worked Examples in Engineering Field Theory. A. J. Baden Fuller, M.A., C.ENG., M.I.E.E. Pergamon Press Ltd. 350 pp. 106 ills. Hard cover: £10·00; paperback: £5·00.

The author, a lecturer at the University of Leicester, has prepared this collection of examples as a companion to an earlier textbook of his on field theory. It will prove very valuable to any undergraduate who is using this textbook; other students may also find it useful as a concise summary of the theory.

It appears to fulfil the author's intentions quite well; it cannot be considered as a textbook in its own right.

H. N. D.

COLOSSUS and the History of Computing: Dollis Hill's Important Contribution

A. W. M. COOMBS, PH.D., B.SC., A.R.C.S.T.†

UDC 681.3 (091)

FOREWORD

Many British Post Office (BPO) engineers who watched the BBC television series "The Secret War" earlier this year will have been surprised to learn of the involvement of the BPO's Research Department—then at Dollis Hill—in the development and manufacture of specialized machines to assist the code-breakers working at Bletchley Park during the Second World War. In fact, the pioneer work carried out at Dollis Hill, under conditions of great secrecy, incorporated many basic ideas in computer design which helped to lead, after the War, to the rapid development and exploitation of computer technology.

In June 1976, an international conference on the History of Computing was held in Los Alamos, USA, and this was attended by Dr. A. W. M. Coombs, who retired a few years ago from the Research Department. As his report indicates, he was part of the original war-time research team which developed the machines under the direction of Dr. T. H. Flowers. After the War, Dr. Coombs was responsible for the design, again at Dollis Hill, of the MOSAIC machine, which was the subject of an article in the *POEEJ* in the early 1950s.[1]

It is, perhaps, unfortunate that security considerations have delayed, until now, full recognition of the part played by Dollis Hill staff in the early development of the electronic computer; this report attempts to put their efforts into perspective.

C. A. MAY,
Director of Research

INTRODUCTION

An International Research Conference on the History of Computing was held at the Los Alamos Scientific Laboratory, New Mexico, USA, during 10–15 June 1976. The conference was designed to serve the triple purpose of encouraging research of high quality into the history of computing, of recording "living history" in the context of discussions among the pioneers involved in the origins of electronic computing, and of providing computer scientists—especially those pursuing historical interests—with an insight into the discipline of historiography.

In the notice calling the conference, it was stressed that the organizers had in mind the unique opportunity of recording the history of modern computing during the lifetime of its creators. Already, the voices of some of the pioneers are stilled, and information they could have given clearly, accurately and completely must now be sought in written records that are often incomplete.

The conference had an international flavour, with representatives from Europe and the Far East adding their voices to those of America itself. It was a limited conference; in addition to the official speakers and session chairmen, there was invited a small number of people who either could contribute to the discussions at the sessions, or whose professional interests would be served by their attendance.

PROFESSOR RANDELL'S DISCOVERY

Professor Randell, of the Computing Laboratory, University of Newcastle-upon-Tyne, was one of the organizers of the conference. It happened that he, in the process of editing a book of selected papers on computing science, had uncovered and, to some extent collated, a number of facts concerning work at Dollis Hill during the years 1942–45. Specifically, he heard of the machines called COLOSSI, designed by T. H. Flowers, then working for the British Post Office (BPO), and his team. These machines were (and still are in their application, though no longer in their technology) highly secret; they were classified ultra top secret during the War. Professor Randell realized that here was a field where BPO research had anticipated developments in the rest of the world by several years, and he sought permission to deliver a paper on the subject at the conference. Permission having been received, he consulted some of the war-time personnel involved, including Flowers himself, S. W. Broadhurst, W. W. Chandler and the present writer, A. W. M. Coombs.

LOS ALAMOS

I had already decided to spend a holiday in the USA, and resolved also that I should like to attend the conference. An invitation was forthcoming and, accordingly, I was a guest at Los Alamos in a semi-official capacity, having received the blessing of the BPO's Research Department, from which I retired several years ago.

The remote area selected in 1942 for the Los Alamos Scientific Laboratory, where the conference was held, was the Los Alamos mesa of the Pajarito Plateau, a 2000 m high shelf of the Jemez Mountains, New Mexico. It is in the Pueblo Indian country, and is surrounded by some of the most beautiful scenery in the world. The nearby Bandelier National Monument, home of prehistoric cliff dwellers, is a treasure chest of South-Western lore. An enormous volcanic crater, the Jemez Caldera, which is 80 km round, lies less than 20 km away. Santa Fe, the oldest capital city in the US, is some 55 km to the south-west; the state's delightfully named largest city, Albuquerque, is about 150 km to the south.

† Formerly of the Research Department, Telecommunications Headquarters

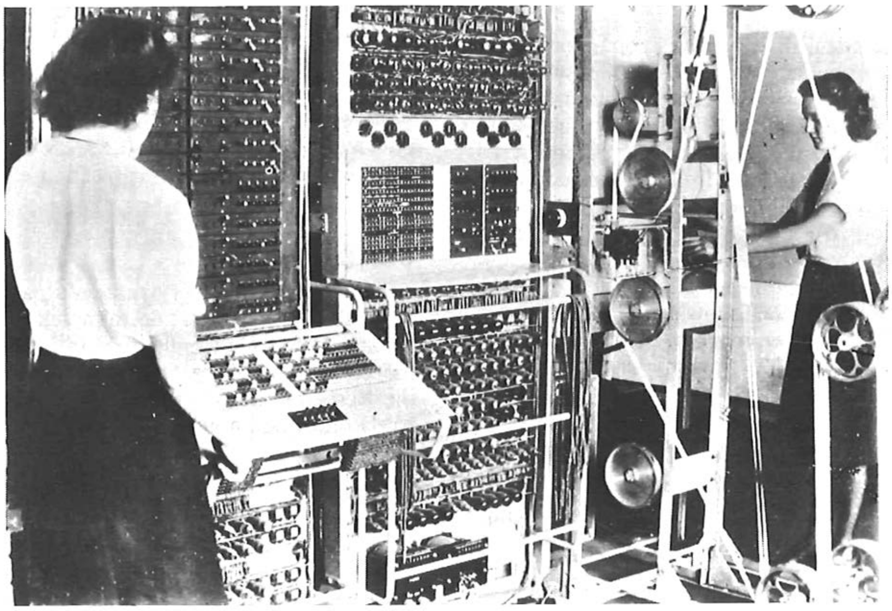

FIG. 1—COLOSSUS

(Photograph by courtesy of the Public Record Office)

Many notable personalities were at the conference: Mauchly of ENIAC fame (the acronym standing for electronic numerical integrator and calculator, by repute the first stored-program computer), Hamming (of Hamming distance), Professor Wilkes of Cambridge, Professor Wilkinson and Dr. Evans of the National Physical Laboratory, Professor Zuse (computer pioneer in pre-war Germany), and many others. It was a splendid experience and privilege to meet them all in the atmosphere of the conference, and I was able, from my own experience, to confirm and extend recognition of the brilliant work of T. H. Flowers, and of the great and unique contribution made by Research Branch (as it then was called) to the war effort in the design and construction of the COLOSSI.

It is not my intention to report in detail the many papers read at the conference. They were of great interest historically, but not very much the concern of the BPO today.

THE BPO's SPECIAL INTEREST

The paper of special interest to the BPO was, of course, that delivered by Professor Randell, entitled *The COLOSSUS*. In fact, he had originally intended to speak on the subject *A Perspective of the History of Computing in the UK*, but became so enchanted with his discovery of the COLOSSI that he concentrated his attention on them.

Professor Randell explained that, in October 1975, after an official silence lasting 32 years, the British Government had made a set of captioned photographs of one of the COLOSSUS machines available at the Public Record Office (see Fig. 1). These photographs confirmed that a series of programmable electronic digital computers was built in Britain during the Second World War, the first being operational in 1943. The first COLOSSUS incorporated 1500 electronic tubes, and operated in a parallel-arithmetic mode at 5000 pulses/s. He went on to disclose a number of its key features, including the fact that it had: 5000 characters/s punched-paper-tape inputs; electronic circuits for counting, binary-arithmetic and Boolean-logic operations; "electronic storage registers changeable by an automatically controlled sequence of operations"; conditional (branching) logic, "logic functions preset by patch-panels or switches, or conditionally selected by telephone relays"; and a typewriter output. Professor M. H. A. Newman was named as being responsible for formulating the requirements for COLOSSUS, and T. H. Flowers as leading the team that developed the machine.

Since the conference, Professor Randell has published papers[2, 3] in which he largely reiterates the revelations made at Los Alamos.

SPECIAL MEETING

The conference reacted strongly to Professor Randell's paper. It was a complete surprise to most members that the BPO Research Department had so far anticipated world developments. They were particularly intrigued with the revelation that an order for up to 10 Mark II COLOSSI, placed in March 1944, resulted in the first being operational before the end of May of that year. This COLOSSUS, a machine of 2400 tubes plus very many other components, including relays and uniselectors, was very considerably redesigned from the Mark I machine, and was 5 times as powerful as its fore-runner. It was acclaimed as a notable example of what could be done by a devoted band under the stimulus of national emergency, and relieved of the incubus of accounting procedures (however necessary these may be in the calmer days of peace).†

So great was the interest shown that a special evening meeting was convened under the joint chairmanship of Professor Randell and myself, at which further questions could be put, and the discussion in general continued. There was, of course, the continuing need for security, and Professor Randell made it clear at the outset that certain questions were taboo (which did not stop them being asked). The meeting lasted for 2 hours, and showed no signs of ending even then, though the closure had to be applied. I, for my part, was impressed with the way in which the US participants (who might very well have thought their thunder was being stolen) showed no resentment, but were clearly delighted with the whole happening.

† To those erstwhile Dollis Hill group leaders who remember being denuded of staff and laboratory space and squeezed out of workshop facilities at that time, this commendation will no doubt be a consolation

ACHIEVEMENT

Professor Randell concluded his paper with some comments very pleasant to Research Department ears. He said that surprise had been expressed at the way Great Britain, despite the ravages of war, had such vitality that it could, immediately after the war, embark on so many well-conceived and well-executed projects in the computer field. He gave his opinion that the COLOSSUS project itself was one of the important sources of the invention of the digital computer. He added that the continuing secrecy surrounding many aspects of the project made its proper evaluation very difficult and, for that reason, he would choose to let the following quotations from those directly associated with the machine serve as his own conclusion.

> "The value of the work, I am sure, to engineers like myself was that we acquired a new understanding of, and familiarity with, logical switching and processing because of the enhanced possibilities brought about by electronic technologies which we ourselves developed. Thus, when stored-program computers became known to us, we were able to go straight ahead with their development. It was a great time in my life."
>
> *T. H. Flowers*

> "A few mathematicians of high repute accidentally encountered a group of telephone engineers, of all people, and they found one really enthusiastic expert in the person of Flowers, who had a good team with him and made these projects possible with, I think, a lot of respect on both sides. And the BPO was able to supply the men, the material and the maintenance without any trouble, which is a great tribute to the men and the organization."
>
> *S. W. Broadhurst*

Broadhurst's comments describe a spirit and a resulting achievement which have a remarkable parallel in events at Los Alamos itself during the Second World War, for it was there that the first atomic bomb was made.

People from widely differing walks of life were brought together to perform the near-impossible; in the face of that challenge, they settled down quite startlingly well to produce incredible results in an unbelievably short time.

As with them, so with us. No member of our team could ever forget the fellowship, the sense of purpose and, above all, the breathless excitement of those days.

CONCLUSION

The conference was very successful, and thoroughly enjoyed by all the participants. I deem myself fortunate and honoured to have been able to take part in it. I was also very pleased indeed to be privileged to speak for the BPO, and especially the Research Department, in a venue where they were probably but little known.

EPILOGUE

T. H. Flowers, in my opinion the most brilliant technical man the BPO has produced, and whose brain-child COLOSSUS was, has just recently been awarded an Honorary Doctorate by the University of Newcastle-upon-Tyne—an honour and a recognition long overdue.

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Book Review

Electronic Inventions 1745–1976. G. W. A. Dummer, M.B.E., C.ENG., F.I.E.E., F.I.E.E.E., F.I.E.R.E. Pergamon Press. v + 158 pp. 21 ills. £4·00.

This work is a catalogue of inventions in electronics, from the Leyden-jar capacitor of 1745 to the single-printed-circuit-board general-purpose computer sub-system of 1976. In fact, for completeness, the author has included the mechanical calculators of Pascal (1642) and Leibniz (1672), considering them to be an essential part of computer history.

The book is designed to be a work of reference, and is organized into 4 major chapters, each using a different approach to indexing and presenting the information. The most important is Chapter 5, a list of inventions in chronological order. Each invention is described in a brief excerpt from a standard source-work on the subject, and reference is made to other useful sources. Chapter 2 is also a chronological list of inventions, but without descriptions, and is intended to simplfy research by compressing the information into 6½ pages, instead of the 120 pages occupied by Chapter 5.

In Chapter 3, the inventions are indexed by topic, and sub-indexed chronologically, making research on a particular subject straightforward. Chapter 4 provides yet another aspect to the indexing by listing the inventors alphabetically, with the dates of their inventions. Throughout Chapters 2–5, the date acts as a common factor, linking the various forms of index. To round off the work, the book's index lists the inventions in alphabetical order.

Chapter 1 presents some miscellaneous (though relevant) information in chart form. For example, the relative numbers of inventions in the UK and the USA are shown for the period 1745–1976; the author attributes the difference over recent years to the "brain drain". Two appendicies list useful books on inventors and inventions. Throughout the book, the presentation is in typescript form, presumably to reduce costs, but unfortunately many minor typing errors are apparent.

The thorough and co-ordinated organization of this work enables information to be found from any starting point. Whether research commences with a name, a topic, a date or an invention, one is quickly led to the relevant descriptions in Chapter 5. Space constraints have dictated that the descriptions contain only basic facts and brief notes on the inventions. For more detailed research, one would have to turn to the referenced sources, but this does not detract from the book's usefulness in establishing a framework for such research. Indeed, for a concise outline of the history of electronics technology, one can learn a considerable amount from this book.

B. S.

British Post Office Experience of Reed Relays in Electronic Telephone Exchanges

C. JOHNSTON, M.SC., C.ENG., M.I.E.E., F.S.S.†

UDC 621.318.5.004.6: 621.395.345

There are some 65 million reed contact units in service in TXE2 and TXE4 electronic telephone exchanges, and the rate of growth of this population is increasing. This article quantifies the achieved reliability performance of reeds, and describes the methods adopted by the British Post Office for controlling failure and degradation mechanisms. Reference is made to specific reed applications where appropriate.

INTRODUCTION

Reed relays are used in TXE2 and TXE4 electronic telephone exchanges and will also be used in the System X local exchange now being developed. Previous articles in this *Journal* have described the basic physical and operational characteristics of reed relays and reed contact units[1], and some of their applications in TXE2 and TXE4 exchanges[2-5]. Since the first TXE2 exchange was brought into service in 1968, the performance of reeds has been closely monitored. A number of advances have been made in methods of quality assessment and control in manufacture and also in the understanding of the constraints on applications of reeds, imposed by the limitations of the mass-produced device. This article describes some of the lessons that have been learned, and the current approach of the British Post Office (BPO) to reed specification and applications.

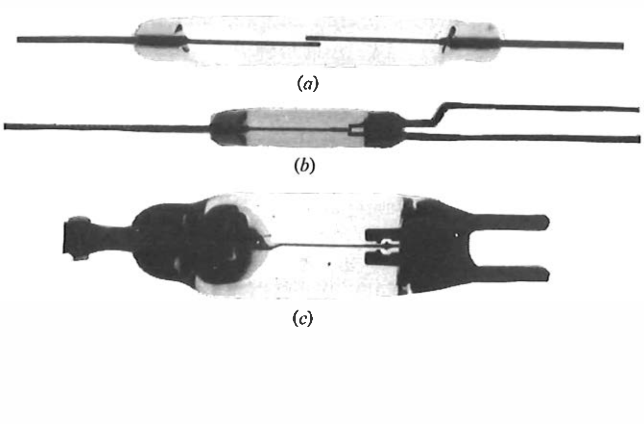
Many varieties of reed contact unit designs exist, having lengths of glass capsule from about 1–5 cm and either magnetically soft or remanent moving-contact blades. A sample range of types available is illustrated in Fig. 1.

The 2 most important features of reeds are that

(*a*) the contacts are hermetically encapsulated in (usually) an inert atmosphere, and

(*b*) the contact blades form part of the magnetic circuit of the reed relay.

† Mr. Johnston is in the Telecommunications Development Department, Telecommunications Headquarters



(*a*) Dry reed contact unit—glass capsule 2·5 cm long
(*b*) Dry reed change-over unit—glass capsule 1 cm long
(*c*) Mercury-wetted change-over reed

FIG. 1—Examples of reed units

The reeds used in TXE2, TXE4, and intended for use in System X, consist of 2·5 cm glass capsules having dry contact-blades that are coined from magnetically soft 51:49 nickel-iron wire, as illustrated in Fig. 1(*a*).

There are about 800 TXE2 exchanges now in service in the UK, and with an average of 100 000 reeds per exchange, there are about 80 million reeds in service in TXE2 exchanges. An average size TXE4 exchange will contain about 1 million reeds. At present, there is only one TXE4 exchange (300 000 reeds) in service. The historic and expected rate of increase in the number of reeds in working exchanges is shown in Fig. 2. By about the end of 1980, there will be as many reeds in service in TXE4 as in TXE2 exchanges and, by 1981, the total is likely to be about 300 million, two-thirds of which will be in TXE4. The sheer number in service is sufficient reason for reeds to be regarded as key components. The expected replacement rates in TXE equipment were of the order of 0·2–0·6 per 1000 reeds per year (approximately 23–70 failures per 10^9 component hours). In an average TXE4 exchange, the lower figure would represent 4 failed reeds per week and, if an out-of-control situation were to arise in manufacture, this could easily become several failed reeds to be found and replaced per day, and this would have

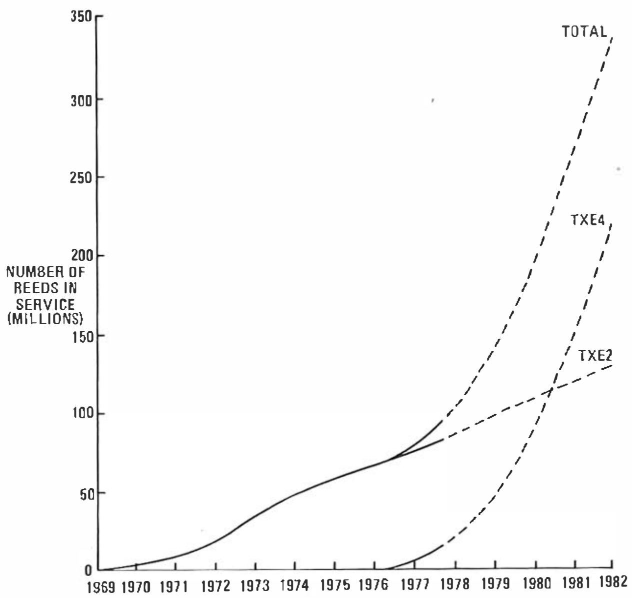


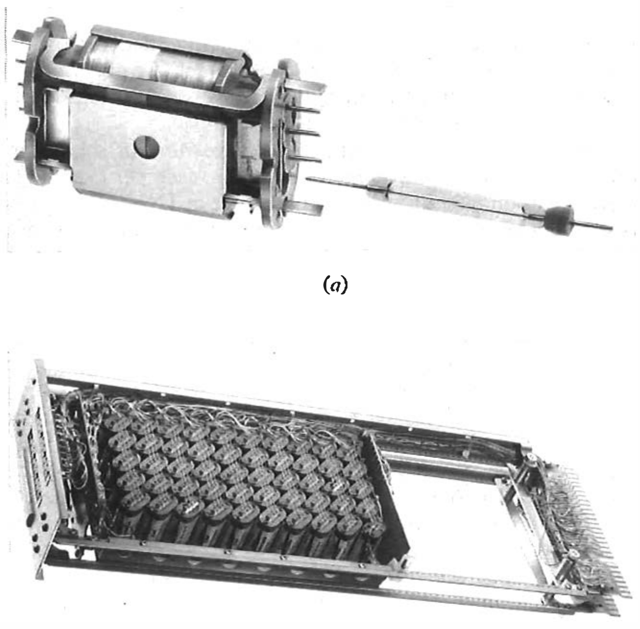
FIG. 2—Historic and expected rate of growth of reed population

serious effects on both the exchange quality of service and the viability of the maintenance strategy. Although the reed appears as a simple device, the technology of production and usage is complex.

In TXE2, reeds are used in switch matrices and in the control area of the exchange; approximately 55% of the reeds in a TXE2 are used in switches. In TXE4 and TXE4A exchanges, the control areas are largely solid-state circuitry, and reeds are used only in switches, and in interface equipment; about 91% of the TXE4 reed population is in switches. Examples of a TXE reed relay and a TXE2 switch-matrix plug-in unit are shown in Fig. 3. The implications of these differences in reed usage are that

(*a*) in TXE2, there is a wide range of operating rates, varying from less than 1000 operations per year in A-switches, through 150 000 operations per year (average) in registers, to 6 million operations per year for pulsing contacts, and

(*b*) in TXE4, the maximum operating rate is less than 100 000 operations per year.



(*a*)

(*b*)

(*a*) Reed relay with 4-reed contact units (one reed extracted)
(*b*) TXE2 B-switch (or C-switch) matrix plug-in unit

FIG. 3—Examples of reed applications in TXE2 and TXE4

REED VARIANTS

The BPO specification for reed manufacture and performance is written in the form of a quality-assessment specification. Maximum external dimensions are specified, but materials (wire, glass, infilling gas, contact finish) and their processing, and the magnetic and mechanical design (blade coining, annealing, gap dimensions, blade overlap and magnetic residual due to plating), are not specified except for a visual inspection for structural and contaminant defects. As a result, there are a number of variants of the reeds used in TXE2 and TXE4 exchanges. The reeds first used in TXE2 were produced by the Plessey Telecommunications Company (PTL); these used 0·056 cm diameter wire and a relatively thick hard-gold plated contact finish. These reeds have now been superseded by a superior PTL reed. The designs used by the other reed suppliers are different, and have also gone through evolutionary stages in which improvements in process control procedures and, in some instances, changes of material or process have improved the performance. Table 1 indicates some of the points of difference between the basic products in service.

IN-SERVICE RELIABILITY OF REEDS

TXE2 exchanges are generally unattended, and a single maintenance officer is usually expected to be able to service 4 or 5 exchanges. However, in the early part of 1972, it became clear that TXE2 was requiring considerably more maintenance effort than had been expected, and this was due to a high incidence of reed failures. A considerable amount of effort by the BPO and industry revealed that the following 2 classes of failure were occurring.

(*a*) Some reed production processes required very critical control, and slight deviations from the optima (that first had to be discovered to some extent by trial and error) could produce either high contact resistance, or failure to release due to adhesion between the gold contact surfaces; in addition, serious contamination had occurred in production of one reed variant.

(*b*) Some applications of reeds in TXE2 were shown to produce very high capacitive inrush-current stresses, sufficient to cause microwelds and resultant failures to release.

Experience has shown that, if the diameter of the nickel-iron wire from which reed blades are coined is as small as 0·056 cm, then gold-plated contacts may be liable to fail to release due to gold adhesion; this susceptibility is also critically dependent on control of the gold-plating bath and other aspects of the reed manufacturing process. In addition, it has appeared that cobalt acid/hard-gold plated reed contact units are more difficult to control in production than nickel acid/hard-gold reeds. The latter have been clear of both significant contact resistance and gold adhesion failures in service. It is difficult to make a comparison of the merits of the gold plating solutions because there are many differences in production-process parameters between reed manufacturers and, in particular, the nickel acid/hard-gold units use wire diameters of 0·066 cm and, therefore, benefit from greater retractile forces.

There are, in fact, many 0·056 cm cobalt acid/hard-gold plated reeds in TXE2 that are giving satisfactory service. However, as part of a process of continuous improvement in reed manufacture, the production of this type of reed has been phased out, and there are at present only 3 variants of reeds which are approved to the current BPO specification: a reed with nickel acid/hard-gold plated contacts (0·066 cm wire diameter), and 2 reeds having relatively thin gold, glow-diffused into a nickel-iron substrate.

The weakest aspect of the performance of glow-diffused gold-contact units has been their susceptibility to fail to release due to microwelding. Microwelding can occur due to high transient inrush currents that flow in arcs that are struck as the blades come close together, just before metallic contact is made. The susceptibility to microwelding is decreased if the thickness of the gold plating diffused into the substrate is increased, because this improves the thermal and electrical conductivities of the contact material. In TXE2, several reed applications existed in which the transients were sufficient to produce microwelding of diffused gold contacts and, also, of gold-plated contacts. The best example of the latter was contacts MK1 and MK4 in the marker unit, where reeds were required to break the contacts of an unquenched Type-12 relay (relay K in the line circuit)[3], and a number of instances of complete and partial exchange isolation resulted. In this case, although the reed contacts were breaking when the failures occurred, welding was caused because the contacts were drawn together again by magnetic interaction and by the high electrostatic forces associated with voltage transients.

Most applications of reeds in TXE2 exchanges having high inrush-current stresses have now been modified to eliminate the stresses, thus protecting the reeds from microwelding. The only remaining case is the A-switch negative contact, which will be discussed later in this article.

After a considerable amount of work by all the reed manufacturers and the BPO, including the implementation of a new

TABLE 1

Reed Variants

Wire Diameter (cm)	0·056	0·066	0·071	
Contact Finish	Cobalt acid/hard gold plating	Nickel acid/hard gold plating	Relatively thin electro-deposited gold, diffused into substrate by a glow-discharge process	
Supply	Two suppliers produced variants of this design; both now discontinued	Two suppliers (commercially linked)	Two independent suppliers currently producing variants	
			Supplier 1	Supplier 2
Service Experience	TXE2	TXE2	TXE2 TXE4	Successful service trial in TXE2
Future Use	—	TXE2 TXE4 System X local exchange	TXE2 TXE4 System X local exchange	TXE2 TXE4 System X local exchange

issue of the BPO reed specification, the reliability standard achieved by the 3 UK TXE2 exchange manufacturers has, since the end of 1972, been better than the target cited in the BPO plant service requirement. For reed switch-matrices, the reliability figures cited were 0·2 failures per 1000 reeds per year, and, for control applications, 0·6 failures per 1000 reeds per year. The reliability figures achieved as a national average in TXE2 exchanges brought into service since 1972, have been better than 0·1 in switch matrices, and about 0·3 in control areas. The reason for the difference between the reed performance in switch matrices and control areas is that, in the control area, the average operating rate is 3 times that in switches.

The first TXE4 exchange to be brought into service was the Rectory exchange in Birmingham and, in the first year's service, the reed failure rate has been better than 0·1 per 1000 reeds per year. The Rectory exchange is equipped with about 300 000 reeds.

THE CONTROL OF REED FAILURE MECHANISMS

There are a number of failure mechanisms inherent in reed contact units, and there are 2 approaches to their control.

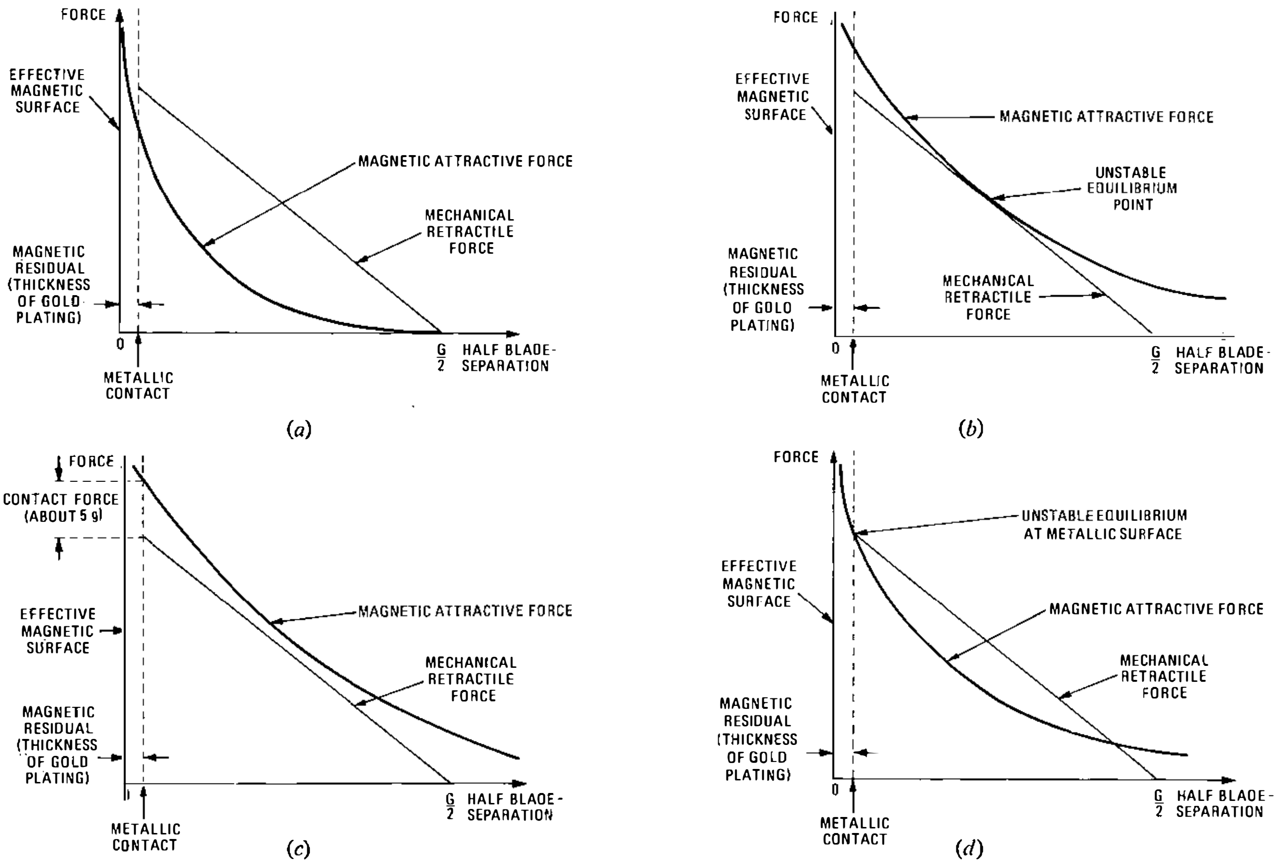
Firstly, inherent failure and degradation mechanisms of specific variants of reeds must be identified and tests devised which can be readily applied in quantity production, both as indicators of process stability and to identify batches of the product that are of unsatisfactory quality. It is very difficult to use a single specification test for both of these purposes simultaneously and, in general, it has to be accepted that a proportion of reeds will fail in particular tests; this proportion must be prescribed in the specification (or an associated quality specification). It is essential to start from a knowledge of process capability, that is, inherent batch-to-batch variations in the product's performance in specific tests; if this is unacceptable in the light of the relation between the test and the conditions of service, then process control has to be improved to reduce the batch-to-batch variations. The acceptable process capability must be seen to be maintained by in-process quality-control procedures and the results of final batch-assessment tests, which are normally performed on a sampling basis. The difficulty in this approach is that the relation between the test criteria and the criteria of failure that would be appropriate in service may not be easily established. Service conditions are often very diverse. Correct simulation in a laboratory of the most relevant service conditions is often very elusive and time consuming; to some extent, it has been necessary to use judgement, based on accumulated experience, in deciding the limits of acceptability for particular batch-assessment tests of reed contact units.

The second aspect of the approach to controlling device failure mechanisms is to define the constraints on device applications, and to ensure that the constraints are applied by system designers. The latter requires the facility to monitor applications at a design stage.

FAILURE MECHANISMS

The inherent failure mechanisms of reed relays, the corresponding product tests of the BPO specification, and the relevant constraints on reed applications are discussed in this section, but first it may be helpful to consider the forces that act on a reed. Fig. 4 illustrates the operating, contact, and retractile forces in a reed contact unit. The mechanical retractile force, which is approximately linear, is determined by the dimensions and elasticity of the coined blades. Figs. 4(*a*), 4(*b*) and 4(*c*) show the situation when the magnetomotive force (m.m.f.)† is increasing, and Fig. 4(*d*) shows the situation at the "just-release" point. It is clear that the contact gap dimension and the slope of the retractile-force line determine the magnitude of the retractile force at the point of metallic contact and, therefore, given the magnetic circuit of the relay which includes the reed, the gap also determines the contact force. The variation of the magnetic forces with time is non-linear; this is due to magnetic saturation of the reed material and to the fact that the existence or non-existence of an air gap in the middle of the reed radically affects the reluctance of the magnetic circuit. Thus, as opening the contacts of a reed increases the reluctance, the flux linking the coil begins to collapse, producing a back-e.m.f. and, if the coil is diode quenched, the energizing current can be increased and the contacts may reclose; the consequence of this effect becomes somewhat complicated when there is more than one reed in the coil since magnetic interactions will then occur. With this system of forces in mind the 4 main failure mechanisms of reeds in BPO systems can now be considered.

† A current of I amperes flowing in a coil of N turns produces a m.m.f. of NI amperes



Note: G is the width of the gap measured between the effective magnetic surfaces of reed blades

(*a*) Magnetic attractive force insufficient to operate reed
(*b*) Just-operate energization: once past the unstable equilibrium point the blades close with a "snap" action
(*c*) Hold energization: the hold energization (m.m.f.) may be less than or greater than the just-operate energization
(*d*) Just-release energization

FIG. 4—Forces acting on one blade of a reed contact unit

Failure to Release due to Gold Adhesion

When 2 clean gold surfaces are brought into intimate contact they tend to adhere. This is because gold is a soft metal and the asperities of the 2 surfaces are largely in plastic, rather than elastic, compression so metallic bonds form between atoms of the 2 surfaces. In reeds, these bonds have, in some situations, been stong enough to prevent the blades separating when the holding magnetic field was removed. Any sliding of the contacts enlarges the area in contact and may, therefore, increase the likelihood of failure to release, depending on whether the area in plastic deformation has increased.

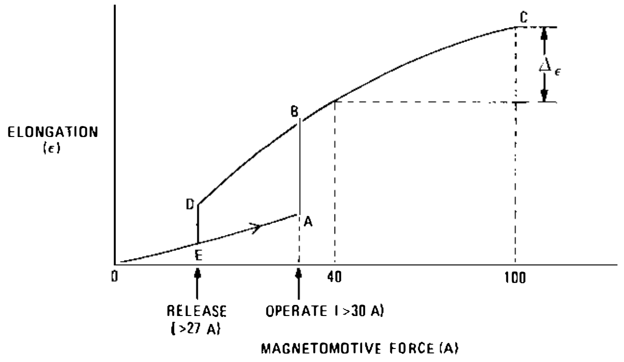
The tendency of gold surfaces to adhere to one another is offset by any films on the surface, because an interposed film decreases the metallic contact area. However, the contacts may be brought into intimate contact by sliding if, by a scrubbing effect, the film can be dislodged. Thus, the liability of a particular reed to fail due to gold adhesion depends on the hardness of the contact surface, and on the incidence and nature of surface films. Hardness is influenced by contact processing and by the heat-sealing of the ends of the glass capsule. The production of films is a function of the co-deposited organic compounds from the gold-plating bath and subsequent processing, particularly the sealing operation. There is some evidence that the character of the films (for example, susceptibility to removal by scrubbing) may be affected by the atmospheric content within the capsule.

Experience has shown that the reed variants with contact finishes consisting of glow-diffused gold and those with nickel acid/hard-gold plating have never failed due to gold adhesion even in applications involving very long (1 year) holding durations. The cobalt acid/hard-gold plated reeds suffer the disadvantage of lower retractile forces because of the smaller cross-sectional area of the blades.

The BPO-specified test that aims at controlling the propensity to fail due to adhesion, uses magnetostriction* to produce a scrubbing effect. The reed is operated in a test coil giving an m.m.f. of 100 A; the m.m.f. is reduced to 40 A, at which the reed remains operated. The m.m.f. is then varied between 100 A and 40 A through 2000 cycles, at a rate of 10 Hz. The magnetostriction thus produced causes scrubbing of the contact areas. The reed is required to release within 2 ms after removal of energization subsequent to the final scrub.

The elongation due to magnetostriction in normal operation is shown schematically in Fig. 5, which illustrates that the single scrub on release is much greater than either the scrub on operate or the length $\Delta\epsilon$ of the scrub in the magnetostrictive test. The value of $\Delta\epsilon$ is of the order of 0·3 mm[6]. Decreasing the lower value of m.m.f. (thereby increasing $\Delta\epsilon$) can dramatically increase the probability of failure for some reeds. The exact relationship between the results of this test and liability to fail in service has not yet been firmly established. However, it is clear that the test explores both

* Magnetostriction is a phenomenon of elastic deformation of certain ferromagnetic materials on the application of a magnetizing force



Note: Elongation during operate cycle (OEABC), release cycle (CBDEO) and BPO test cycle (Δε)

FIG. 5—Elongation due to magnetostriction

TABLE 2

Approximate Optimum Conditions for CR Increase

Contact Variant	Electrical Load most likely to produce CR Increase	Likely Range of CR Increase
Nickel acid/hard-gold contact	24 V 50 mA d.c. resistive load	0–20 Ω
Thin-gold glow-diffused into substrate	(*a*) Switching dry, carrying 12 V, 2 mA (*b*) Switching 0·1 V, 1 mA	0–5 Ω

the susceptibility of any films present to be removed by scrubbing, and the propensity of the basic contact surfaces to adhere to one another. The total scrubbing effect is undoubtedly greater in the test than in normal release, but reliance cannot be placed on films to prevent adhesion, and so the test is applied to control the basic liability to fail in this mode.

Contact Resistance Characteristics

The contact resistance (CR) of an unused reed (including the resistance of the blades) lies in the range 50–80 mΩ. Some of the worst cases of increased CR, found in service before 1972, have been due to contamination, due to the unintended inclusion in the reed capsule of foreign material. However, there are other mechanisms of CR increase which are intrinsic to the production process; these may be controlled but not eliminated.

The significance of films on the contact surface has been discussed in the context of gold adhesion; these same films are the main element in the intrinsic mechanisms of CR increase. All the gold-plating solutions used by manufacturers of BPO reeds lay down some quantity of organic compounds in the gold; the quantity depends on the thickness of gold plating on the blades, and the characteristics and the state of the plating bath. Subsequent stages in reed manufacture (particularly the sealing-in operation and any diffusion processes) alter the form of the organic compounds present within the capsule and the properties of the contact material. During the operational life of a reed, these sealed-in organic compounds may form non-conducting films in the contact area, depending probably on the thermochemical balance required for film formation, and the energy dissipated during operation with a particular electrical load and duty cycle.

The operating conditions which most readily generate non-conducting films are slightly different for the 2 basic variants of the BPO reed which use gold-plated or diffused-gold contacts. The gold-plated contacts begin life with slightly lower CR values than diffused gold types because, after the diffusion process, the contact surface of the latter contains a proportion of base metal (it is actually a gold/base-metal alloy). The thickness of gold deposited before diffusion is considerably less than on the gold-plated contacts and, as a result, diffused contact unit capsules contain less organic compounds than the gold-plated contact units. The electrical load conditions in which CR increases most readily, and their approximate values, are shown in Table 2. The 24 V, 50 mA resistive-load quoted in Table 2 against gold-plated reeds is used as load in a batch-acceptance test of the BPO specification, in which reeds are required to switch 20 000 times at a rate of 20 operations/s, with CR monitored against a 1 Ω criterion on every operation. The acceptable quality level for CR increase is 1%, and the nickel acid/hard-gold reeds just meet this criterion. When the test is extended to 2 or 3 million operations, a larger proportion of reeds exceed 1 Ω CR and, if switching is continued, the CR increases (maximum 20 Ω) and then recovers to values less than 1 Ω. These CR excursions generally extend over 0·3–0·5 million operations. The 12 V, 2 mA load (not switched), quoted in Table 2 against diffused-gold reeds, is also used as a batch-acceptance test requiring CR to be less than 1 Ω over a test duration of 1 million operations at 15–20 operations/s. About 1% of diffused-gold contacts may rise to CR values of 1–5 Ω in this test. However, there is evidence that this mechanism depends on the rate of operation and possibly on the duty cycle. When the reed is left unoperated, the CR tends to recover to low values.

Both of these mechanisms occur to a less significant degree under operating conditions, for example, the diffused contact mechanism occurs when current in a contact is 100 mA from a 50 V source but, in this case, appreciable cable discharge at closure or breaking the d.c. supply, tends to dissipate the films as fast as they are formed.

Surveys of the CR of several thousands of reeds in service in TXE2 exchanges have shown that only a very small proportion of reeds have a CR exceeding 0·5 Ω. One application in which gold-plated reed CR has increased approximately as predicted by test results is in the TXE2 H-wire crosspoint relay contact, where 24 V transients occur during contact bouncing. None of the observed CR values has been sufficient to cause malfunction. Increases of only a few ohms could be of significance in speech-path reeds from a transmission point of view and, as crosspoint reeds switch dry and carry line current in all UK reed systems, it is clear that the propensity to form films must be controlled. In crosspoint applications there is usually a cable discharge on closure of the contacts; however, in B-switches and C-switches, the discharge is usually very small. While the mechanisms are controlled as at present, there is no likelihood of serious transmission impairment[7].

Welding due to Inrush Currents

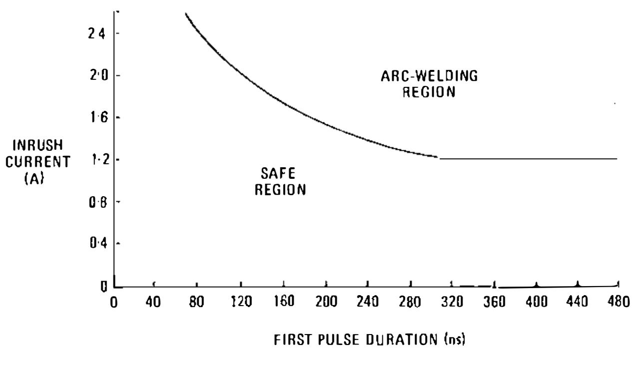
When reed blades close on voltages above 12 V, an arc is likely to be struck just before metallic contact is made. If there is sufficient current available to maintain the arc, then it is terminated only by metallic contact, and there will be a molten area on the contact surfaces. The amount of material melted is proportional to the energy dissipated in the contact surface during the arc. If the arc is terminated by metallic contact then, at 50–100 V, its duration is generally of the order of 50–300 ns. If a sufficient amount of material of the contact surface has been melted, then the contacts are liable to microweld together, and may subsequently fail to release.

Diffused-gold contacts are much more liable to fail in this way than gold-plated contacts because of their relatively low thermal and electrical conductivities.

The current that flows in an arc struck on closure of reed contacts is usually a transient current that results from the discharge of stray capacitance or capacitance distributed in rack wiring and inter-rack cabling. The magnitude of this current depends on the surge impedance, Z_s, where $Z_s = \sqrt{(L/C)}$, and L and C are the inductance and capacitance per unit length. The duration of the first pulse is determined by the length of cable between the contact and an open-circuit (or a high-impedance to transients, such as a coil). The surge impedance found in exchanges varies depending on physical features such as tightness of cable forms, terminations of other wires in close proximity to the switched circuit, and proximity of rack or grid framework at earth potential. Measured values range from 45–140 Ω; a nominal value of 100 Ω is assumed. Transient currents may be enhanced by reflections from points at which cable is branched, and it is important that a cable should never be fanned-out into 3 or more branches at any point.

To avoid contact welding, a sound rule to follow is to ensure that the inrush-current transients are kept below 1 A. A method of achieving this is to insert a resistance between the reed and the source of the capacitive discharge. If this is not practical, then the absolute limits of inrush current to avoid welding, at various first-pulse durations at 100 V, are as shown in Fig. 6. A new batch-acceptance test using the circuit given in Fig. 7 has been added to the BPO reed specification, the inrush current is 1·4 A for 300 ns (produced by 30 m of cable).

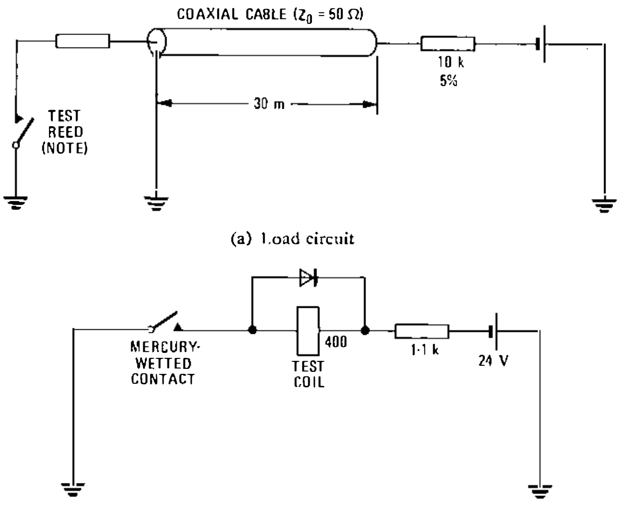
When a contact opens and breaks an inductive load, the voltage transients produced depend on the quench and the total capacitance across the contact. The voltage transient is associated with an electric field between the blades (see the force diagram of Fig. 8). This electric field is important, because it aids the attractive-magnetic forces, and contact reclosures may occur. There is evidence that the reclosure mechanism is more critically affected by magnetic field variations than by the electric field. As previously described, on the opening of a contact, the coil flux decreases. This causes a back-e.m.f. in the coil that produces a transient increase of current, particularly if the coil has a diode quench, and so the m.m.f. will increase, which, together with the electric field, may cause the contacts to reclose. From Fig. 8 it can be seen that the electric field is important only at very small separations. As the voltage across the contacts has reached a high level when reclosure occurs, the resulting



Note: The graph shows the safe region when the first pulse of inrush current is rectangular. For a pulse duration < 320 ns, in general,

$$\int I^2 dt \leqslant 0{\cdot}46 \times 10^{-6}\,\mathrm{A^2\,s}$$

FIG. 6—Threshold of inrush current to weld reeds (diffused thin-gold contacts)



(a) Load circuit

(b) Coil-drive circuit

Note: Test voltage across contact when open is 100 V ± 2%

FIG. 7—Inrush current weld-test circuit

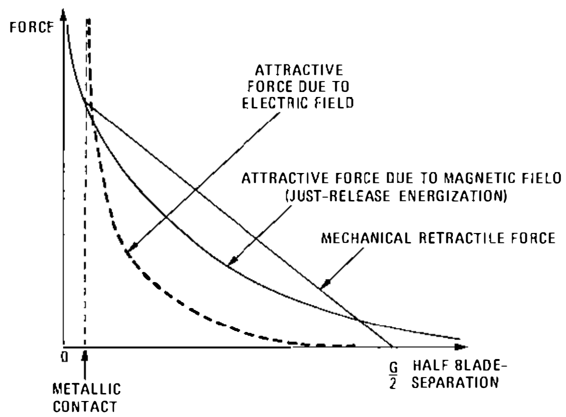


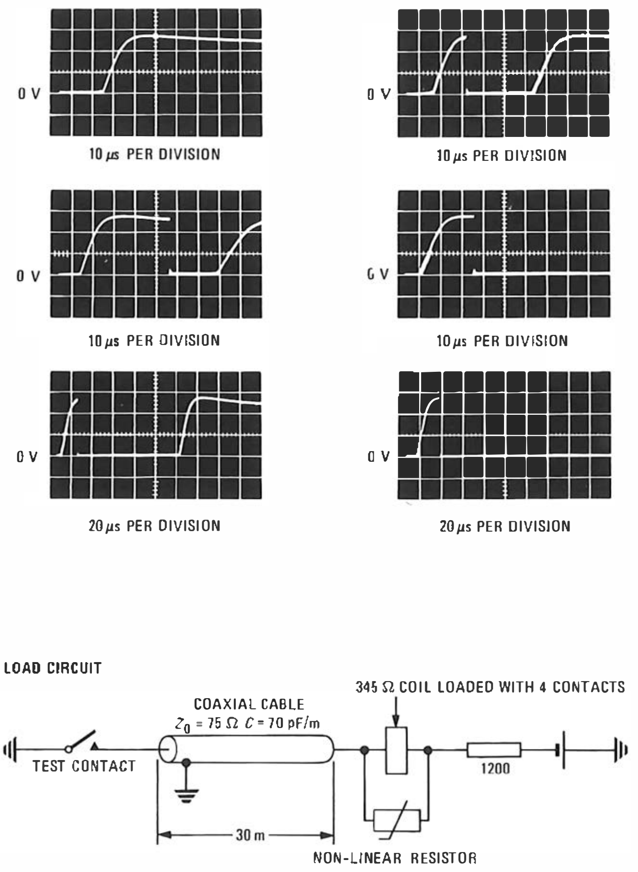
FIG. 8—Forces acting on one blade when breaking an inductive load

discharge may produce a large inrush current, and micro-welding in such cases is likely. A laboratory simulatation of reed reclosure is illustrated in Fig. 9.

The initial rate of rise of voltage across the contacts, dv/dt, is equal to I/C, where I is the d.c. (current) broken, and C farads is the total (distributed, lumped, or stray) capacitance across the contacts. If dv/dt is less than 1 V/μs, then remakes will be insignificant in their effect because the voltage reached is not likely to be excessive. If the value of C associated with a rapid voltage rise is small, then the energy stored will be insufficient to maintain an arc long enough to cause welding. Values of C less than 500 pF are safe in most cases. Between these 2 safe extremes, the transient voltage, when the contacts open, should be limited to keep the inrush currents below 1 A or, exceptionally, a value determined from a derived curve similar to that of Fig. 6, for the maximum voltage produced by the load coil and its quench.

Wear-out Mechanisms

When reeds switch loads that produce arcing, either on closure or opening of the contacts, the ultimate failure mechanism is failure to release due to the contacts locking. Locking occurs because material is transferred in the arc from one contact surface to the other, generally from anode to cathode, resulting in a crater on the anode and a pip, or



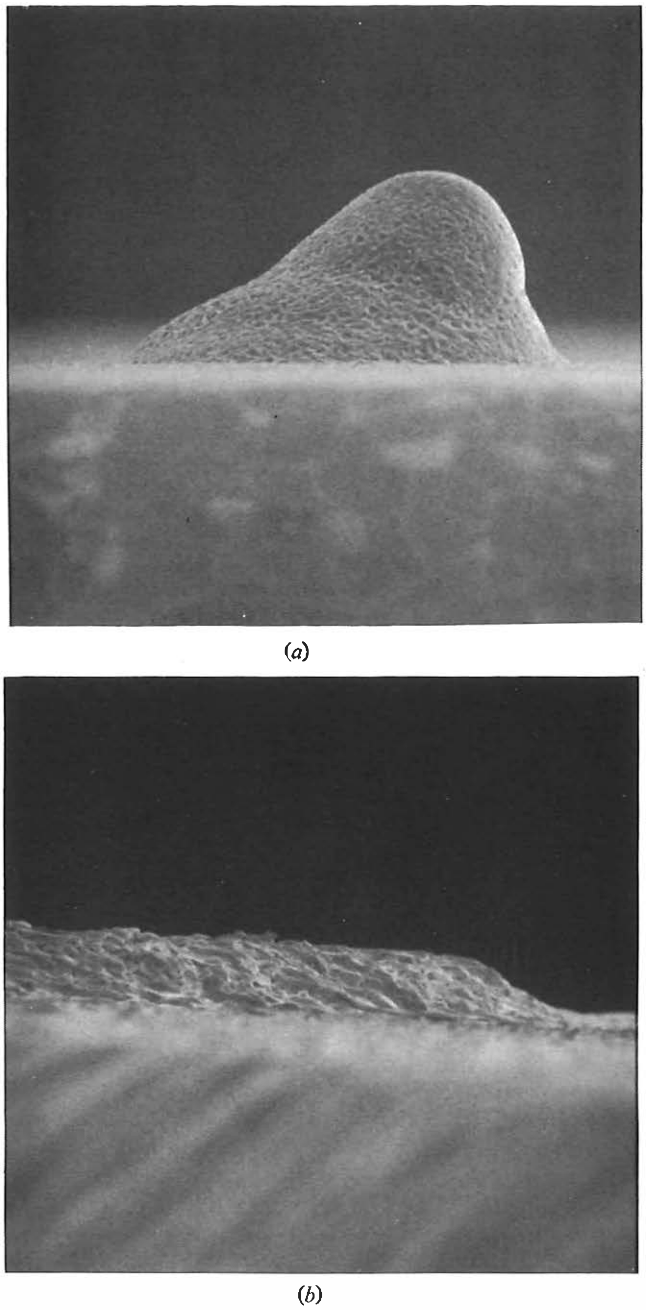
Notes: Drive conditions: test-reed in standard test coil (diode quenched)
Load condition: load current = 32 mA.
Oscillogram: expected voltage across contact = $\frac{dv}{dt}$ = 15 V/μs.
Vertical sensitivity = 50 V/division

FIG. 9—Laboratory simulation of reed reclosure after initial release

a *mesa*, on the cathode. The topography of the erosion determines the probability of locking on each operation. The topography is determined by the properties of the contact surface and by the electrical load. When erosion is concentrated in a small area of contact surface, a large pip forms on the cathode and is opposed by a deep hole on the anode. This erosion topography has, of course, a high probability of causing locking. If the erosion is spread over the contact surface, the resulting *mesa* and corresponding crater have a low probability of locking. Some examples of erosion topography are shown in Fig. 10.

There is evidence from life-test data that this wear-out mechanism is such that particular reed variants in particular electrical loads form a repeatable erosion pattern, and that this characteristic pattern is developed over a statistically definable number of operations. Once the characteristic form of the erosion has been produced, it does not change significantly to affect the probability of locking; thus the failure rate tends to a constant value. Such failure mechanisms may be modelled as Markov chains in continuous time and, in their simplest form, produce a gamma probability distribution of time to failure; that is, unlike the log-normal distribution whose failure rate rises to a maximum and then descreases to zero, the failure rate rises to a maximum and stays there. The useful lifetime of reeds in specific electrical loads may be defined as the number of operations during which the failure rate remains at an acceptable level, say 2% per million operations (the acceptable value depends on the operating rate).

The erosion pattern of diffused-gold contact units is



Note: Both examples are from switches that failed to release due to locking.
(a) Pip produced in laboratory (Magnification: × 795)
(b) *Mesa* produced in service in TXE2 (Magnification: × 2000)

Fig. 10—Examples of erosion topography

primarily affected by the amount of arcing, and for a particular load (for example, a cable terminated in a resistance) the useful lifetime is inversely related to the length of cable and the inrush current. However, the relationship is not simple, and is compounded with a relation to the value of current broken. In the case of good-plated reeds, the relationship between lifetime, inrush current, d.c., and the nature of the load, is even more complex; for example, increased arcing may decrease the failure-to-release rate in the wear-out phase to a value less than 2% per million operations, although contact resistance also increases. At this time, there is not yet sufficient data to enable a tabulation of lifetimes in various loads, but a research programme is now progressing aimed at characterizing reed lifetimes. In TXE2, the number of wear-out failures so far encountered, even in pulsing contacts in registers, has been small. This indicates that the dominant erosion pattern occurring in service is not pip and crater,

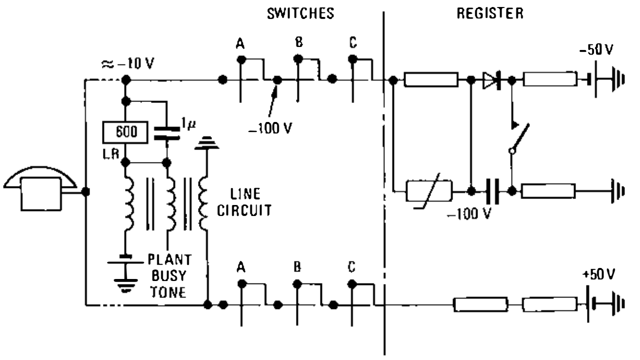


FIG. 11—Part of TXE2 register and loop-check circuit

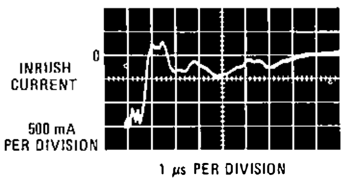


FIG. 12—Transient inrush current on closure of TXE2 A-switch negative contact

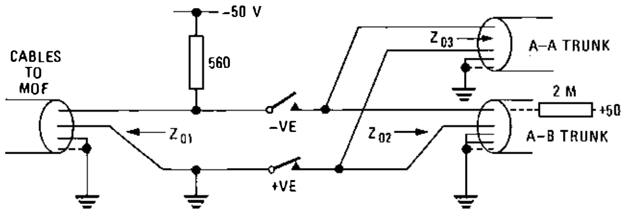
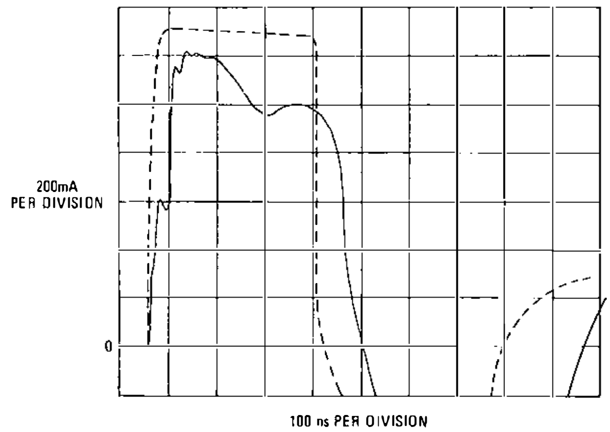


FIG. 13—Equivalent circuit of TXE4 A-switch negative contact



Note: Inrush current of BPO weld test

FIG. 14—Worst-case inrush current in TXE4 A-switch negative contact

but is usually a *mesa* formation, or that pip formation is very slow.

In the BPO reed specification, the wear-out failure mechanism is monitored and controlled by a full-load test in which reeds switch 100 mA (resistive load) with an inrush current peaking at about 700 mA in a first pulse of 40 ns duration. The test cycle is 1 million operations; generally the performance of reeds in this test is better than 1% failure.

EXAMPLES OF REED APPLICATION

In TXE2, almost half the total number of failures of the diffused-gold contact reeds have occurred in the A-switch negative contact due to inrush-current welding. A simplified circuit for an incoming call is shown in Fig. 11. When a customer's circuit loop is short, most of the voltage from the line circuit is developed across the coil of relay LR, and the line side of the A-switch negative contact is at, say, −10 V before closure of the contact. In the register, a voltage doubling circuit provides −100 V for a loop-check test. The crosspoint contacts close in the order C, B, A and, when A operates, the A-switch contacts close with about 90 V across them. A transient inrush-current results, and its magnitude and duration are determined by the surge impedance and time constant of the path involving the by pass 1 μF capacitor in the line circuit. A typical surge for a customer's short loop is shown in Fig. 12.

An in-service trial of a modification to this application has been successfully completed at 3 TXE2 exchanges. The modification is to delay generation of the register loop-check voltage until after the switched path has been established. The modification will be implemented on a national basis.

The A-switch negative contact in TXE4 is much less onerous an application than its counterpart in TXE2, and no in-service failures have occurred. However, as the TXE4 case illustrates different conditions which could be onerous, it is worthy of consideration.

An equivalent circuit of the TXE4 A-switch negative contact is shown in Fig. 13. It is assumed that the A-switch positive contact closes before the A-switch negative contact, (this is a matter of chance); the positive wire will be earthed, as will many other positive wires in the line-side cable to the MDF when the relevant circuits are in the idle state. When the A-switch negative contact closes, the resulting surge impedance towards the MDF has been shown, by measurement, to be as low as 45 Ω. On the exchange side of the A-switch, the cable branches into A–A and A–B trunks, and the resulting surge impedance at the branch points can be in the region of 50–70 Ω, being the impedance of Z_{02} and Z_{03} in parallel. The MDF side of the A-switch negative contact is at −50 V potential when the contacts close and a marker check-gate voltage, derived from a 2 MΩ source, raises the potential of the line-side cable network to +50 V. The resulting worst-case inrush current waveform is shown in Fig. 14; also shown in Fig. 14 is the inrush current that is applied in the new inrush-current weld-test, included in the BPO specification. It can be seen that there is a safe margin in the TXE4 application. However, longer cables or a 3-branch point (which never occurs in TXE4) might cause a serious problem.

Finally, as an illustration of the robustness of the 2·54 cm dry reed used in exchanges, it is worth mentioning pulsing contacts in TXE2. To take just one example, the pulsing-out contact (AA3) in the outgoing supervisory relay-set with metering-over-junction: the operating rate of this pulsing contact is about 1·5 million operations/year; the d.c. switched is about 40 mA, and inrush current is in the order of 100 mA. There have been very few reed failures in pulsing relays.

CONCLUSIONS

The main lesson to be learnt from the BPO experience of reed contact units in TXE2 and TXE4 telephone exchanges is that, however simple a component may appear to be, if large-scale production and application are intended, then an adequate system of quality assessment is required based on a knowledge of the intrinsic failure mechanisms and in the appreciation that things may unexpectedly go wrong. All aspects of the technology of reeds still need careful management; for example, the glass-to-metal sealing process is a delicate operation requiring a fine match of materials and a fairly critical setting of assembly machines. Thus, the quality-control function must be vigilant for changes in measured parameters and seek explanations even if the changes are ostensibly innocuous. A knowledge of the intrinsic failure mechanisms of key components must also be available to system designers so that the constraints on usage can be observed.

The performance of reeds within the last 5 years in TXE2 and, more recently in TXE4 exchanges, has demonstrated that failure rates of 0·1 per 1000 reeds per annum (about 10 failures per 10^9 component-hours) can be sustained.

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Feasibility Trial of Optical-Fibre Transmission System

UDC 621.391.63: 666.22

On the 4 February 1977, the first transmissions took place on an optical-fibre communication system between the British Post Office Research Centre, Martlesham Heath, and the Kesgrave telephone exchange, which is on the route to the group switching centre (GSC) at Ipswich. The complete system has now been installed as far as Ipswich and, after further evaluation of performance, the system will provide traffic circuits connecting the experimental telephone exchange using stored-program control* (Pathfinder) in operation at Martlesham, to Ipswich. The complete system will probably be the first optical-fibre system in the world to be used for live traffic.

The optical-fibre cable, which was manufactured by B.I.C.C. Telecommunication Cables Ltd., contains 2 Corning fibres; the loss of the cable is less than 5 dB/km when installed, and the bandwidth is greater than 300 MHz when measured over a length of 1 km. The cable was installed by staff of the Colchester telephone area in 1 km lengths in the existing duct network. Normal techniques of rodding and roping were used, and the cable itself was drawn satisfactorily into existing occupied ducts without mechanical aids. The cable was jointed by Research Department staff using a V-groove substrate to locate the fibre ends, and polyester epoxy resin as an index-matching fixative to prevent lossy discontinuities between fibre ends and to provide protection against moisture. The joints are housed in resin-packed sleeves.

The system equipment was built by Research Department staff and housed in 62-type racks, installed in the Ipswich and Kesgrave telephone exchanges and at the BPO Research Centre. At terminal and intermediate repeater buildings, the cable was installed in continuous lengths, from external duct to equipment racks via trunking, without additional internally-housed joints. The fibre ends were connected to the opto-electronic transducers (for example, lasers or light-emitting diodes (LEDs) and photodiode detectors) through demountable lens couplers that were designed in Research Department.

Binary transmission provides maximum repeater spacing in an optical-fibre system, but some redundancy is required to cater for monitoring facilities which enable the error-rate performance of the system to be recorded on a semi-continuous basis. For the feasibility trial, the system operates at 8 Mbit/s and provides 120 telephone circuits. In the initial tests, the attenuation between Martlesham and Kesgrave measured a little over 24 dB on each of the two 5·75 km fibre lengths, this level providing a very substantial margin of performance for the equipment; thus, to gain a near estimate of the maximum repeater spacing, the fibre was tested as a direct loop, providing a total length of 11·5 km and an attenuation of 50·5 dB. Under these conditions, the equipment recorded an error rate of better than 1 in 10^9, using lasers as the sources. On a single-way basis, a substantial margin was also obtained using the simpler LEDs, and a repeater spacing of at least 8 km may be possible using these devices.

The fibre used in the 8 Mbit/s experiment gave a frequency bandwidth of more than 100 MHz over the 6 km length. This was sufficient for operation at 140 Mbit/s, and so, as an additional experiment, laboratory equipment under development at the Research Centre was connected on 10 February 1977 to the system to allow transmission tests to be made at the higher bit rate. With suitable attenuation/frequency equalization to obtain optimum pulse transmission, the system provided a substantial operating margin, and repeater spacings greater than 7 km could be confidently expected. This latter experiment demonstrates the margin of bandwidth available; a system using the fibre at 8 Mbit/s will be principally attenuation-limited.

Another cable has now been installed between Martlesham and Kesgrave to allow experiments at 140 Mbit/s and above to take place. Its bandwidth, as measured, is greater than 140 MHz and the attenuation is of the same order as that of the 8 Mbit/s fibre.

The experiments so far have demonstrated that optical-fibre systems can be developed for implementation in the junction network, and indicate the possibility of considerable savings by the use of existing ducts and in the provision of non-repeatered junctions for the future digital network. At the higher bit rates, there is promise of repeater spacings of about 7 km using a multifibre cable having a cross section of less than 10 mm.

Full details of the installation and transmission performance of this experimental optical-fibre system will be the subject of articles in later issues of this *Journal*.

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* An article in this issue of the *Journal* (p. 68) describes the operation of the Pathfinder stored-program-controlled exchange

Meteorological Operational Telecommunications Network: Europe

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UDC 551.5:659.2:621.39

This article describes the network structure and operational facilities of a European meteorological information system. Also included is a description of the loop-switching equipment designed by the British Post Office for use at the interface of the UK and European distribution networks.

INTRODUCTION

In 1965, the International Civil Aviation Organization defined the structure, technical parameters, and operational facilities and procedures for meteorological information networks. A European network was planned to conform with the international standards, and the network was to become known as the Meteorological Operational Telecommunications Network: Europe (MOTNE). The object of MOTNE was to provide a common pool of meteorological information, to which all participating countries could contribute, and from which they could obtain, current meteorological information. The structure of the MOTNE linked European and Middle Eastern countries. At selected centres, facilities were to be provided for the distribution of information to national networks. In 1966, the British Post Office (BPO) undertook the design and implementation of the UK network on behalf of the, then, UK Ministry of Aviation.

The MOTNE system became operational in July 1968, and provided a vast information gathering and distribution network which covered the major centres of Europe and the Middle East; in all, the information was distributed to 39 countries. The modulation rate of the system was, originally, 50 bauds.

The MOTNE system operated successfully until 1974 when it became clear that the traffic-carrying capacity was inadequate. At the request of the UK Civil Aviation Authority (CAA), the BPO was responsible for the redesign of the switching equipment at the UK interface of the international and national distribution networks. The switching equipment was redesigned making use of modern technology, and the modulation rate of the MOTNE was increased to 100 bauds.

THE MOTNE SYSTEM

Structure of the Network

The MOTNE system is based upon a duplex telegraph circuit that links 9 major European centres. The circuit is routed on multi-channel voice-frequency telegraph systems, and the arrangement of the network is shown in Fig. 1. Within the network configuration there are 2 unidirectional circuit loops, designated *Loop 1* and *Loop 2*.

Loop 1 connects London–Brussels–Amsterdam–Offenbach–Vienna–Zurich–Paris. There are 2 spur connexions from Loop 1: the first connects London–Copenhagen–Offenbach; the second connects Vienna–Milan–Paris.

Loop 2 connects London–Paris–Milan–Vienna–Offenbach–Copenhagen. There are 2 spurs off Loop 2: one connects Paris–Zurich–Vienna; the other connects Offenbach–Amsterdam–Brussels–London.

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The structure of both circuit loops is such that, should a break occur in a transmission path, the loop can be automatically reconfigured to bypass the break. At each MOTNE main station, loop-intercept facilities are provided to enable information to be inserted. In addition, a means of removing information for distribution to national networks is also provided.

Distribution to National Networks

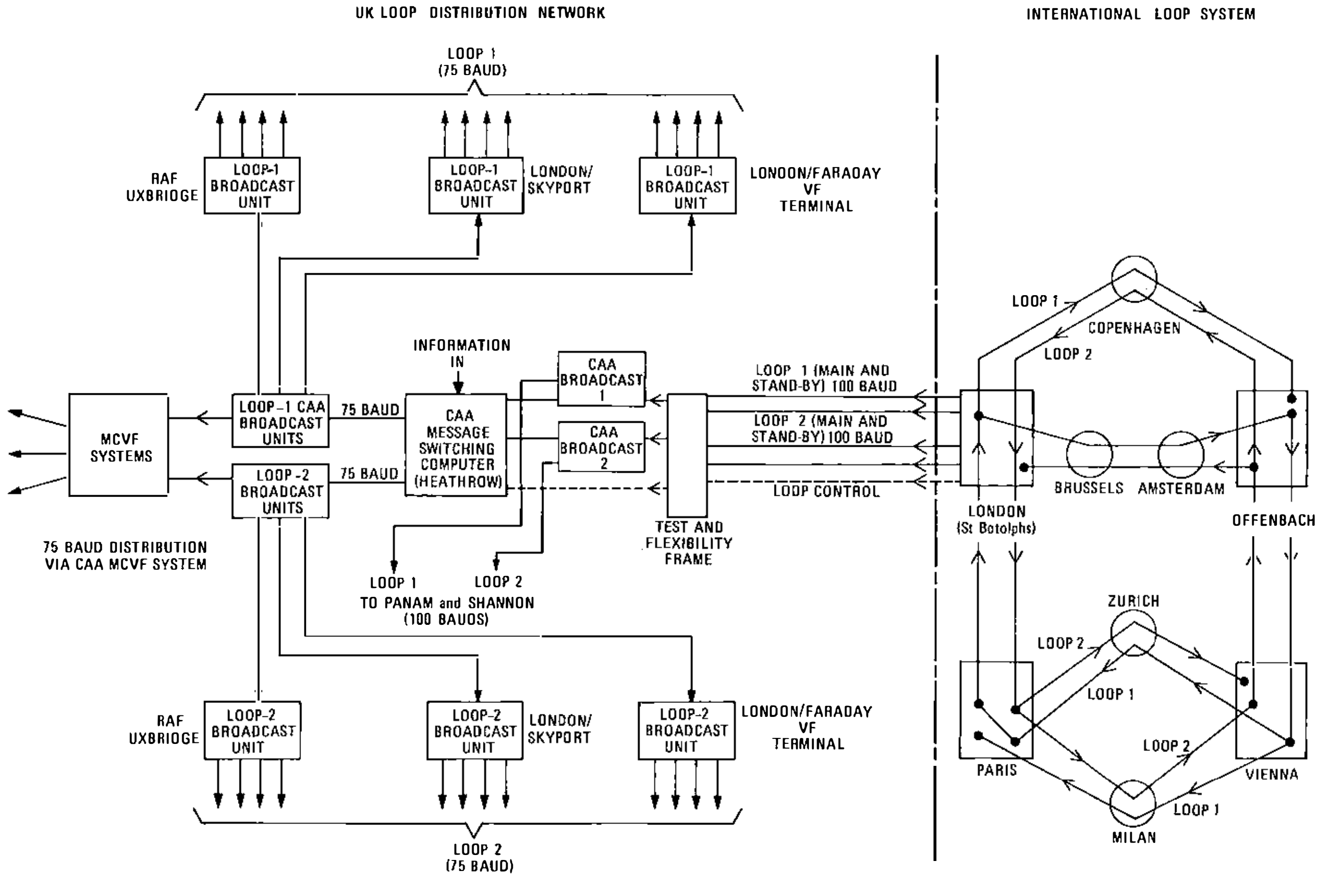
Distribution of meteorological information to national networks is effected from the MOTNE main stations. In the UK national network, the information is distributed using telegraph broadcast units. These units accept one input message and provide 5 simultaneous output messages. An output feed from a telegraph broadcast unit can be connected to the input of a similar unit; in this way, multiple feeds are derived and are distributed to airfields throughout the country. At the receiving terminals, the message content is reproduced on teleprinters. The transmission paths to a particular receiving station may include multi-channel voice-frequency telegraph systems. A typical distribution arrangement is included in Fig. 1.

System Operation

The traffic-carrying capacity of MOTNE is 2 erlangs and the meteorological information is transmitted using telegraph characters specified by the International Alphabet No. 2; the modulation rate was 50 bauds but is now 100 bauds. The transmission performance characteristics of the MOTNE circuit loops are maintained by the use of regenerative repeaters; however, to ensure that the propagation delay of the network is kept to a minimum, the regenerators operate on an element basis rather than a character basis. The injection of information into the circuit loops is effected by relaying techniques which ensure that contributors conform to the requirement that national networks must not introduce distortion, nor cause interruption to the main network. Similarly, when information is taken from the MOTNE for national distribution, there must be no adverse effects on the performance of the main network.

When the MOTNE circuit loops are not carrying information the loops remain closed. To prevent spurious signals circulating within the circuit loops, spurious-signal detectors are provided that open the loops momentarily.

The MOTNE circuits are monitored at selected stations to detect the presence of information on spur and main circuit loops; for example, on Loop 2, monitoring occurs at London, Paris, Offenbach and Vienna. If a main loop is not carrying information, but information is detected on a spur then, provided that this condition persists for more than 10 s, a break of the main loop is indicated, and the spur is connected to the



Note: Loop switching equipment situated at London, Offenbach, Paris and Vienna

Fig. 1—M●TNE loop system

outgoing loop to maintain service. For this condition, and for failures of station equipment, local alarms are activated.

Transmission of Bulletins

Meteorological information is transmitted in the form of bulletins. Each bulletin includes a *start-of-message*, and an *end-of-message*, signal sequence. Each station on the MOTNE circuit loops is allocated time, in a half-hourly schedule, in which to transmit a number of bulletins. The average time taken to transmit a bulletin is 2 min. A 7 s delay between each bulletin enables other stations to access the loop for priority messages. To insert a message on a circuit loop, the station wishing to transmit a bulletin opens the loop; the incoming side is terminated and a *start-of-message* signal is sent on the outgoing circuit path. The *start* signal is transmitted around the circuit loop and, if detected on the incoming side, the continuity of the loop is established and the bulletin may be transmitted.

Non-scheduled or priority bulletins have a level of priority inserted in the *start-of-message* signal sequence; also included is a number that identifies the sending station. A station wishing to send a non-scheduled or priority bulletin waits for the *end-of-message* signal sequence on the current bulletin, the loop is then opened and the incoming side is terminated. The *start-of-message* signal sequence is transmitted on the outgoing side and, if the loop is established, the bulletin may be transmitted. A different *start-of-message* signal sequence received on the incoming side indicates that another station wishes to transmit. Preference is given to the higher-priority message; however, if the priority categories are equal, the station number is examined, and the station having the lowest number is given priority to transmit.

Stations on the spur circuits that wish to send bulletins in the direction of an unconnected end of a spur are able to prefix the bulletin by a 4-character code, which is identified by the main switching stations (London, Offenbach, Vienna and Paris), and the spur is connected to the loop.

Modulation Rate

By 1974, the traffic-carrying capacity of the MOTNE was found to be inadequate. Therefore, it was decided to double the modulation rate from 50 to 100 bauds, and thus double its traffic-carrying capacity. This decision posed some problems for national administrations because the existing MOTNE equipment and its distribution system required modification to be compatible with the new modulation rate.

At the time of the decision to increase the modulation rate, the UK CAA decided to install a message switching computer that would also control the loop-switching circuits. As a result of these changes the BPO redesigned the loop-switching equipment for 100 baud working and greater reliability, thus allowing the CAA to provide a 100 baud service to customers willing to accept it, and to distribute a 75 baud service to other customers. The 75 baud output was to be obtained from the CAA message switching computer.

THE UK 100 baud LOOP-SWITCHING EQUIPMENT

The loop-switching equipment provides facilities that permit the CAA at Heathrow airport to access, supervise, monitor and control the information-carrying loops. A block diagram of the switching equipment associated with Loop 2, is given in Fig. 2. The equipment comprises input and output change-over units, input interface units, loop 1 and 2 logic units, character-detection units and line-output units.

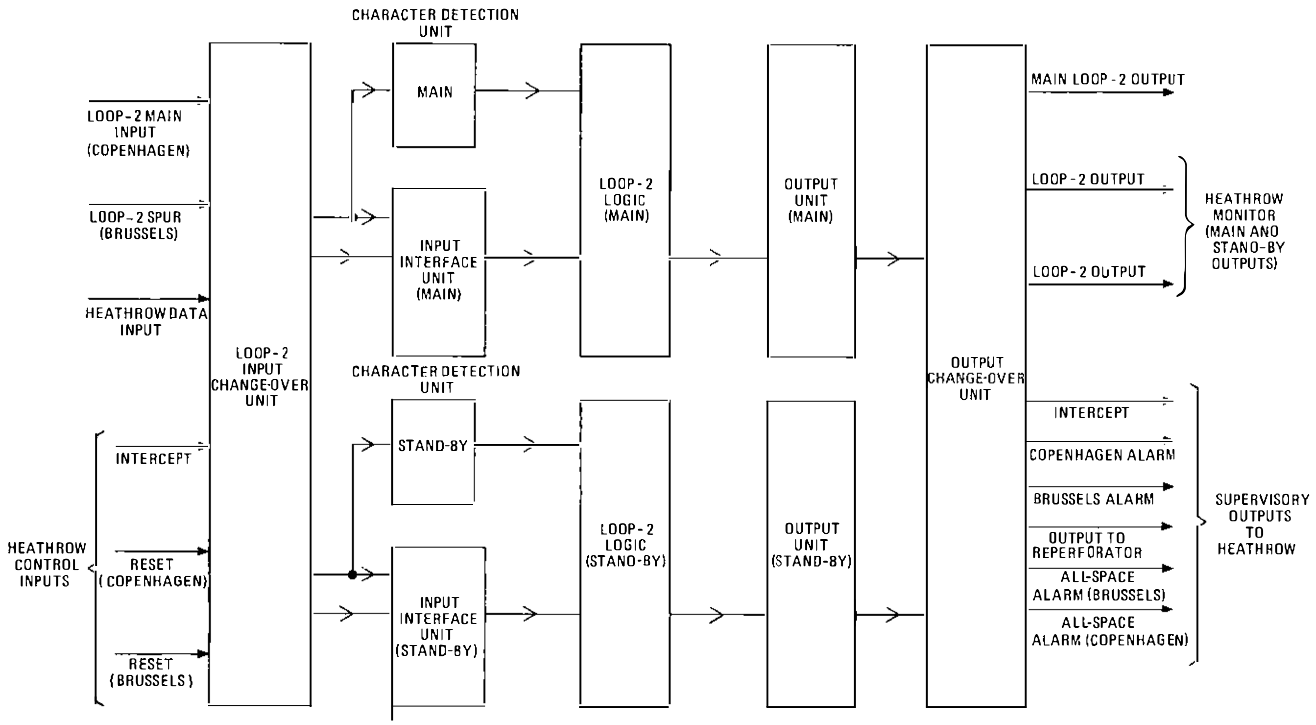


FIG. 2—Block diagram of loop-2 switching equipment

The purpose of each of these units is as follows.

Change-over Units
The change-over units, which use BPO Type 23 relays and Type 2000 keys, provide the facility to switch, manually, from main to stand-by equipments for loops 1 and 2.

Input Interface Units
The input interface units convert ±80 V line signals on the data and supervisory inputs from Heathrow to logic levels. All line inputs are terminated in an impedance of 4 kΩ. Operational amplifiers are used in the interface units in 2 basic circuit configurations: the open-loop comparator, and a comparator with Schmitt trigger action. Control inputs have ±30 V d.c. thresholds, and a capacitive-resistive filter circuit at each input provides immunity to a.c. noise spikes greater than 30 V. The data inputs from Heathrow have 0 V thresholds but other inputs, including the loops, have ±20 V thresholds.

Voltage thresholds are necessary on control inputs to provide a margin of d.c. noise immunity under open-circuit input conditions, thus preventing timing circuits being activated by induced noise signals.

Loop 1 and 2 Logic Units
The logic units provide the main intelligence functions of the control system. They accept data and control signals from the interface units, and transmit supervisory and data signals to the output units.

Character-Detection Units
To enable spur stations to intercept a main loop, a sequence of 4 consecutive *G* characters† is sent from the spur station. At the parent main station, this signal sequence is detected by a character-detection unit which sends a control signal to the logic units to initiate the setting-up of the required connexion. On receipt of 4 consecutive *N* characters*, the character-detection unit resets, and the connexion is restored.

† International alphabet No. 2, character combination No. 7
* International alphabet No. 2, character combination No. 14

Output Units
The supervisory, monitor and data outputs from the logic units are derived from logic buffers that act, in a push-pull mode, as relay drivers. The signals from a logic unit operate mercury-wetted relays in an output unit that transmits ±80 V telegraph signals to line.

Design Parameters

To ensure continuity, the out-of-service time of the MOTNE circuit loops, due to faults in the loop-switching equipment, must be kept to a minimum. To achieve this, the loop-switching equipment has been designed using worst-case design techniques, and all components are of high reliability and dual sourced. Station d.c. supplies are used to power most of the equipment. The equipment is provided in duplicate and is operated on a main and stand-by basis; either of the equipments may operate as the main. On discovery of a fault in the main equipment, the manual operation of keys replaces the main equipment with the stand-by equipment, thus giving minimum interruption to service, and allowing the fault on the main equipment to be cleared.

The loop-switching equipment has been manufactured in the BPO 62-type construction practice, and occupies 2 shelves of a 62-type rack (see Fig. 3). To keep costs as low as possible, an existing a.c. powered unit, the Unit Telegraph 35D, was incorporated in the design and is used to perform the character-recognition functions. The logic power supply is derived using an on-board Zener regulator, operating from −50 V and −80 V supplies.

To minimize noise problems, special attention was given to separating the ±80 V signals from the logic circuitry during the design of equipment layouts and printed-wiring boards.

THE CHOICE OF TECHNOLOGY

The loop-switching equipment embodies a wide range of technologies. The character-recognition unit uses diode-transistor-logic (DTL), and operates from its own power supply. Bipolar operational amplifiers are used at the interface of ±80 V telegraph signals and the loop-switching equipment. The design of the logic units uses complementary-

TABLE 1

Comparison of Noise-Immunity Performance for Logic Devices

Logic Family	Supply Voltage (V)	Propagation Delay (ns)	Signal-Line DC Noise Immunity (V)		Signal-Line Impedance (Ω)		Typical Energy Noise Immunity (J)	
Logic Condition			Low	High	Low	High	Low	High
DTL	5	30	Min 0·7	Min 0·7	50	1·7k	3	1·5
TTL	5	10	0·4	0·4	30	140	4	2·5
CMOS	5	45	1·5	1·5	600	1·2k	3	1·5
CMOS	15	12	4·5	4·5		450	22	13

metal-oxide-semiconductor (CMOS) integrated circuits, and the ±80 V output signals are generated using CMOS-driven mercury-wetted relays.

Two major factors influenced the choice of CMOS technology; these were,

(*a*) the need for good noise-immunity, and

(*b*) the need to keep current to a minimum, thus simplifying power supply arrangements.

Noise Immunity

Noise immunity depends on many parameters; for example, supply voltage, stray capacitance, stray inductance, fan-in and fan-out capacitances, and the source of the noise and its signal shape. Immunity to noise is characterized in terms of noise-voltage pulse width, and this naturally favours logic families such as CMOS with high threshold voltages. To assess the degree of noise immunity, factors such as device output impedance and speed of the logic family must be taken into account. For instance, a device with a low threshold voltage and a low output-impedance may have a better energy noise immunity than a device with a high threshold voltage and a high output-impedance. For the design of the loop-switching equipment, noise immunity was defined in terms of the total noise energy needed to cause a faulty output.

To give an indication of the superior performance of CMOS integrated circuits in terms of voltage and energy noise immunity, some comparison must be made with other logic families. From Table 1, which gives some typical figures for transistor-transistor logic (TTL), DTL and CMOS devices, it can be seen that CMOS devices have extremely good voltage and energy noise immunity when operated with a supply voltage in excess of 5 V

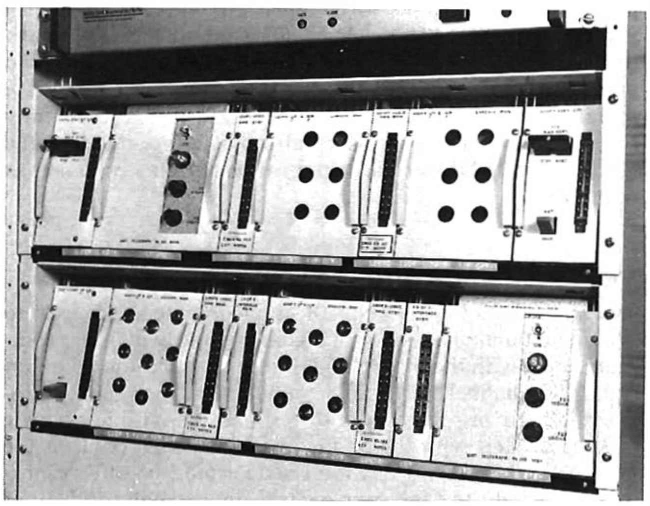


FIG. 3—Loop-switching equipment

Power Dissipation in CMOS Devices

Power dissipation in CMOS devices may be considered in 2 parts: static power dissipation and dynamic power dissipation.

Static, or quiescent, power dissipation (P_Q) is due to leakage currents in the parasitic diode and is very small, typically being in nanowatts.

Dynamic power dissipation is caused by 2 effects: power dissipation due to a through current (P_{TC}) when a gate is operating in its linear region, and power dissipation due to the charging of internal and external load capacitances (P_L). The through current depends on the supply voltage input rise and fall time, output rise and fall time, and input frequency. With input rise times in the order of 20 ns, this component is insignificant. The component of dynamic power dissipation due to the charging of load capacitance can be represented by the relationship

$$P_L = CV^2f \text{ watts,}$$

where C is the load (plus internal) capacitance, V is the supply voltage, and f is the frequency of the input waveform.

Thus, power dissipation increases linearly with load capacitance and frequency, and as the square of the supply voltage. Total power dissipation (P_T) is given by the expression

$$P_T = P_Q + P_{TC} + P_L \text{ watts.}$$

The loop-switching equipment, which is designed to operate at 100 bauds (50 Hz), has gate input rise times (except for timing and interface circuits) in the order of 20 ns and has a dynamic power dissipation of less than 4 μW/gate. The low power requirement of the logic circuitry, coupled with the wide operating range of supply voltage, makes the use of simple on-board Zener regulators possible.

Input Impedance of CMOS Gates

CMOS gates have an input impedance in the order of 10 TΩ, and this makes them ideal for use in analogue circuits. The loop-switching equipment includes timing circuits that use CMOS gates which give time-outs ranging from 200 ms to 10 s.

The Use of Mercury-Wetted Relays

To transmit telegraph signals and supervisory conditions to line, a conversion from the logic levels to ± 80 V is necessary. Transistor and mercury-wetted relay output stages were considered but, for modulation rates up to 100 bauds, the mercury-wetted relay was selected as the most cost-effective solution.

The type of mercury-wetted relay selected has also been specified in the design of a new BPO telegraph broadcast unit and has a dynamic current rating of 1 mA making it suitable for being driven from CMOS buffers. The driving gates are protected from back-e.m.f.s by a simple capacitive-resistive circuit fitted across the relay coil.

The mercury-wetted relay is an extremely reliable device having a life expectancy of some 25×10^9 operations; the contacts, which are rated at 100 VA, have a make-before-break action and are bounce free. Output telegraph distortion is guaranteed to be less than 2% at 100 bauds. Care was taken to ensure that contact protection was applied; failure to do so would have resulted in greatly reduced contact life.

CONCLUSION

To accommodate an enhanced modulation rate for MOTNE, BPO staff designed and installed loop-switching equipment that takes full advantage of the use of advanced technology in regard to speed of operation, equipment reliability and reduction of equipment size. The experience gained from this project by BPO development staff will be invaluable for further development, the production of specifications and the assessment of proprietary equipment. The introduction of advanced technology in this small system should also provide experience for maintenance staff.

Traffic Recording Facility for the SPADE Communication-Satellite Terminal

J. P. WROE, B.A.†

UDC 621.396.946: 621.395.31

The need for special traffic recording facilities for the SPADE terminal and the method of providing these facilities are described.*

INTRODUCTION

The global communication-satellite network uses frequency-modulated carriers with basebands varying in size from 24–1332 telephone channels, the smaller capacity carriers being relatively wasteful in the use of satellite power and bandwidth. The SPADE[1] terminal was installed at the Goonhilly satellite earth station in Cornwall by the Nippon Electric Company of Japan in 1973, and works through the third aerial at Goonhilly to the Atlantic primary INTELSAT IVA satellite. The SPADE system provides more efficient use of the space sector on routes with low traffic levels. This improvement is achieved by using a voice-actuated carrier for each channel and by allocating, under processor control, satellite carrier frequencies in such a way that a communication path is established only when required by an actual call; that is, the radio-frequency carriers are assigned on-demand to telephone channels.

This demand-assignment feature of the SPADE system makes it impossible for the international accounting and traffic-analysis equipment[2], installed at the Wood Street International Switching Centre in London, to obtain all the information about each of the routes operated via the SPADE system. Total traffic times for accounting purposes are measured by the INTELSAT Management Services Contractor (COMSAT), using a special SPADE terminal that monitors the common signalling channel, a time-division multiple-access channel that links all SPADE terminals in the system. As the British Post Office did not have the means to check the COMSAT figures, nor to determine either the proportions of traffic on various routes or the engineering performance of the system, suitable facilities were recently provided using the processors already incorporated in the Goonhilly SPADE terminal, the software being modified as necessary.

TRAFFIC RECORDING FACILITIES

Two processors (VARIAN 620F minicomputers) are used to provide redundant control of signalling and switching, communicating with the other SPADE terminals via the common signalling channel. Both minicomputers hold the same program in their respective core stores, and the off-line machine is kept in step with the on-line machine which controls the system; in this way, if any fault is detected, the off-line processor is ready to take over control immediately and automatically.

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* SPADE: Single-channel-per-carrier, pulse-code-modulation, multiple-access demand-assignment equipment

The operational program is provided by COMSAT in the form of binary data on magnetic tape (assembled from a source program in the machine's assembly language), and is occasionally updated and re-assembled by COMSAT to cater for new terminals and routings. Therefore, the program modification required to provide traffic recording facilities could not be integrated into the main program before assembly; it had to be assembled separately. Furthermore, the additional program had to be sufficiently flexible to allow for adaptation to changed operational programs with the minimum of effort, and certainly without the need for re-assembly. This meant that the additional program had to remain fixed in the memory.

To provide sufficient core storage for call data, and to ensure that future versions of the operational program did not overwrite the additional program, additional memory was installed in each processor, bringing the core store sizes up to 16 kwords and allowing the additional program to be located in the extra memory.

Preparation of the additional program was made easier by the use of a third minicomputer at Goonhilly (a VARIAN 620L machine) normally used for analysis of interference data, and equipped with disc storage, magnetic tape and line-printer facilities. Program editing and assembly could, therefore, be achieved with the aid of an operating system without hazard to the traffic carried by the SPADE system. Magnetic tape was used to transfer the program in binary form to the SPADE system for debugging before a corrected version was assembled in its final form.

The additional program essentially forms an extension to the base-level routines of the original program, several memory locations of which must be changed to incorporate the new program. To cater for possible changes in the addresses of flags or tables in subsequent editions of the main program, all reference to them from the additional program is via a table of main program addresses, using post-indexed, indirect addressing methods. Thus, when a new operational program is received from COMSAT, the only work necessary to integrate the 2 programs is to change a few memory words in the new operational program and adjust the reference table.

Print-Out Facilities

In addition to accumulated traffic times, the following information for each call can now be printed-out by a teleprinter:

(*a*) time (GMT),
(*b*) call duration,
(*c*) local access-circuit number,
(*d*) call direction (incoming or outgoing),
(*e*) satellite-circuit number,
(*f*) distant-terminal number,
(*g*) distant access-circuit number,
(*h*) digits dialled, and
(*i*) call-state sequence.

Maintenance Aids

While these facilities were being provided, the opportunity was taken to include several additional maintenance aids; teletype commands were added to those normally recognized by the processor, enabling call data to be obtained when required, the content of individual memory locations to be checked or changed without interrupting normal operation, and the processor to be restarted more simply following certain more frequent types of failure.

CONCLUSION

Two main difficulties were encountered during the installation of the SPADE traffic recording facilities. Firstly, use of the slightly different VARIAN 620L computer to assemble the program was not straightforward. Its standard software ("stand-alone" programs and on-line operating system), together with high-speed peripheral devices, greatly simplified source program preparation, editing and assembly, but handling the binary data was difficult because of the fixed memory location of the call-recording program coinciding with the core-resident parts of the operating system. Secondly, the need to design the new program around the existing automatic and manual computer change-over philosophy required special attention to prevent the coding from becoming over-complicated.

The work was, however, completed on schedule and this can be attributed to the close co-operation of the maintenance and development staffs at Goonhilly.

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Book Review

Telegraphy. R. N. Renton, C.G.I.A., C.ENG., F.I.E.E. Pitman Publishing Ltd. ix + 407 pp. 315 ills. £11·90 (paperback: £8·90).

This is the latest volume to bear this title in an honoured line stretching back through Freebody's work (1958) to Herbert's, which was first published in 1906.

Essentially, the approach throughout has remained the same: expositions in some depth of the techniques and hardware currently in use by the British Post Office, although the present author has attempted to include a selection of equipment in use elsewhere.

The chapters covering basic principles and theory are adequate if somewhat abbreviated, but the sections on codes, alphabets and telegraph distortion are particularly informative.

A major difficulty in the preparation of a volume of this nature is the inevitability of hardware changes, and concentration on specific equipment has lead to a number of unfortunate omissions. Telegraph time-division-multiplex equipment, operating as an alternative to pulse-code-modulation over a digital line system, has been around for some time, as has the Creed A2300 semi-electronic teleprinter. Earlier this year, the largely electromechanical automatic system for handling overseas telegrams was replaced by a computer-based fully-electronic system, and a processor-based private automatic telegraph exchange became available.

One is still left in some doubt about the present-day value of the extremely detailed contact-by-contact operation of obsolescent electromechanical equipment.

In summary, this is a useful reference book for students and many workers in telecommunications, and a good companion volume to the author's earlier books.

R. W. B.

STD Goes Over the Sea to Skye

A. FERGUSON, C.ENG., M.I.E.E.†

UDC 621.395.344:654

In 1964, a plan was formulated to modernize the telephone service throughout the Highlands and Islands of Scotland, ensuring that service in the most remote areas would be equal to that in any of the large cities. The programme culminated last year in the closure, at Portree, of the last manual exchange in Britain.

INTRODUCTION

At 11.27 on Thursday 14 October 1976, the final call on the 10-position CBS2 switchboard at Portree, on the Isle of Skye, was completed. Two minutes later, a modern crossbar exchange (TXK1) was brought into service for the 440 subscribers in Portree.

That final call marked the end of an era in the history of the British telephone service, for Portree was the last manual exchange in service in the British Isles. Fig. 1 shows the switchboard on the day of the transfer.

For nearly 100 years, ever since the first manual exchange was installed in 1879 at Coleman Street, London, manual exchanges were a mainstay of the telephone system. At these exchanges, a team spirit was engendered between operators and engineers, and all had a sense of belonging to the community; in many cases, telephone numbers were less important than names. The progressive replacement of manual exchanges has been a quiet revolution, paving the way for a smooth transition to full STD.

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HISTORY OF PORTREE EXCHANGE

The history of Portree exchange is typical of many others throughout the Highlands and Islands of Scotland. The first exchange was opened in 1926 at 1 Wentworth Street—the home of the first operator, 15-year-old Helen Nicolson. With occasional assistance from her parents, Helen gave a round-the-clock seven-days-a-week service for a weekly wage of 17/9d. There were 20 connexions when the exchange opened, and Helen, now Mrs. Helen Ramage of Bearsden, Glasgow, can recall quite vividly some of the original subscribers. Colonel Jock MacDonald, of Viewfield House, was one of the original twenty and, from the opening date in 1926 until the final day in October 1976, he asked for his calls in Gaelic.

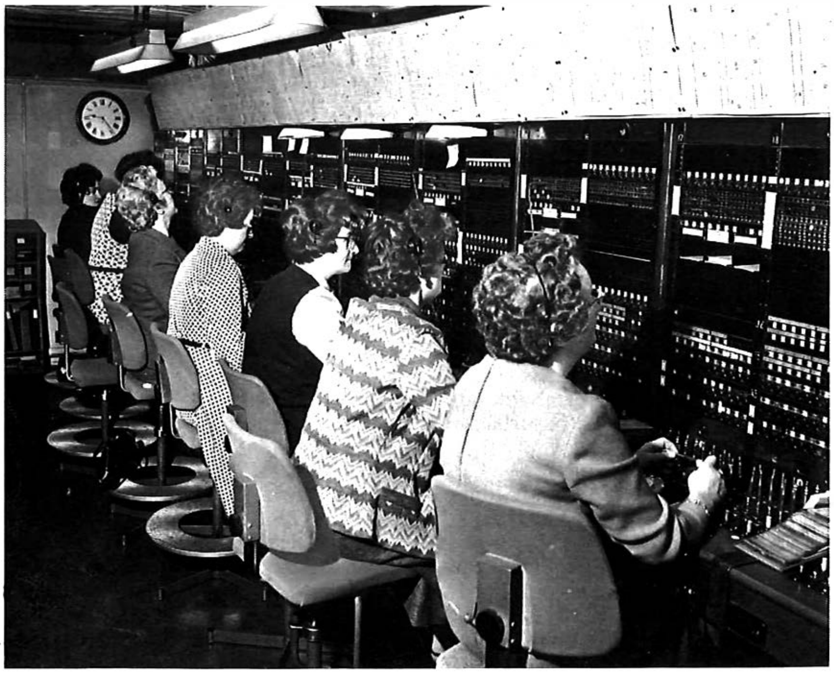


FIG. 1—Portree CBS2: the last hours of Britain's last manual exchange

(Photograph by Capital Press, Edinburgh)

Fig. 2—The wooden huts housing Portree CBS2

(Photograph by Capital Press, Edinburgh)

Fig. 3—Portree TXK1 GSC

(Photograph by Capital Press, Edinburgh)

In May 1947, the exchange in Wentworth Street was closed. A new 5-position CBS2 was opened in Bridge Street, accommodated in wooden huts (see Fig. 2) that had previously been occupied by the Army during the war years. This exchange was expected to meet needs for the following decade. With the steady growth of traffic and connexions, additional positions were added until, finally, 10 CBS2 positions served 440 customers in Portree, and 13 dependent rural automatic exchanges in the north and west of Skye. At its closure in October 1976, this exchange had outlived its expectations by 19 years.

THE NEW EXCHANGE

The manual exchange was replaced by a TXK1 group switching centre (GSC) and local exchange. Considerable difficulties were encountered in obtaining a site for the new exchange. The site finally acquired was in Shulishadder Road, 700 m from the old manual exchange. A standard H-type building was designed by the Department of the Environment, and sufficient ground is available for a substantial building extension in the future. There were no unusual problems during construction, and the building, exchange manhole and 24-way lead-in duct were completed by a local contractor in December 1973.

In February 1974, the main equipment contractors commenced installation of the TXK1 GSC and local exchange, providing an initial multiple capacity of 1000 lines.

The conversion to STD working of the 13 dependent exchanges in the north and west of Skye was a unique organizational exercise. Apart from Portnalong and Dunvegan exchanges, which were already unit automatic exchanges No. 13 (UAX 13s), all were UAX 12s. Subscribers on these exchanges were transferred to new adjacent UAX 13s having full STD facilities and pay-on-answer coin-collecting-box lines. At the time of the transfer, there were 880 working lines served by the dependent exchanges.

The installation and testing work at the dependent exchanges was carried out by teams of exchange-construction engineers from Manchester, Preston, Lancaster, Edinburgh and Inverness. Travelling from Portree to these exchanges, the teams were appreciative of the opportunity to view some of the most magnificent scenery in the Highlands and Islands. Regrettably, the opportunities were too few: Skye is aptly called the Misty Isle.

The GSC was completed in August 1976, following a successful call-through test. The overall cost of the modernization, including that of the dependent exchanges, was £606 000: about £466 for each of the 1300 customers served by the GSC. Fig. 3 shows the new exchange.

During September 1976, the dependent exchanges were progressively parented on the new GSC. The combined testing team, of engineering and traffic staff, did an excellent job, working to a very tight schedule. By the beginning of October, customers served by the dependent exchanges were enjoying full STD facilities via the new GSC. To obtain operator assistance or calls to Portree, customers now dialled 100, which routed them to the auto-manual board at Kyle of Lochalsh, their new parent manual board. Portree calls were extended back on temporary trunk lines.

The new GSC was then subjected to further proving tests, and by the transfer date for Portree customers (14 October), there was every confidence in its operational efficiency.

An exhibition on the theme of past, present and future communications was held in the Skye Gathering Hall, Portree, between 5–14 October, and created considerable interest. Following the successful transfer, an open day was held at the new exchange on 15 October, and this was well attended by many customers from throughout Skye.

Main-Network Routes

Main-network lines from Portree are routed over coaxial-cable systems and radio links. From the new exchange, a coaxial cable is routed to Skriag radio station, on the outskirts of Portree. From Skriag radiate three 300-channel radio links. One is directed to Kyle of Lochalsh on the mainland. Over this system is routed the assistance traffic from Portree and its dependents to the auto-manual centre at Kyle. A second link is directed to Melvaig radio station, further north on the mainland, and thence by coaxial-cable system via Gairloch to Inverness. Main-network routes are provided over this system from Portree to Inverness and Glasgow. The third link from Skriag is directed to Scoval in the west of Skye, with links beyond to Benbecula and Harris in the Outer Hebrides.

THE HIGHLANDS AND ISLANDS SCHEME

During the period of rapid expansion of the national telephone system in the 1950s and early 1960s, priority was inevitably given to the bigger towns and cities. In Scotland, however, the British Post Office (BPO) was faced with a unique problem in the north and west. Along the rugged

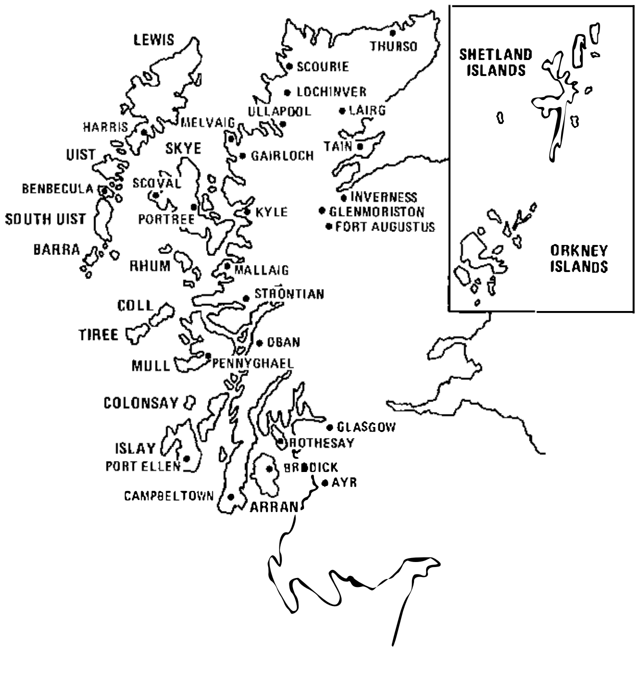


FIG. 4—The north and west of Scotland, and the Western Isles

coastline, there are hundreds of islands, 150 of them inhabited. Throughout the vast territory of the mainland, there is a multitude of villages and crofting communities. They are remote and scattered, with mountains, lochs and sea creating natural barriers to a telecommunication network. Fig. 4 illustrates some of the geographical features of the north and west of Scotland. Many of the hundreds of small exchanges were single-position manual switchboards situated in sub-Post Offices, shops and homes. Some were served by single-channel radio links.

The BPO accepted a social obligation to provide a modern telecommunication system throughout the Highlands and Islands, with STD facilities and transmission standards comparable with those elsewhere.

In 1964, a scheme was formulated for the conversion of remote manual exchanges: the *Highlands and Islands development scheme*. The plan embraced a backbone network of coaxial-cable systems, broadband radio systems and 18 GSCs, 8 with auto-manual switchboards. The cost of the scheme was originally estimated as £6·5M.

The main artery of the network was to be a coaxial system from Inverness to Ullapool and Gairloch. The route distance is nearly 200 km. Completion was delayed by extensive road works, mainly consisting of converting single-track roads to double-track. To the north and west of this system, the terrain in the mainland is unsuitable for burying cable. Roads are carved through rock for great distances. Main-network and junction routes therefore had to be provided over 300-channel radio links. Similar radio links were used for most of the islands, with some 6-channel ultra-high-frequency radio systems on low-traffic routes.

A major feature of the Highlands and Islands scheme was the building of 56 radio stations and access roads on the islands and in the remote north-west area of the mainland. Modernization of the Highlands and Islands telephone service was finally completed on 2 March 1977, with the provision of STD facilities and pay-on-answer coin-collecting boxes at Glenmoriston and Fort Augustus exchanges, near Inverness.

Service Aspects

Maintenance problems, likely to arise because of the remoteness of sites and the problem of travelling to islands, were very much in mind when the transmission and switching networks were planned and designed. Reliability was an important consideration.

The Inverness–Ullapool–Gairloch coaxial system has had no failures on the main section from Inverness to Ullapool since December 1974. The Ullapool–Gairloch section, however, is a lightning-prone area, and has suffered on a number of occasions from lightning storms. Additional lightning-protection devices have now been added to this section.

The 300-channel radio systems operate in the super-high-frequency band at 4 GHz. Main and stand-by (protection-channel) transmitters operate on separate frequencies, and both are continously energized. Monitoring and automatic selection of the better channel are carried out at the receiving end. The radio equipment has proved to be most reliable. There are more than 20 links in service, and records show that, since the commissioning dates in 1972, only 4 have suffered failure of the main transmission path.

CONCLUSION

In 1964, when planning began for the Highlands and Islands scheme, it was generally accepted that the BPO was obliged to provide a reliable service to all customers in the remote areas of the north and west of Scotland. At the same time, it was conceded that the costs could in no way be justified on economic grounds. There were few telephones per exchange; Lairg GSC, for example, was opened with only 220 working lines on the local exchange. The GSC served 5 exchanges of a uniform size, having a total of only 361 lines. Calling rates and growth of connexions were low for most exchanges in the Highlands and Islands.

However, since 1972, there has been a dramatic change in the pattern of telecommunication traffic in the north of Scotland. Off-shore oil exploration has intensified, and important oil installations have rapidly developed around the coast and on main islands in the Orkneys, Shetlands and Hebrides.

The backbone network of the Highlands and Islands scheme was completed in time to meet this new challenge to provide telecommunication facilities for the oil industry. Spare capacity in many of the cable and radio systems is being used rapidly, and additional systems are being provided.

The rapid growth in traffic is typified by the revenue from one of the most remote exchanges for the period August to October 1976. Compared with the same period in 1974, revenue has increased by 540%. Thus, as the oil flow from the North Sea increases, so does the cash flow from the Highlands and Islands telecommunication network, and a reasonable return on capital may soon become a reality.

ACKNOWLEDGEMENTS

The author wishes to thank colleagues in the Aberdeen and North of Scotland Telephone Area, and in the headquarters of the Scottish Telecommunications Board, for their valuable help with the preparation of this article.

Common-Trench Cabling

G. MITCHELL and D. G. WARNER†

In 1970, Birmingham Telephone Area negotiated an agreement with the Southern District of the Midlands Electricity Board (MEB) to carry out common-trenching operations on a new estate—the Woodgate Valley estate, containing about 3000 houses. The success of that work has prompted the same agreement to be made with all other Districts of the MEB in the Birmingham Telephone Area. The photograph shows British Post Office (BPO) Duct No. 56 and a power cable in a common trench at the Woodgate Valley estate.

The agreement consists of 16 clauses, and contains detail of the trench profiles and cost-sharing ratios likely to be met in practice. The minimum separating distance between the 2 sets of plant is specified as 225 mm. The basic principle is that the BPO employs the MEB's contractor, at MEB rates, to carry out its part of the trenching, duct-laying and cabling operations, and any ancillary work. Where no suitable rates exist, they are negotiated with the contractor and, if his rates are not competitive, the BPO employs its own contractor.

Putting this principle into practice has meant adopting many MEB procedures, and modifying our own estimating, planning, works supervision and contracting practices. Examples are that the BPO has adopted MEB field sheets and contract invoices, and that, instead of adding common-trench details to the estate plan (thereby congesting it to the point of illegibility), only the route of the plant is shown, and this is divided into sections that are then fully described in a schedule associated with the estimate.

From time to time, problems are encountered in interpreting the agreement or MEB procedures. Generally, these can be solved on-site, but an MEB/BPO liaison committee has been set up to monitor the agreement. A current problem is the effect of the Health and Safety at Work Act on the agreement.

The results of Birmingham's common-trenching agreement cannot easily be compared with those obtained under the agreement described in Telecommunications Instruction A2 C1056, for that type of agreement is not attractive to the MEB, but we think we can claim to obtain the majority of the benefits. Furthermore, some of the MEB's techniques that we have adopted compare favourably with our own standard practices.

† Birmingham Telephone Area

Damage to Television-Link Equipment

J. E. TURNER†

Blaen Plwyf, in the Shrewsbury Telephone Area, is the remote end of a microwave-radio link from Cardiff to West Wales, where British Broadcasting Corporation (BBC) and Independent Broadcasting Authority (IBA) transmitters radiate BBC1, BBC2 and Harlech Television programmes to West Wales and, via satellite transmitters, to North Wales. The British Post Office (BPO) radio station is sited in a room inside a BBC building, and is maintained by a Technical Officer stationed at Aberystwyth.

During the early morning of Tuesday 8 February 1977, PROMPT alarms were received at Aberystwyth exchange and Cardiff television network switching centre (TVNSC) from Blaen Plwyf. The night-duty Technical Officer at Cardiff TVNSC contacted the maintenance officer for the radio station and asked him to attend to the alarms. On his arrival at 06.00, the maintenance officer found that an intruder had cut the lock from the site gates, broken a glass pane in a side door, and cut another lock from grille gates protecting this door. An inspection by torch-light revealed extensive damage to BPO equipment. The engineer returned to the nearest telephone kiosk, called the police, and informed Cardiff TVNSC and his Assistant Executive Engineer of the problem.

The police would not allow access to the radio station until approximately 09.00. By this time, the Wales and The Marches television outside broadcast team and the Carmarthen rigging gang had been alerted, and had been asked to assume that replacement links would have to be set up over the last hop of the microwave link to make good 3 unserviceable television channels.

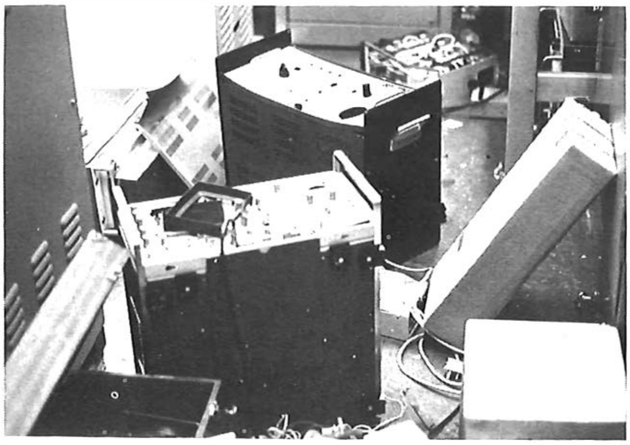
On entering the equipment room, it was found that all the test equipment had been smashed, apparently with a small sledge hammer. Further investigation showed that various meter and lamp-indicator panels had also been

† Service and Marketing Division, Wales and The Marches Telecommunications Board

smashed, and that all the mains power switches had been turned off. Some of the damaged test equipment is shown in the photograph.

The police had asked that disturbance of equipment should be kept to a minimum, as they were still collecting evidence. The staff were, therefore, severely hampered in making good the 3 lost television services; they had no test equipment, no meter panels, and were restricted in movement. Nevertheless, by a system of cross-patching and checking with BBC and IBA control centres, the 3 television services were restored to a temporary but satisfactory state by 09.40 the same morning.

The police eventually gave permission to clean up at 11.30, when it was possible to start making repairs to the damaged equipment without impairing television services. Power units, oscillators, meter panels and coaxial connectors on change-over panels were temporarily repaired by substitution and by salvaging parts. All the test equipment and one of the change-over panels associated with baseband equipment were beyond repair. Other Areas and Regions quickly provided assistance in replacing the damaged equipment. As soon as the television transmitters went off the air at the end of the day's programmes, the repaired equipment was put back in service, except for one change-over panel,



the functions of which the BBC were able to provide in their own equipment room.

Although the damage was extensive, and time and equipment limited, it was possible to maintain service to the BBC and the IBA without the loss of any programme time.

Cardiff's Traffic-Control Network

L. F. P. MOORE†

Networks have been supplied by the British Post Office (BPO) to the South Glamorgan County Council for a computerized traffic-control system, and for a system of visual monitoring of potential traffic bottle-necks in the city of Cardiff. The control system depends on input signals from traffic sensors and pedestrian-demand units situated at pedestrian crossings, the signals being fed to a computer housed at a control centre. Output signals are then sent to equipment cabinets which control the operation of traffic lights. The system is illustrated schematically in Fig. 1.

Control messages from the computer are transmitted on CCITT Channel 2; that is, on a centre frequency of 1·08 kHz, modulated such that the logic 1 state is represented by a 960 Hz signal and the logic 0 state by a 1·2 Hz signal. Messages to the computer are transmitted on CCITT Channel 4, which has a centre frequency of 2·04 kHz. To activate the outstation receivers, the control centre transmits a continuous logic 1 state between control messages. Signal levels into BPO plant are restricted to −13 dbm.

† External Works Division, Cardiff Telephone Area

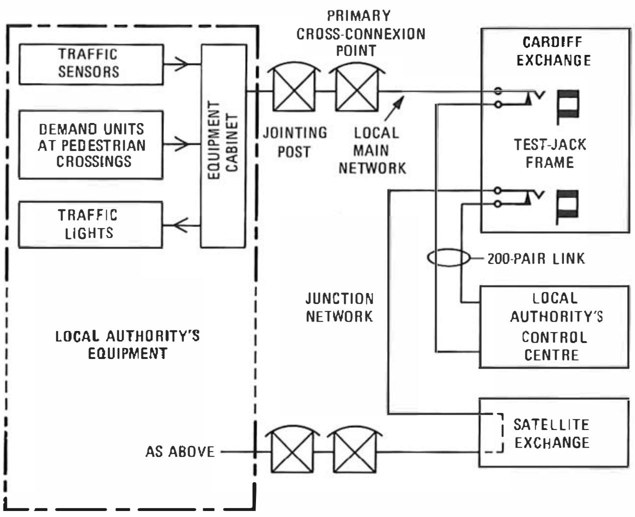


FIG. 1—Block diagram of traffic-control network

The control links are provided by 122 Tariff S2 circuits; such circuits are specified as providing an insertion loss of less than 10 db at 800 Hz. By agreement, the BPO's responsibility for the provision and maintenance of these circuits extends only to a jointing post adjacent to the equipment cabinet. The local authority has linked the equipment cabinets to the jointing posts with Polyethylene Cable No. 3, and crimped joints in the posts are used as the BPO's test points. From these joints, individual 2-pair cables (Polyethylene Cable No. 3) run in duct to the nearest primary cross-connexion point. Circuits are thence routed in the local main network to the local exchange, and in junction cables (where necessary) to the main exchange at Cardiff. A separate 200-pair cable was provided to link Cardiff exchange and the control centre. To avoid interference with the circuits by working parties, special markings and terminating methods have been used in primary cross-connexion points.

Vision circuits have been provided for cameras at 15 important road junctions, with 2 circuits to the local transport headquarters. Individual Polyethylene Quad Cables No. 4 have been run to each camera point, and the video circuits were lined up by regional headquarters staff.

Close liaison between the South Glamorgan County Council and the Area Sales, Installation and External Works Divisions was necessary to co-ordinate the installation work, which was completed with 2 weeks to spare. The External Works staff contributed approximately 8000 man-hours to the supervision of contractors laying 5 km of duct, and to the direct-labour cabling and jointing of 22 km of cable for the control circuits and 43 km of wideband cable for the vision circuits. Connexion charges for all the circuits amounted to £57 000, and Cardiff Telephone Area will collect some £8000 per annum in rental charges.

Historic Poles for the Science Museum

J. H. McCULLOCH†

The Science Museum has acquired 2 antique H-type telephone poles as part of a permanent record of the fascinating story of the growth of this country's communications.

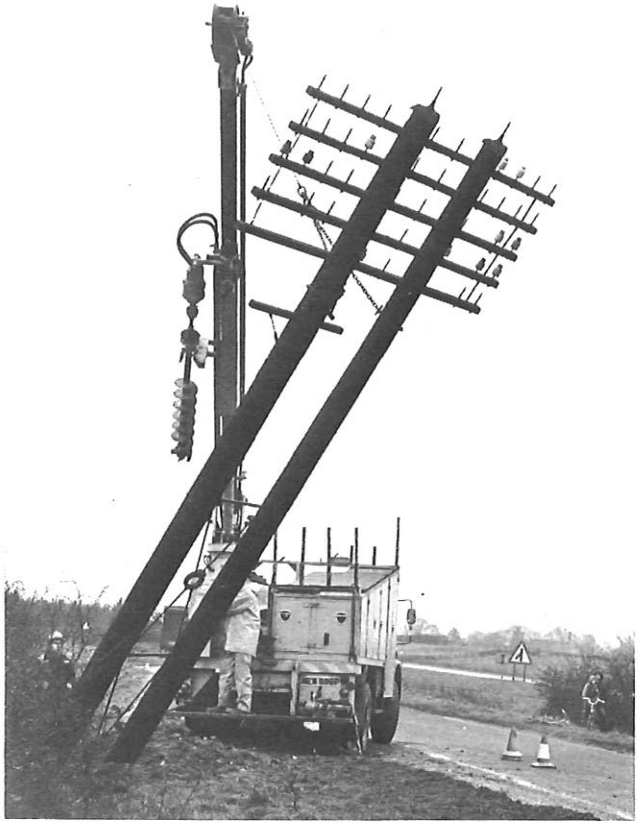
The poles, which, until recently, were sited on the old A1 road near Sawtry, are thought to be among the oldest trunk-route H-poles remaining in the country. Established about 1898, this trunk route carried telephone and telegraph circuits between Edinburgh and London, and Leeds and London, providing connexions to the network for centres along the route, such as Peterborough.

In those early days, to achieve an acceptable standard of transmission, it was necessary to use very heavy gauge copper wire, varying in weight between 200–600 lb/mile. To cope with this weight of wire, and to withstand the rigours of extreme climatic conditions, stout double poles, laced together with ironwork, had to be used, and the result was referred to as *H-pole construction*.

In the years 1920–1940, most overhead trunk routes were replaced by underground cables, and the old A1 route, after being replaced, has carried only lines within the local distribution network. Finally, after giving sterling service for nearly 80 years, the route is being dismantled.

Mr. F. A. Gilpin, General Manager, Peterborough Telephone Area, presented 2 of the poles to Mr. Walter Winton, Head of the Science Museum's Department of Electrical Engineering and Communications, at a short informal ceremony held on 25 February 1977 near Sawtry.

† Peterborough Telephone Area



Recovery of H-type pole by pole-erection unit
(Photograph by courtesy of Tyrer Photography, Maidenhead)

Completion of Ilford Sector Switching Centre

J. D. WARREN †

May 1977 saw the completion of the installation and commissioning of all units at Ilford sector switching centre (SSC), making this the first completed SSC in the London Telecommunications Region (LTR).

The incoming trunk unit has been in service for 2½ years, and is carrying approximately 1000 erlangs of traffic, using 2500 incoming trunk and adjacent-charge-group (ACG) circuits plus 2400 outgoing junction circuits to East Telephone Area exchanges. The tandem unit has been in service for just over a year, and is at present carrying approximately 600 erlangs of traffic; incoming and outgoing routes are being progressively augmented.

Ilford SSC has an associated cordless-switchboard auto-manual centre (AMC), serving most of the East Telephone Area director exchanges. Commissioning of the AMC started on 1 November 1976, and was completed by 16 December 1976. It involved reparenting some 12 exchange buildings (28 units) onto the AMC, with the subsequent closure of 3 existing manual boards.

The transfer of East Telephone Area director exchange STD and ACG traffic from central London to the outgoing trunk unit was completed on 6 May 1977.

The successful commissioning of the outgoing trunk unit depended upon the co-operation of staff in exchanges all over the country, and this the staff of the East Telephone Area gratefully acknowledge.

† East Telephone Area, London Telecommunications Region

Ilford SSC under construction in 1971

Institution of Post Office Electrical Engineers

INSTITUTION FIELD MEDAL AWARDS 1975-76

In addition to the Institution's Senior and Junior Silver and Bronze Medals, Field Medals are awarded annually for the best papers read at meetings of the Institution on field subjects, primarily of Regional interest. A Field Medal was awarded to Mr. F. C. Salter for his paper *The Midlands Radiophone Service*.

A. B. WHERRY
Secretary

IPOEE CENTRAL LIBRARY

Members are reminded that prize-winning essays, Associate Section prize-winning papers and various unpublished papers are held in the IPOEE Central Library for loan, and that a list will be sent on request. Field Medal award-winning papers are also held for loan, and are listed in the 1974 Library Catalogue.

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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 secretaries, and from Associate Section local centre secretaries and representatives. Alternatively, the form opposite, 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*.

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The Associate Section National Committee Report

NATIONAL TECHNICAL QUIZ

The fourth National Technical Quiz final was held on 25 March at the Institution of Electrical Engineers (IEE), Savoy Place, London, and the evening's proceedings included the presentation of both the Cotswold Trophy and the new E. W. Fudge Trophy.

The finalists were last year's winner, Exeter (representing the South Western Telecommunications Region), and Oxford (representing the Eastern Telecommunications Region). At the half-way stage, there was only 1½ points between the scores of each team, with Oxford holding the advantage. The Oxford team then steadily increased its lead to win the competition by 30½ points to 21.

Our thanks are offered to the question-master, Mr. J. F. P. Thomas, the time-keeper, Mr. S. Newcombe, the scorer, Dr. Bray, and the adjudicators, Messrs. G. I. Andrew and R. Webb. The Bray Trophy was presented by Mr. D. P. Wratten, Senior Director: Telecommunications Personnel.

Afterwards, about 90 people attended a buffet at Lutyens House, Finsbury Circus. This rounded off a most enjoyable and well organized evening.

PROJECT COMPETITION

The National Committee has acquired a beautiful Waterford crystal globe, which is to be known as the E. W. Fudge Trophy. The Trophy will be presented each year to the winner of the project competition. It is mounted on a plinth, and comes in a handsome carrying case.

At the IEE's theatre, our president, Mr. K. E. Stotesbury, handed the Trophy initially to Mr. Fudge, who then presented it to Mr. S. Newcombe, the winner of last year's competition.

The 6 entries for the 1976–77 competition have, at the time of writing, still to be judged. The 1977–78 competition will require competitors to produce an essay, drawing or model of a novel application of alternative energy sources for use by the British Post Office; say, using solar, wind, geothermal or tidal power.

COTSWOLD TROPHY

The winning centre for the Cotswold Trophy this year is Evesham, for their magnificent Telephone Centenary Exhibition. Evesham is a comparatively small centre, but managed to put together a good collection of historical exhibits from many sources, and the exhibition was well praised by both visitors and the press. The trophy was presented by Mr. J. Dow, Vice-President of the National Committee, to Mr. Bonson of Evesham Centre.

NATIONAL NEWS

It is proposed to continue to publish the *National News* in its present form for the time being, with 2 or 3 issues a year. The number of issues will depend on the copy available; if anyone has an article of interest, perhaps they would contact the editor, Colin Newton, on 094 34 4071.

FAREWELL

Sadly, I am relinquishing my position as secretary to the National Committee, but I would like to take this opportunity of thanking all who have assisted me during my term of office.

C. J. WEBB
Secretary

Associate Section Notes

BOURNEMOUTH CENTRE

Our 1976–77 session started in July with a visit to Pirelli Cables Ltd. (Power Division) at Eastleigh. Rather surprisingly, a visit arranged to Vauxhall Motors Ltd., at Luton, had to be cancelled because of lack of support.

We later had a very interesting visit to The Royal Aircraft Establishment (RAE) at Farnborough, where we visited the aircraft museum and saw the remains of crashed aircraft, including the wreck of the light aircraft in which Graham Hill lost his life. The wrecks are being examined to determine the causes of the accidents. Our visit coincided with the imminent retirement of the museum's curator, Wing Commander Unwin, and RAE photographers were there to take pictures. The Assistant Public Relations Officer, Mrs. P. E. Page, kindly sent us a number of full-plate photographs of the occasion.

In October, a repeat visit was made to Radio Solent at Southampton. Forthcoming visits include the Central Marine Depot, Southampton, and the Television Centre, London.

G. H. SEAGROATT

DUNDEE CENTRE

Our 1976–77 programme continued in January with a visit to the power station at Carolina Port, Dundee. This fairly modern oil-burning station takes load only at peak-demand periods, and then only after receiving an 8 h warning. The oil-storage tanks are estimated, at the present rate of usage, to hold sufficient stocks to last most of the year.

January also saw the last of the Dundee challenge in the National Technical Quiz, Dundee being soundly beaten by an excellent team from Exeter. Our disappointment is aggravated by hearing that we were beaten by the runners up, and not the eventual winners, Oxford.

G. K. DUNCAN

GLASGOW CENTRE

The 1976–77 session began in October with a lecture by Mr. D. G. Vance, Deputy General Manager, Glasgow Telephone Area, entitled *Financial Forecasting and Control*. In November, we visited the Task-Force control of Strathclyde Region's Police Headquarters, and, in December, returned for a second visit to the Police Headquarters, this time to see the black museum.

Our January meeting was a lecture entitled *The Regional Promotion Board—How it Works*, given by Mr. D. Leask, Deputy Controller of Staff, Scottish Telecommunications Board. In February, Mr. D. B. Harris, Technical Officer, Glasgow Telephone Area, gave a talk entitled *Datel Services*.

At the time of writing, we have one more meeting to come, at which there will be 2 lectures: *Area Finance* by Miss M. H. Graham and *Traffic Planning* by Miss E. W. Docherty. Both ladies are heads of their respective divisions in the Glasgow Telephone Area.

R. I. TOMLINSON

GLOUCESTER CENTRE

Our 1976–77 series of lectures commenced with a joint meeting with the Stroud Scale Model Society, at which Mr. George Davis, of the East Somerset Railway Preservation Society, talked of the work of his group and of David Shepherd, whose wild-life and steam-locomotive paintings have justly become famous. The talk was illustrated by 2 excellent BBC films covering the life and works of Mr. Shepherd, "the man who loves giants".

On 3 November 1976, our Centre visited the Royal Naval Air Museum at Yeovilton. The morning was taken up by a tour of the museum, which contains aircraft dating from before the First World War as well as modern exhibits. During the afternoon, we were shown around the station which, apart from being responsible for most of the Royal Navy's helicopter maintenance, including that of the new Westland Lynx, is the home of a most interesting and historic aircraft flight.

Towards the end of November, Messrs. G. Adams and J. Moxey talked of the work of the British Post Office's (BPO's) radio interference group, illustrating their talk with slides and a selection of the various devices used to prevent those irritating spots and flashes appearing on our television screens. Sadly, Mr. A. J. Taylor's talk on the art of bee-keeping was poorly attended, but did provide us with a most fascinating evening. The organization and industry with which these insects go about their tasks is truly amazing.

On 1 March 1977, we were privileged to entertain Mr. D. J. Withers, Deputy Director of the BPO's Space Systems Divisions. Apart from talking on the development of satellite communications, Mr. Withers gave us an insight into the future of this important field, and illustrated his lecture with a film and slides. The evening began with the presentation of the Gloucester Area Apprentice-of-the-Year Awards by Mr. Withers.

The final event of our session is to compete in the annual 4-way non-technical quiz, for which Bristol are acting as hosts. We look forward to an exciting contest and an enjoyable evening.

J. R. SMITH

GUILDFORD CENTRE

The Guildford Centre has been very busy in the past few months; our involvement in the Tower Trophy Quiz entailed a lot of work by the committee, and it really is a shame that this event does not draw the interest of the general membership. The heats began in July, with Guildford narrowly beating Worthing; we then played Portsmouth and became the Regional winners on 30 November. A hastily arranged National Technical Quiz round was held on 9 December between Guildford and Preston, but our fortunes were short-lived in this Bray Trophy competition, as we were beaten in the first round. However, the experience was interesting, as this was the first land-line quiz the Centre had been involved in since 1956, when Guildford played Portsmouth in a general knowledge quiz.

The final of the Tower Trophy Quiz was held on 2 March at Guildford, and we regained the trophy, which we last held in 1972. The Centre Area of the London Telecommunications Region (LTR) had hoped to return the trophy to its home in London, but the Guildford team maintained a lead throughout the contest. We should like to thank all those who helped stage the event, especially: Mr. Blair, question-master; Messrs. Bluring and Bell, adjudicators; Mr. Morgan, our Planning Controller, who presented the trophy; Mr. B. Hill, Area Publicity Officer; the ladies of the Guildford Drawing Office; and the gentlemen from the Regional Power Workshop. Finally, our congratulations go to the team: Derek Powell, Dave Heather, Dave Howell, Dave Leedham, Robin Hackney and Cliff Watts. We hope that the LTR team enjoyed their visit, and offer our commiserations. We would also like to thank the LTR for their gesture of presenting gifts to the Guildford team; we regret we had nothing to offer in return apart from our hospitality.

The final was not well attended; only one member of our Centre came to support us although all our 500 members had received a notice early in February, and some 30 posters were distributed throughout the Area. It is quite an expensive function to finance from the Centre's funds and, with so little support, there is some concern for the future of the Tower Trophy Quiz; its abandonment would be a great pity.

Turning to our other functions, we have visited the Royal Aircraft Establishment Radio Station at Cobbetts Hill, Fuller's Brewery in Chiswick, and the Ford Motor Company at Dagenham. We held a Christmas party that was entirely self-supporting and most enjoyable. Our most successful function this session was a talk given by David Shepherd, the artist famous for his interest in wild life and steam locomotives. About 150 members and friends attended this interesting talk. The Centre was fortunate in engaging Mr. Shepherd, who made no charge other than to request a donation to the World Wild Life Fund.

The Guildford Area General Knowledge Quiz Competition commenced on 17 January, and there have been 3 rounds since then, with 2 more to follow. Thirty-five teams of 4 members each have entered this year, and the event kept our Quiz Secretary, Keith Hannah, very busy. This quiz, in contrast to the Trophy Quiz, is more popular with our membership, and provides many enjoyable and informative evenings.

At the time of writing, we are looking forward to a talk on optical-fibre systems, to be given by Mr. C. J. Lilly, and visits to the BBC television studios, the British Aircraft Corporation, Filton, and Pirelli Cables Ltd.

R. STONE
D. HEATHER

OXFORD CENTRE

Our 1976–77 programme included talks on a variety of topics, including *Hospital Broadcasting*, given by Mr. N. Stockton, one of our own members. In December, we had our most well attended lecture, *Archaeology in Oxfordshire*, given by Mr. Hassall of the Oxford Archaeological unit. The unit is asked to excavate sites that are to disappear forever, usually beneath modern civil engineering projects. Mr. A. Chapman gave an absorbing talk in February, entitled *The History of Nineteenth-Century Apprenticeships*.

Following our annual general meeting in March, Mr. B. Collins, our treasurer, treated us to slides of the Lake District, using a synchronized sound track. In April, we toured Didcot power station.

During the winter, our National Technical Quiz team, representing the Eastern Telecommunications Region, won its way through to the final of the Bray Trophy competition, held at the Institution of Electrical Engineers in London on 25 March.

B. J. POST

Notes and Comments

REGIONAL NOTES

Regional Notes have been given a new style of presentation in this issue, the intention being to enhance their status relative to that of main articles. An important characteristic of the new styling is the increased prominence given to the author's credit and, consequently, authors are asked in future to list their qualifications when submitting copy, so that these can be given in the credit. The editors will be pleased to receive comments about the presentation of Regional Notes.

Over recent years, there has been a pleasing increase in both the number and quality of regional contributions, and the Board of Editors will be delighted for this trend to continue. Several of the longer contributions have been interesting enough for conversion to main articles, thus imparting a better balance to the *Journal*'s coverage.

Anyone who feels that he or she could contribute an interesting Regional Note, short article or, indeed, full-length article 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 printer and illustrators, and help ensure that authors' wishes are easily interpreted. Any author preparing an article is invited to write to the Managing Editor, at the address given below, to obtain a copy.

All contributions to the *Journal*, including those for Regional Notes and Associate Section Notes, must be typed, with double spacing between lines, on one side only of each sheet of paper.

As a guide, there are about 750 words to a page, allowing for illustrations, and the average length of an article is about 6 pages, although shorter articles are welcome. Regional Notes are generally up to about 500 words in length, and longer contributions will be considered for publication as short articles. Articles and Regional Notes should preferably be illustrated by photographs, diagrams or sketches. Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that is required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour prints and slides can be accepted for black-and-white reproduction. Negatives are not required.

It is important that approval for publication is given at organizational level 5 (that is, at General Manager/Regional Controller/THQ Head of Division level), and authors should seek approval, through supervising officers if appropriate, before submitting manuscripts.

Contributions should be sent to the Managing Editor, *The Post Office Electrical Engineer's Journal*, NP 9.3.4, Room S 08 River Plate House, Finsbury Circus, London EC2M 7LY.

CORRESPONDENCE

The Board of Editors would like to publish correspondence on engineering, technical or other aspects of articles published in the *Journal*, or on related topics.

Letters of sufficient interest will be published under Notes and Comments. Correspondents should note that, as it is necessary to send copy to the printer well before publication date, it will be possible to consider letters for publication in the October issue only if they are received by 15 August 1977.

Letters intended for publication should be sent to the Managing Editor, *The Post Office Electrical Engineer's Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

CORRECTIONS

In the article *Audio Transmission Equipment*, published in the April 1977 issue of the *POEEJ*, a line was omitted from the final paragraph of the section entitled "Historical Background" (p. 29). The missing line should be inserted between the third and fourth lines of that paragraph, and reads as follows.

routes. By the late 1960s, cables were being installed with

Also, in the article *Network Synchronization*, several lines were misprinted in the final paragraph of the section entitled "Technical Feasibility of Retuning" (p. 22 of the same issue). The paragraph should read as follows.

A third method would be to provide a frequency source of caesium standard in each exchange. This would eliminate the problems of retuning, but at the present time would be an extremely costly solution, and the routine and specialist maintenance that such standards need would introduce additional problems.

On behalf of the printer, the editors would like to apologise to the authors of these articles, and to readers, for the errors.

The reference on p. 59 of the April 1977 issue of the *Journal* is intended only to provide background information about injection welding. The reference describes the technique developed by Telephone Cables Ltd., whereas that used on the unidiameter joint at Oxford was a system more recently developed by the Operational Programming Department, Telecommunications Headquarters.

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It will be held at the National Exhibition Centre, Birmingham, between the 4th and 7th of April 1978.

For further information, contact:

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The Post Office Electrical Engineers' Journal

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Communications

With the exceptions indicated above, all communications should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Model Answer Books

Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Details of the books available are given at the end of the Supplement to the *Journal*. Copies of the syllabi and question papers are not sold by *The Post Office Electrical Engineers' Journal*, but may be purchased from the Department of Technology, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

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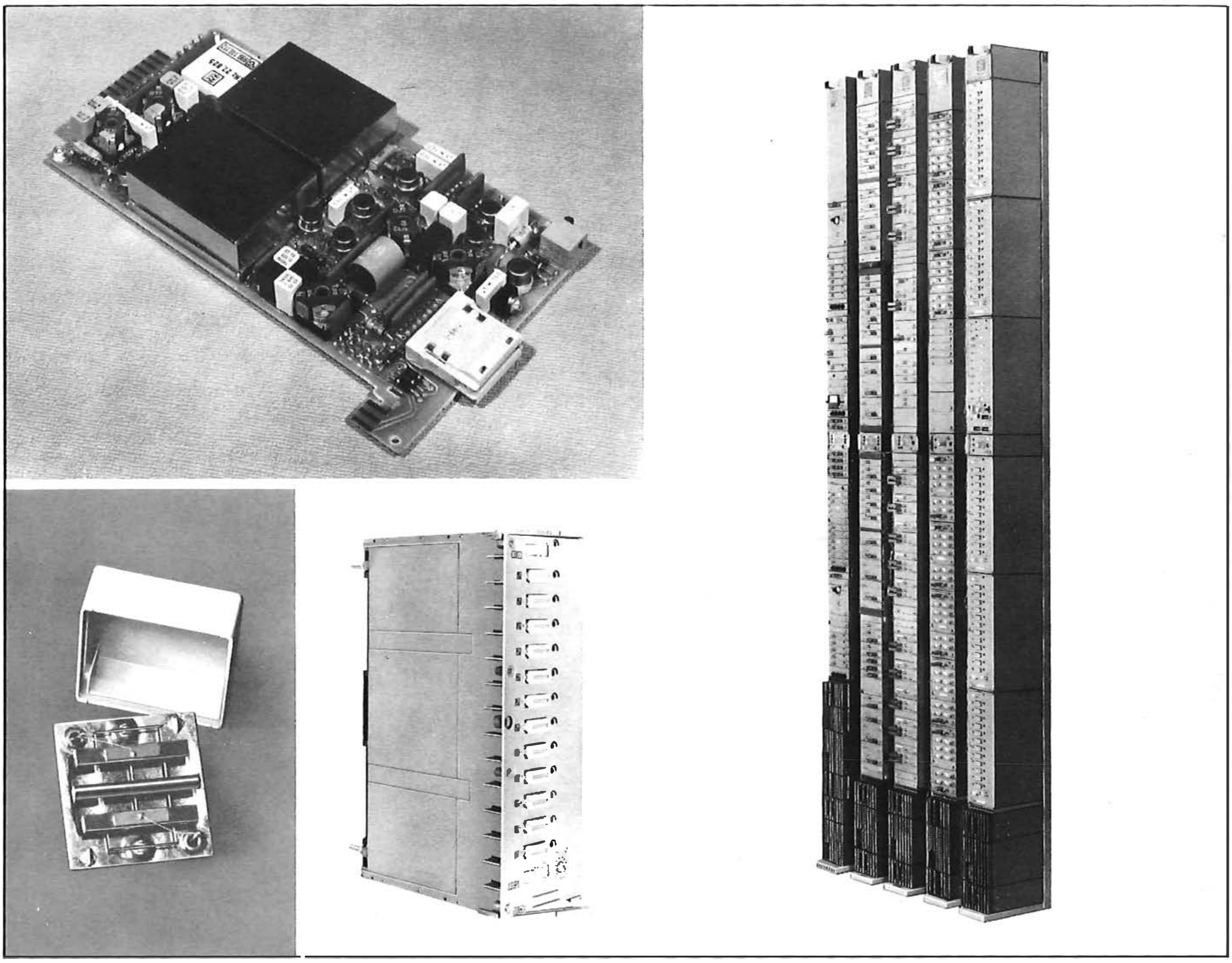

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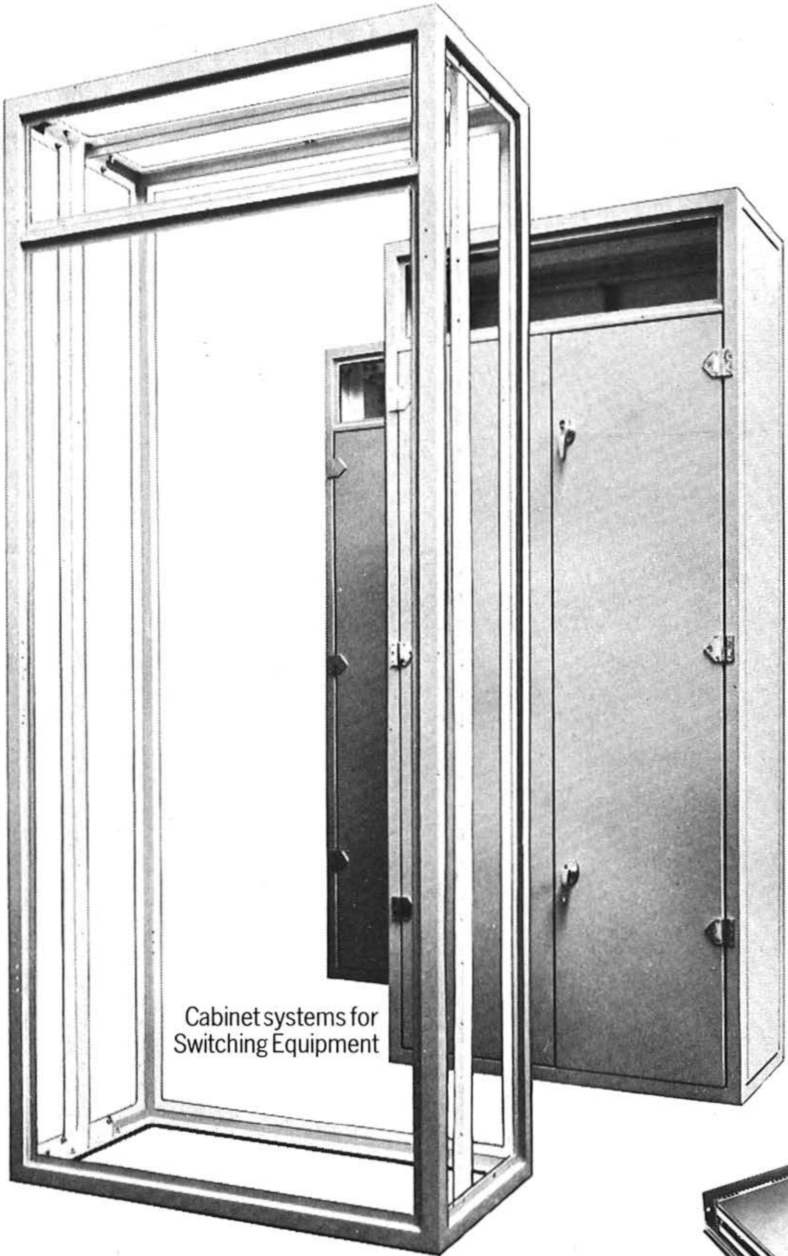

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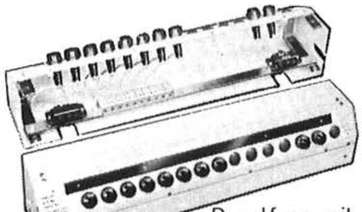

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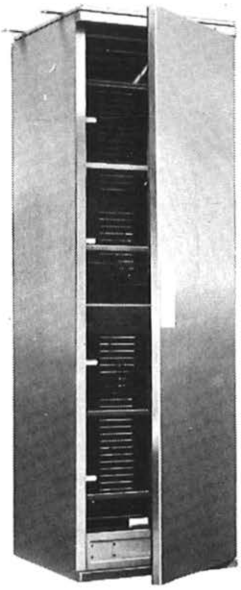

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