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Contents

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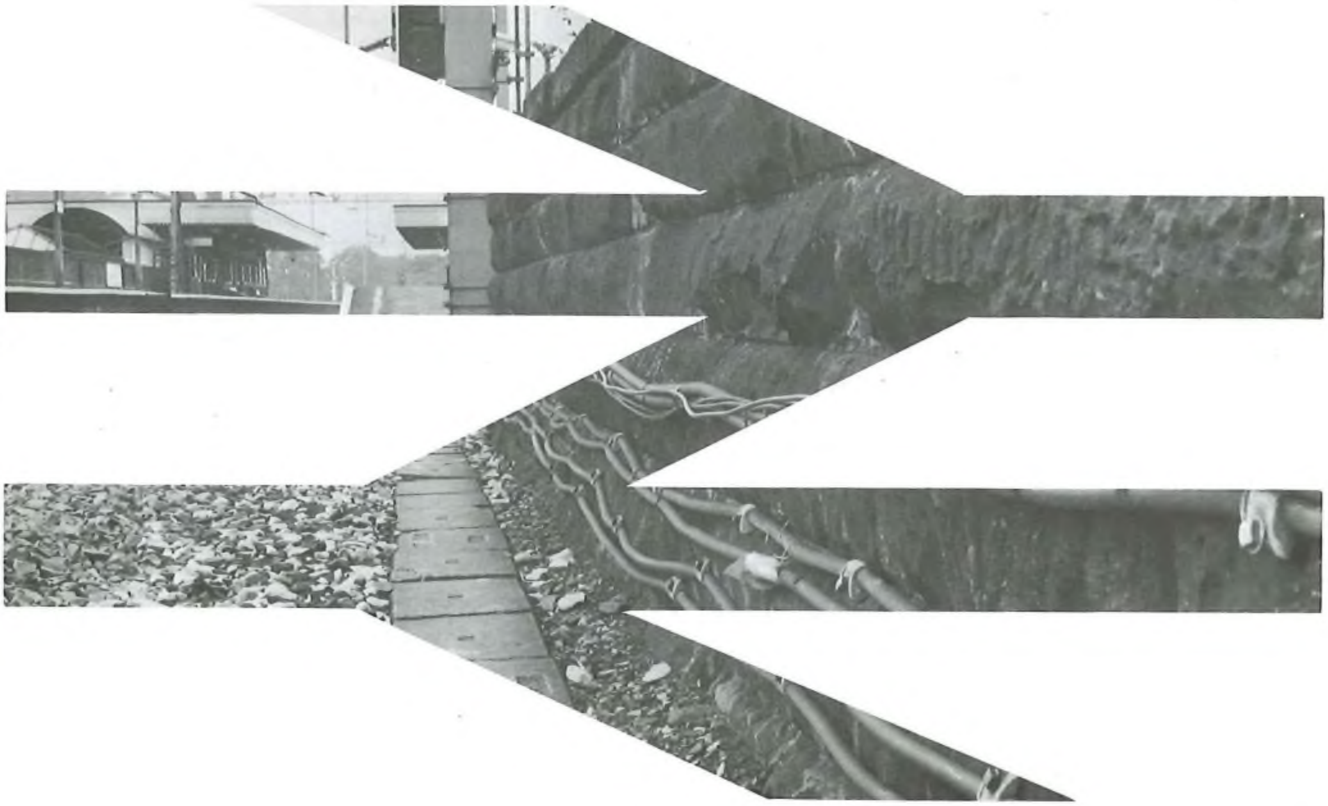

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The Post Office Electrical Engineers' Journal

EDITORIAL

For many years past, lectures given by senior British Post Office (BPO) personnel, and articles published under the auspices of learned societies (including those published in the *Journal*), have given promise of exciting prospects in the use of millimetric waveguide and optical-fibre transmission systems. Despite the saying "tomorrow never arrives", perhaps it can now be admitted that the future is within sight in regard to these transmission media. On p. 206, a press notice records the decision to install in the UK the world's first commercial waveguide system, and an article on p. 146 describes the feasibility trial of an optical-fibre transmission system that is now in operation and carrying telephone traffic. The little fellow who has encroached on Fig. 15 on p. 152 is not part of the equipment design (although he does appear in many places these days)—perhaps, unlike Nelson, he has a laser as a "good eye".

A series of articles on microprocessors starts on p. 136 which it is hoped will prove both interesting and valuable in bringing an understanding of a major new trend in technology to readers of the *Journal*. A complementary article to the subject of microprocessors, concerning the automatic testing of large-scale digital integrated circuits, is featured on p. 161. The article gives an insight into the problems of testing devices of infinitesimal size that may contain thousands of circuit elements.

Coming down to earth—the contributions entitled *Tunnelling into History* and *Lines for Lundy's Lights* provide an apt reminder of the varied aspects of work that confront us daily as BPO engineers.

Programmable Logic and Microprocessors

J. D. TONGE, D. L. GAUNT, and J. P. KENDALL†

UDC 681.31.181:681.3.06

Memories and other programmable devices are first considered as part of the programmable logic spectrum leading to the microprocessor. The architecture and operation of a simple microprocessor are then explained. This introductory article is the first of a series on microprocessors that will include the programming, selection and use of microprocessors in the British Post Office.

INTRODUCTION

Digital integrated circuits were first used in large numbers by the British Post Office (BPO) in the Empress experimental exchange.[1] Here, standard circuits of the diode-transistor logic (DTL) and transistor-transistor logic (TTL) families[2] were used economically to handle traffic on multiplexed highways. During the last decade, with the increasing availability of large-scale integration (LSI), more-complex integrated circuit (IC) devices have found wider use in telecommunications equipment. With the advent of LSI, the possibilities of special circuit designs for telecommunications use began to be considered but, although the production costs of such *custom-designed* circuits can be low, the initial design costs are relatively high, and generally these LSI devices were not economic except when required in large numbers. In considering their use for the replacement of telephone-exchange relay-sets and other peripheral exchange equipment, the number of circuit variants required was thought to be too large to justify the design of a special circuit for each requirement; the use of programmable logic was seen as a way out of this difficulty.

The economic advantages of programmability, as applied to electronic-logic circuits, have been recognized since the birth of the electronic age. These advantages stem from the inherent flexibility of a programmable device, which allows it to perform a variety of different tasks depending upon the way it is programmed. A further advantage arises from the ability of many types of programmable logic to be reprogrammed, thus enabling modifications to be made easily without the need to redesign the equipment. Programmable logic is therefore seen as an effective solution for those cases where a large variety of similar circuits is required. The circuit variants are then realized by programming a standard logic circuit to perform the function required. In particular, several years ago, a microprocessor was invented[3] within the BPO for use in such applications, although at the time it was called a *miniprocessor* or *peripheral processor*. Since that time, the BPO has gained operational experience in using such devices, for example, in the Pathfinder experimental exchange,[4] in which various forms of programmable logic are used in the hierarchy of stored-program control (SPC). Today, the value of programmable logic has become widely accepted and a multiplicity of devices is available from a number of manufacturers throughout the electronics industry. Some devices are self-contained, while others require an external memory array to store the program, but each relies upon some element of programmability to achieve flexibility.

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PROGRAMMABLE LOGIC ELEMENTS

A traditional method of providing flexibility in various equipment designs is the use of wire straps; for example, to interconnect different resistors to vary, or program, the gain of an amplifier. This method is still very effective, but electronic approaches in programmability can now be used advantageously to supplement mechanical strapping.

Any type of programmable logic has to retain the program supplied by the system designer, and the electronic equivalent to the wire strap, used for this purpose, is called a *memory element*. The program is stored by making the memory element adopt one of, say, 2 stable states. One such element is known as a *bistable*[5] circuit (*flip-flop* in American parlance), which can store one binary digit (bit) of information (see Fig. 1.) The bistable circuit can be set to store a logic state 1, or it can be reset to logic state 0. This type of memory element is known as *volatile*, because it relies on a continuous current flow, and loses the stored information if the power supply to the element is removed.

A memory element that can store and retain information for some time, even if the power supply fails, is known as a *non-volatile* memory element. An example of such an element is the ferrite core (see Fig. 2) which has been used in computers for many years for magnetic storage of both program and data.

Capacitive storage has been used to store information, but the stored charge gradually leaks from each capacitor. A periodic application of a charge is therefore needed to *refresh* the memory, thus retaining the stored information.

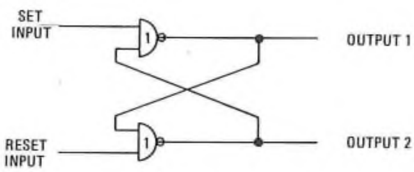


FIG. 1—Bistable circuit

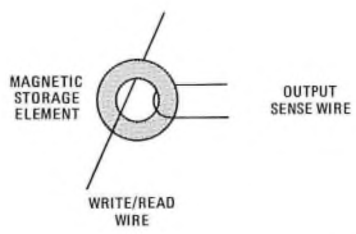


FIG. 2—Ferrite-core bistable memory element

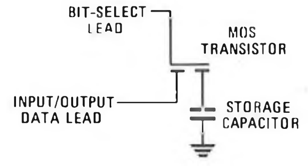


FIG. 3—Capacitor memory element

A storage capacitor is shown in Fig. 3. It is charged or discharged via a metal-oxide-semiconductor (MOS) transistor,[6] which acts as a switch.

RANDOM-ACCESS MEMORY (RAM)

Where several bits of information are to be retrieved at one time, it is convenient to group the memory elements into a *word*, such that one WORD lead can energize all the cell-select transistors in the word simultaneously. Because other words of stored information may have to be retrieved or accessed at later times, the storage elements are arranged into a matrix of words. In a random-access memory (RAM), each word location is independent and can be referred to in any order.

Consider, for example, a small capacitor store, as illustrated in Fig. 4, constructed as a matrix of 12 capacitors arranged in 4 words, each of 3 bit. If word 0 is selected (by energizing the appropriate word lead), all 3 MOS transistors (T_1, T_2 and T_3) are switched on, so allowing the 3 capacitors storing the wanted word of data to be connected to the three bit leads. The output data on these bit leads could be used to control transducers or solenoid valves in an industrial control process or, as will be described later, additional combinatorial logic, to perform the function specified. In either case, the memory and any additional logic provided is functioning as programmable logic, in that this general-purpose configuration can be made to perform any one of a number of tasks as determined by the specific program in the memory. If required, the data in the word selected can be changed to allow a new task to be performed, by writing in the required new data pattern over the three bit leads while the appropriate word is being addressed.

Where there is a large number of words in a store matrix, an address decoder is provided to reduce the number of word-address leads. In practice, the address decoder is much more complex than shown in Fig. 4. It is essentially a means of selecting a particular word in the store matrix by means of a coded input address word applied to the address leads. By using n address leads, up to 2^n words can be addressed by this technique, resulting in a big saving in word-address leads. If, for example, 1024 words (1 kword) of storage are used, these addresses can be coded on only 10 address leads, while still allowing any one of the 1024 words to be selected at random. The RAM, as its name implies, is in contrast with a serially-addressed memory such as a magnetic drum or a shift register, where words can be accessed only sequentially. The principle of random addressing (using an address decoder) is used extensively by microprocessors—for addressing RAMs and other devices, such as read-only memories, which are described in the next section.

READ-ONLY MEMORY (ROM)

In a read-only memory (ROM), the program data is stored permanently in the memory and cannot subsequently be changed; data can only be read out repeatedly as required, in contrast with read/write memories such as RAMs and shift registers. In practice, the ROM data is stored during manufacture in such a way that changes cannot be made under normal conditions of use.

ROM Structure

In a conventional ROM which is programmed during manufacture, the memory cell is simpler than the RAM cell in that the ROM cell requires only a transistor. If a logic state 1 is to be stored in the cell, then a transistor is provided; for a logic state 0, the transistor is omitted, so that there is no connexion between earth and the bit leads.

A matrix of ROM cells can be constructed using MOS transistors (see Fig. 5) and addressed in the same way as for the RAM. In Fig. 5, the gates of the MOS transistors in the matrix are shown dashed because they may not all be present, as one way of providing a transistor is to specify the formation of the gate at the appropriate point on the IC thin oxide mask. The term *mask-programmed* ROM is thus used where the ROM program is placed on one of the various masks used in the IC manufacture.

If, in the ROM matrix shown, both T_1 and T_2 were provided and T_3 omitted then, when word 0 is addressed, the programmed pattern 110 would appear on bit-leads *A*, *B* and *C* respectively. Although this device is then permanently programmed, it is easy, by the use of computer-aided design

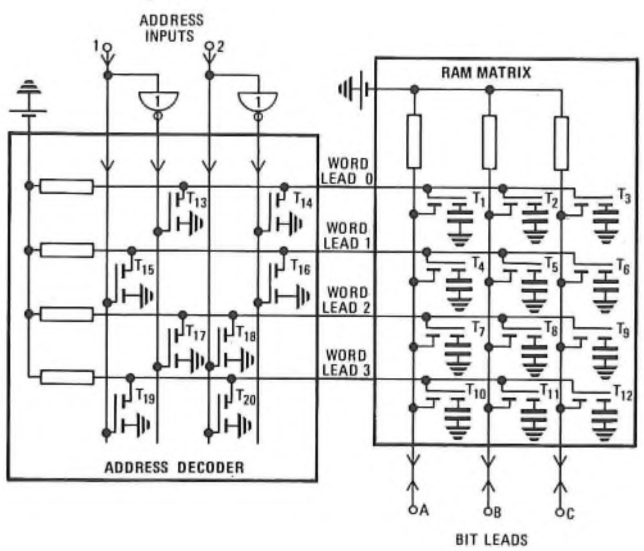


FIG. 4—Random-access memory

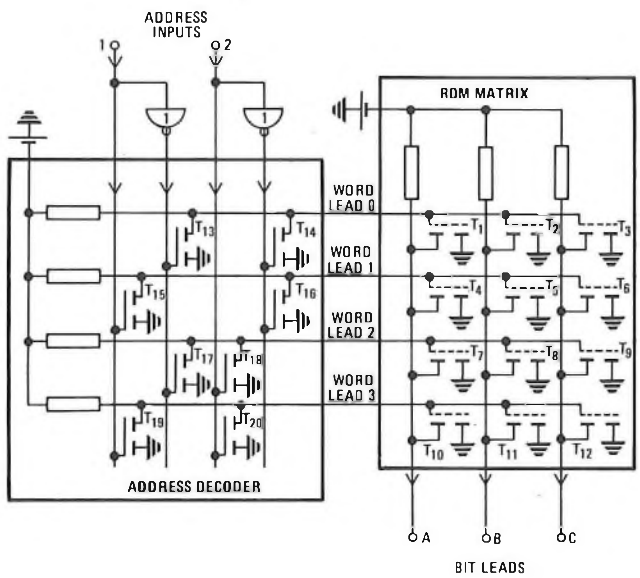


FIG. 5—Read-only memory

(CAD), to generate a new mask for producing other ROMs with different programmed patterns. In fact, ROMs are now so quick and easy to design that random logic is sometimes realized as a custom-designed ROM (that is, a specific arrangement of words and bits for a particular task) rather than as a custom-designed random-logic IC. In general, mask-programmed ROMs can be economically justified in quantities down to a few-hundred units, where the ROM replaces simple combinatorial logic, typically with less than 10 inputs and less than 12 outputs (that is, using less than 24 package pins, including power-supply connexions).

Where a very small number of devices is required, the cost of mask programming may favour the use of a newer type of ROM which allows the customer to program it as required. This type of ROM, called a *programmable read-only memory* (PROM), which uses either fusible-link or avalanche-induced-migration (AIM) technology, can be customer programmed but cannot be altered subsequently. The electrically-programmable read-only memory (EPROM), however, can be reprogrammed once the previous data has been removed by irradiating the chip with ultra-violet light. Both electrical programming and erasure is possible with the electrically-alterable read-only memory (EAROM).

ROM Applications

There are several types of ROM available using different technologies. Inexpensive ROMs, with access times of 1 μs or more, can be used in simple sequence controllers, whereas very fast ROMs are available for use in computers where data manipulations may have to be undertaken in less than 100 ns. ROMs are often used for storing "look-up" tables in small computers. They can also be used to generate digitally-coded sine waves for tone synthesis, or to generate alpha-numeric characters and graphical symbols for optical read-outs or visual display units. Manufacturers now sell, as standard components, ROMs already programmed as character generators, keyboard encoders and priority encoders. Microprocessors frequently use standard ROMs or PROMs to store the main control program.

A traditional ROM application is code conversion, where data supplied in one format has to be converted to another format; for example, hexadecimal-to-binary. Programmed

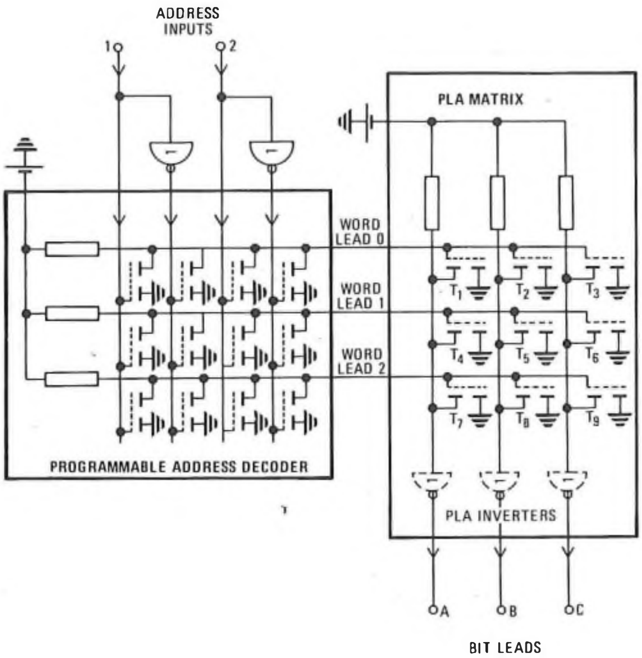


FIG. 6—Programmable logic array

ROMs are available to convert between commercial codes such as USASCII, Selectric line-code Baudot and EBCDIC. However, where highly redundant codes are used for data transmission it becomes prohibitively expensive to use a ROM for code conversion, and a programmable-logic array (PLA) is to be preferred.

PROGRAMMABLE LOGIC ARRAY (PLA)

The PLA is basically a compact version of ROM where not all 2^n words are required in the memory matrix and address decoder. The resultant arrangement is often described as a set of programmable AND gates feeding programmable OR gates; hence the term *programmable logic array*. In some cases, the PLA may also contain bistable circuits to allow sequential logic to be realized on the chip but, for ease of description, the basic PLA only is considered here.

PLA Structure

Using a very simple ROM for comparison, as shown in Fig. 5, and assuming that some applications need only the first 3 of the 4 possible words of the memory matrix to be addressed, it is not necessary to provide space for MOS transistors T_{10}, T_{11}, T_{12}, T_{19} and T_{20}; thus the chip area taken up by the memory matrix can be reduced. In general, however, it is not possible to predict which input addresses will be required to correspond to the 3 words available, as not all address combinations are now used. To reduce the size of the memory matrix, it is therefore necessary to make the address decoder programmable too; for example, if in certain applications, accessing word 2 is dependent only on address lead 1, transistor T_{18} is not required. The resultant structure is then virtually a PLA, as shown in Fig. 6. The choice of including or bypassing the output inverters exists on some PLAs. The memory matrix is then an array of programmable OR/NOR gates (or *sum-term array*), while the address decoder is an array of programmable NAND gates (or *product-term array*).

Although more of the chip has now to be programmed, much of the work can be done quickly by CAD, one manufacturer claiming only 12 h to progress from Boolean logic equations to the PLA programming mask. As with the ROM, several types of PLA are available, some of which can be programmed by the user. Such a device is generally known as a *field programmable logic array*, and is economic for certain applications where only small quantities of a particular variant are required.

PLA Application

For a PLA to be economically justified in an application, it is necessary to be able to reduce the equivalent ROM matrix size by a factor of about 10. A well known example of such an application is the conversion of the highly-redundant 12-bit Hollerith code into the 8 bit USASCII code format. Only 96 of the possible $2^{12} = 4096$ combinations are actually used in the Hollerith code to ensure that transmitted data has a high error immunity. If a ROM were used for this code conversion, a memory matrix of 4096 words, each 8 bit wide, would be required. Because a total ROM size of 32 kbit (excluding its address decoder) would be large and expensive, it is cheaper to use a smaller PLA; the comparison is illustrated in Fig. 7. The PLA memory matrix required contains only 96 words each 8 bit wide, that is a total of 768 bit. The programmable address decoder of the PLA (which is designed as a form of ROM) requires $2 \times 12 \times 96 = 2304$ bit. The combined total of 3072 programmable binary digits takes up less chip area than the 32 768 of equivalent ROM, and is thus cheaper.

There is a number of applications in the field of telecommunications where simple PLAs can be used to replace combinatorial logic; for example, in the conversion of 12 bit

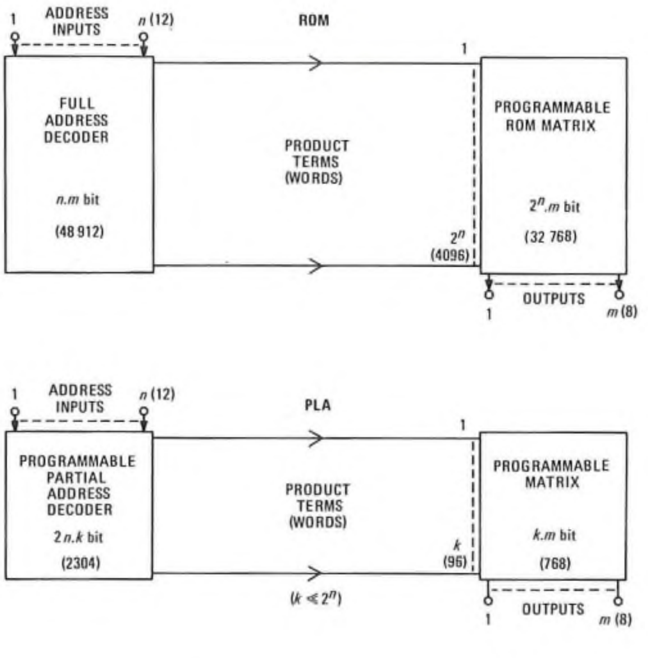


Fig. 7—Comparison of ROM and PLA

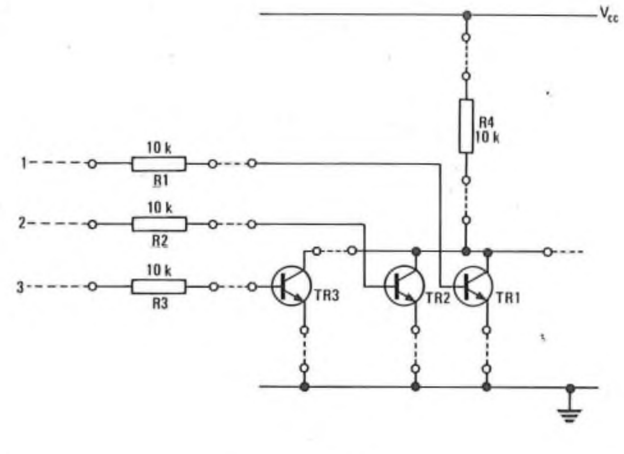


Fig. 8—ULA cell

linearly-encoded speech into 8 bit pulse-code-modulation (PCM) format, in which 128 possible codes exist for each signal polarity. In applications where sequential logic is being considered, bistables must be associated with the PLA so that previous output states can be made available later as inputs. Such a PLA could replace simple process-control logic, a commercial example being a washing-machine controller. However, many logic applications are not conveniently realized with ROMs or PLAs, which have the constraint of a rigid AND/OR configuration of gates. In such applications, there is a need to alter not just the memory-array nodes, but also the complete array interconnexion—as is possible with the uncommitted logic array (ULA).

UNCOMMITTED LOGIC ARRAY (ULA)

There are many peripheral subsystems in telecommunications system designs that require a varying apportionment of gates, bistables and other logic elements. The ULA has been designed to enable such a variety of functions to be realized, and to allow their interconnexion. Existing bipolar ICs are manufactured by a combination of transistor and resistor diffusions into a silicon slice, with metallization on top of the oxidized silicon for interconnexion purposes. By adopting a suitable master-design of transistors and resistors repeated over the chip, it is possible to complete the diffusion process, and to hold in stock uncommitted ICs awaiting the various interconnexion patterns to be specified by the customer. This means that most of the costly processing is not customer-dependent, and that the ULA realization can be achieved more quickly and at less expense than a fully custom-designed IC. The ULA has been successful in this field because the particular bipolar technology used for its manufacture allows virtually the whole of the metallization mask to be used for the functional interconnexion of the ULA components.

ULA Structure

The ULA structure is basically an array of cells, each cell being equivalent to a 3-input NOR gate. Present-day ULAs have an array of about 200 cells and 40 or more external chip-bonding pads which can be associated with buffers for use as inputs, outputs or test points as required. Even within the uncommitted cell there is considerable flexibility (see Fig. 8). Here, each transistor is always provided, but, unlike in the PLA, it is the interconnexions between transistors and between cells which are programmable. For example, the dashed connexions shown in Fig. 8 would implement a 3-input NOR gate. Alternatively, the components from several cells could be interconnected in a completely different configuration to realize a far more complex logic function. Furthermore, the general-purpose transistors in the array are sufficiently versatile to allow the formation of basic linear functions such as amplifiers, oscillators, and comparators. The 2 photographs show the ULA detail before metallization (Fig. 9) and after metallization (Fig. 10).

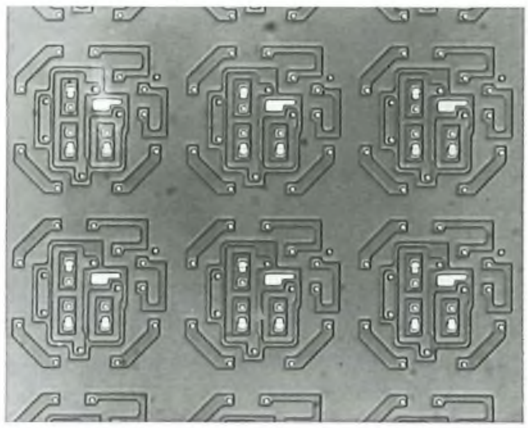


Fig. 9—ULA (before metallization)

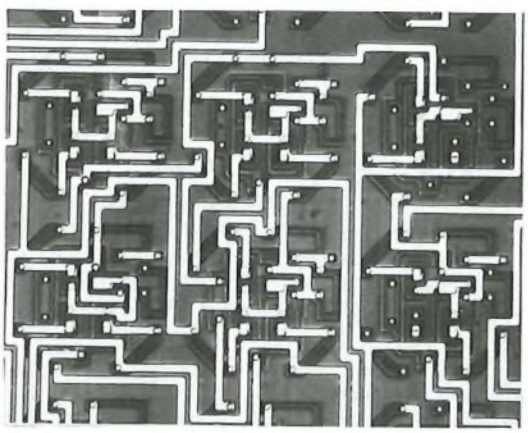


Fig. 10—ULA (basic cells with aluminium interconnexions)

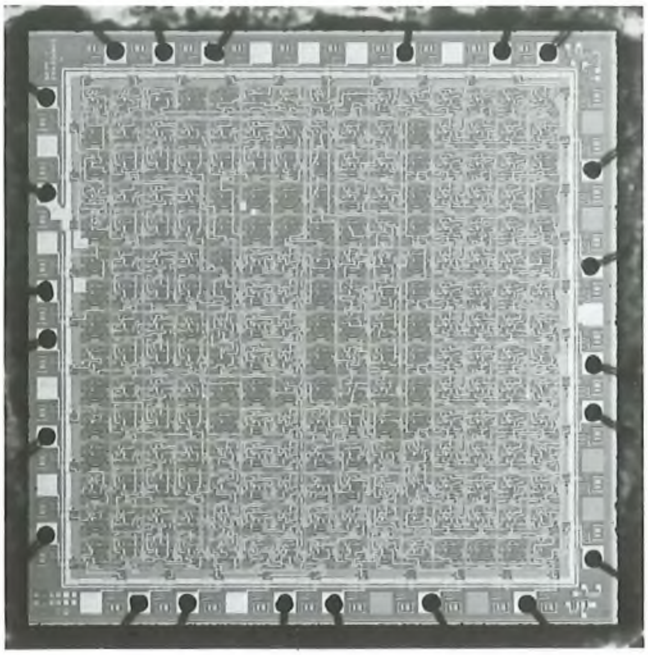


FIG. 11—Photograph of ULA chip

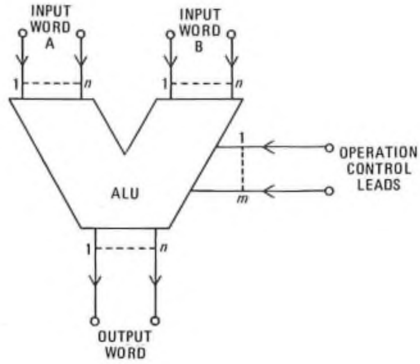


FIG. 12—Arithmetic logic unit

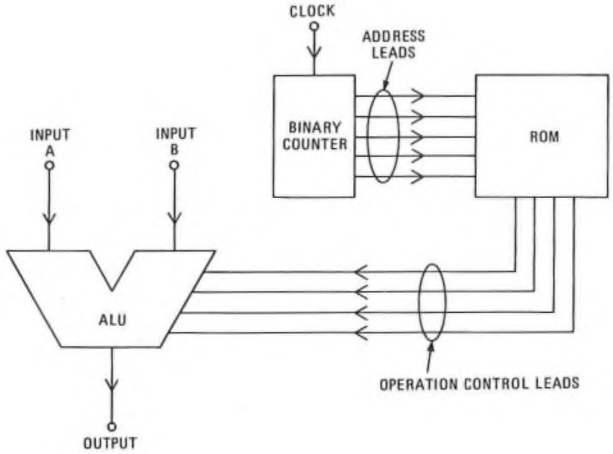


FIG. 13—ALU control

ULA Applications

Despite the mask-programming involved, ULAs are proving to be economic in applications where circuits are required in quantities of up to several thousands for each design, or where prototype LSI circuits are needed quickly. They are particularly attractive for replacing medium-speed digital functions consisting of both combinatorial and sequential logic. In a fairly regular logic circuit more than 90% of the cells may be used effectively, but highly-random logic could reduce this factor to 75%.

Existing ULAs of 200 cells have been used for industrial knitting machine sequencing, domestic camera control and a number of telecommunications tasks. An example of a telecommunications application is the ULA designed by BPO staff for the logic of an early PCM coder/decoder, this ULA was equivalent to 30 TTL packages, or over 200 gates. By careful design it was possible to realize this logic, including some buffer amplifiers, on one chip utilizing 195 cells. A completed ULA chip 3·4 mm × 3·4 mm is shown in Fig. 11. In applications such as the PCM coder/decoder the logic has to operate relatively quickly and most of the logic elements operate in parallel to perform only one function in the time allowed. Several ULA chips may be needed for highly complex applications operating at high speeds. However, where operating speeds are low, a single chip containing a suitable logic block can be programmed to carry out a complex task by performing several logic and arithmetic operations in sequence rather than in parallel. The arithmetic-logic unit (ALU) is such a general purpose logic block, and is available as a standard programmable component.

ARITHMETIC LOGIC UNIT (ALU)

An ALU is a collection of gates arranged such that various operations can all be performed by the same logic block under external control. A succession of these operations can be executed in sequence to perform a complex task. Different tasks can be performed by changing the sequence of basic operations.

Flexibility of the ALU

By connecting the ALU to 2 sources of data, words A and B as shown in Fig. 12, it is possible to perform a specified sequence of operations on these words and to produce the required outputs from the ALU under control of the operation control leads†. For example, one set of signals on the operation control leads could initiate a logic AND operation, and another set could initiate an arithmetic ADD operation. The ALU must obviously contain sufficient general purpose logic (generally including a full adder[8]) to allow all the required operations to be implemented. Usually, several logic operations: for example, NOR, EXCLUSIVE OR, ROTATE; and several arithmetic operations, such as, SUBTRACT and ADD, are possible. If an ALU has 4 operation control leads, these can be decoded to give 16 different operations.

Control of the ALU

The operation code must be applied to the operation control leads and, when a sequence of operations is to be performed, it is appropriate to store the corresponding sequence of operation codes in a store such as a ROM. This store is then accessed sequentially to supply each function word in turn to these control leads (see Fig. 13). The sequence of operation code words is commonly called the *stored program*. A simple binary counter could be used to supply the ROM address inputs required to step the ROM sequentially through the stored program.

The ALU and Accumulator

The output word from the ALU is often required to be fed back to the ALU input for a later operation and it is con-

† The ALU symbol shown in Figs. 12, 13 14, 17 and 19 though commonly used, is not yet an agreed British Standard[7]

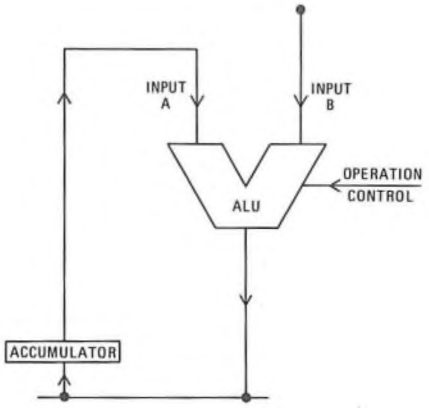
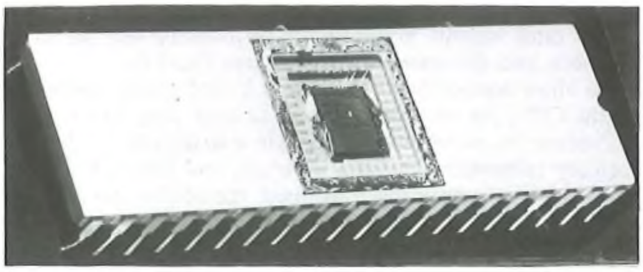
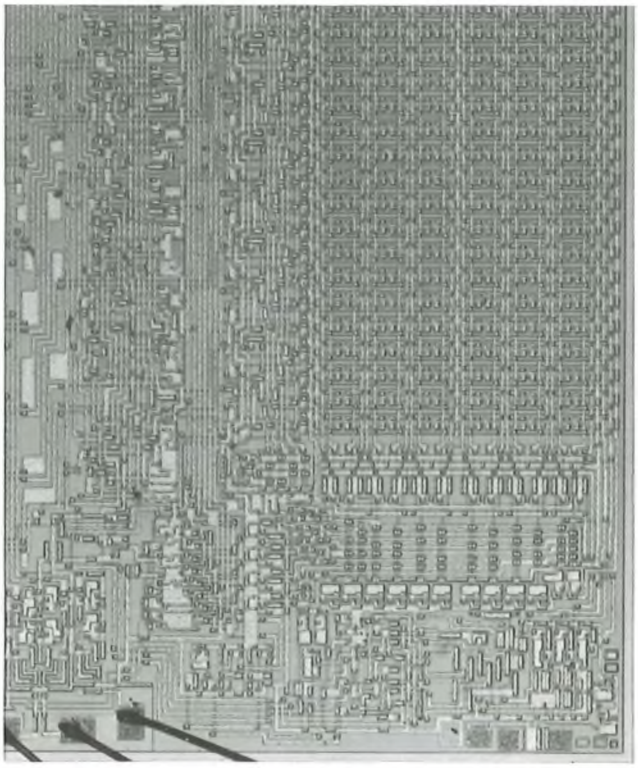


FIG. 14—ALU and accumulator



(*a*) Chip size 5·7 mm × 4·9 mm



(*b*) Enlarged section (2·4 mm × 2·9 mm)

FIG. 15—Photograph of UK designed microprocessor chip

venient to associate a register (a collection of bistables) with the ALU for storing these output words between operations. A simple instance of when this register is needed is the addition of several binary words. As the ALU handles only 2 numbers (words A and B) at a time, it has to add each number in turn to the previous sum total. The register is used to hold the accumulated sum; hence, the register is known as an *accumulator*. This simple structure of ALU, control and accumulator (see Fig. 14), forms the basis of a microprocessor. A microprocessor is often referred to by the size of word that is handled by the ALU and accumulator, typical sizes being 4, 8, 12 or 16 bit.

MICROPROCESSOR ARCHITECTURE

A microprocessor realizes the structure described (ALU, control and accumulator) in microelectronic form, using LSI technology. The heart of a microprocessor is an IC called the *central processing unit* (CPU). It usually contains several other registers in addition to the accumulator, ALU, and control circuit. These registers can be dedicated to particular functions such as the binary counter (commonly called the *program counter*) which sequentially steps through the program, or they may be used as general-purpose data registers for storing intermediate results of program operations. A British design of microprocessor has 48 general-purpose registers included on its CPU chip (Fig. 15*a*) which measures 5·7 mm × 4·9 mm, an enlarged section of which is shown in Fig. 15(*b*).

Microprocessor Memories

Some of the general-purpose registers are often grouped in the form of a RAM, provided on the CPU. To carry out an operation with a particular register (for example, to connect it to ALU input B), the instruction must specify which register is to be used. An instruction that refers to a particular memory address is called a *memory-reference instruction*. It must contain a memory address (to locate the required data in the memory) and an operation code (to instruct the ALU what to do). A small RAM of 16 words could be addressed by a 4 bit address code and, if the operation code is also 4 bit, the total instruction word is 8 bit, as shown in Fig. 16.

The program of instructions is usually stored in a uniformly partitioned memory, each word of which is the same width; for example, 8 bit (sometimes called a *byte*). It is convenient therefore to have all instructions of 8 bit width, or multiples of 8 bit in the case of multi-byte instructions where these are necessary. In many microprocessors the program instructions are stored in a separate memory device. They could be stored in RAM but, in practice, ROM or PROM is used for security.

OPERATION FIELD				ADDRESS FIELD			
BIT 1	2	3	4	5	6	7	8
OPERATION CODE				MEMORY-ADDRESS CODE			
1	2	3	4	1	2	3	4

FIG. 16—Memory-reference instruction word format

Microprocessor Bus Structure

In the case considered above (program instructions of 8 bit width), instruction words are transferred from an external program store to the CPU via 8 leads. Since with an IC package the number of leads available is limited, the same 8 leads are often used for the transfer of data between the CPU and other external devices. These data leads are termed the *data bus*, which is a bi-directional highway, interconnecting various devices supplying data to, and receiving data from, the CPU. The address leads to the program store can also be used by several external devices to conserve CPU package pins. When, for example, an external RAM is needed to increase the microprocessor data storage, both the RAM and ROM (and various input/output peripherals) use the same data bus and the same *address bus* (see Fig. 17).

To allow memories larger than 4 kword to be addressed by the CPU, the address bus needs to be at least 12 bit wide. To reduce the number of multi-byte instructions needed for memory referencing within a program, and hence, to reduce the program memory space required, the address can be held in a register on the microprocessor IC. By simply referring to this *pointer register*, a single-byte instruction can be used to access a location in the main memory. The term *register-indirect* addressing is commonly applied to this scheme.

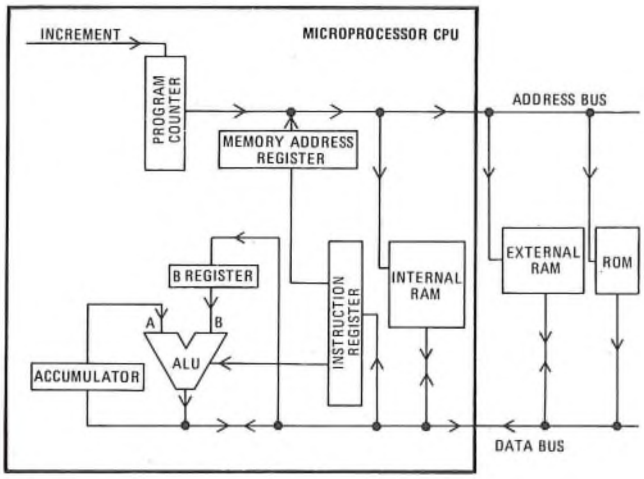


FIG. 17—Microprocessor CPU and bus structure

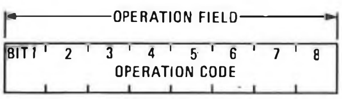


FIG. 18—Non-memory-reference instruction word format

Many variations in addressing modes are possible. In an *indexed* addressing scheme, a partial address in the instruction is added to (or subtracted from) an address contained in an *index register*. If the register contains only part of the address, and the instruction contains the other part, the 2 partial addresses can be assembled to form a complete address. Such schemes offer the advantage that the register need not be reloaded for each reference to a different location. In all the techniques, the object is to provide the ability to refer to an arbitrary location in the memory without having to carry the full address within each and every instruction. The problem is particularly acute in microprocessors where the length of a single instruction word is often less than that needed to access the full memory-address range.

Instruction Register and Decoder

The instruction word obtained from the program store is sometimes held in an *instruction register*, while the instruction is segregated into the operation code (which is fed to the control logic) and the memory address code, if present. Some instructions have no memory address; examples are CLEAR ACCUMULATOR (often abbreviated to the mnemonic CLA), INVERT ACCUMULATOR CONTENTS (INV) and PROGRAM HALT (HLT). In such cases, all 8 bit of the instruction word are available to specify the operation code, as shown in Fig. 18. The *instruction decoder* has therefore generally to examine the whole of the instruction word before the control logic can be instructed on which operation has to be performed. A block diagram of the microprocessor CPU architecture (including the location of the instruction register and decoder) is given in Fig. 19.

One of the most complex parts of the CPU is the control logic. This logic controls the operation and information flow within the CPU, and also the transfer of information over the data bus and the address bus. This logic usually operates synchronously under the control of a *cycle counter* (*or state generator*) driven from a system clock. When a memory-reference instruction is to be executed, the control logic has to transfer the memory address specified in the instruction to the address bus, possibly via a memory-address register. Alternatively, the control logic can transfer a memory address to the program counter to cause the program sequence to be

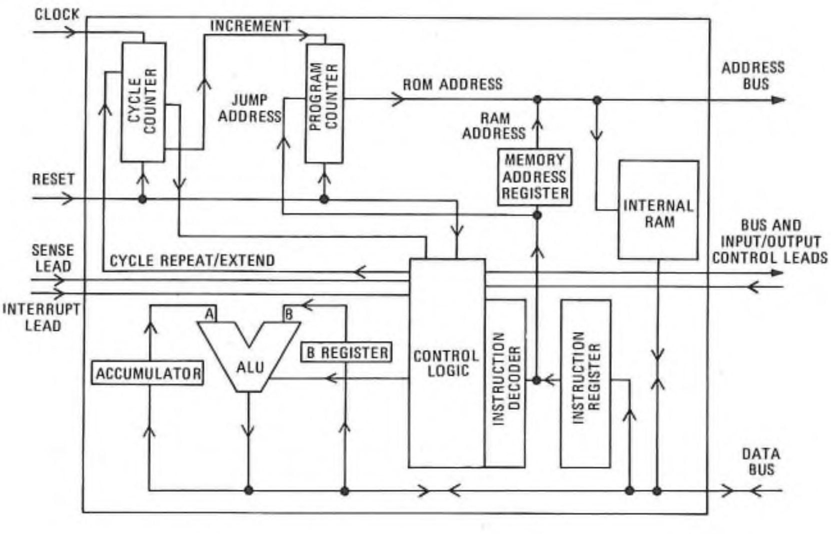


FIG. 19—Microprocessor CPU architecture

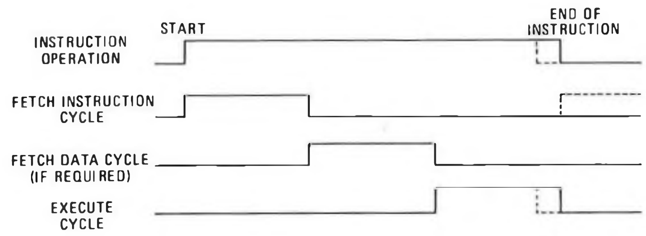


FIG. 20—Typical cycle sequence

changed by what is known as a JUMP instruction. Several JUMP instructions are usually provided, and some are made conditional on the status of internal data or external sensing leads. By using JUMP instructions, branching can be introduced into the program flow. The control logic and instruction decoder may be designed to handle many instructions other than those discussed, but there is a sequence of operation that is basic to all instructions.

MICROPROCESSOR OPERATION

Each operation starts with a FETCH instruction cycle, which may be followed by various other cycles, according to the instruction being executed. If data has to be fetched from a ROM or RAM before the basic instruction is executed, a second FETCH DATA cycle is required before the EXECUTE cycle (see Fig. 20). These cycles are subdivided into a number of elementary activities, called *micro-instructions*, within the microprocessor.

Fetch Instruction Cycle

During the FETCH INSTRUCTION cycle, the instruction to be executed is fetched from the program store. At the start of a program, the program counter has to specify the address of the first instruction; for example, location 0. If the program counter is reset to 0 at the start of the program, it will contain the correct ROM address and can be connected to the address bus to select word location 0 in the ROM (see Fig. 21). The content of this location is the first instruction word of the program, which is then returned to the CPU over the data-bus, and stored in the instruction register. The instruction decoder can then determine which instruction is to be executed and what the control logic must do to that end.

Fetch Data Cycle

An example of a simple instruction is "ADD contents of RAM location 5 to the contents of the accumulator, and store the result in the accumulator" this instruction is sometimes abbreviated to ACC $\leftarrow$ (ACC) + [5]. The instruction requires a FETCH DATA cycle to fetch the data (the contents of RAM location 5) into the CPU before the addition can be performed (Fig. 21). The RAM address 5 is specified in the *address field* of the instruction word. This address (coded say on 4 bit as 0101) is then forwarded to the address bus to fetch the contents of RAM location 5 into the ALU via the data bus and B register.

Execute Cycle

The operation code, specified typically by another 4 bit code, is also part of the instruction word held in the instruction register and is used during the execute cycle. The operation code instructs the ALU to add together the contents of the accumulator and the contents of the B register, which now contains the data from the RAM. In this instruction, the result is fed back into the accumulator but, in more complex

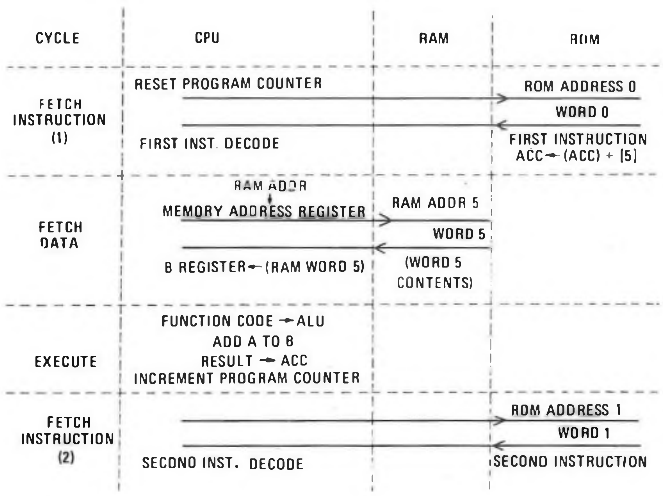


FIG. 21—Typical microprocessor operation

instructions (for example, INCREMENT THE CONTENTS OF A RAM LOCATION BY 1), the result may have to be returned to an off-chip device; to achieve this would require a WRITE cycle to send the result over the data bus to the peripheral, for example to the RAM. Multi-byte instructions need more than one FETCH cycle to obtain the full instruction from the ROM. In some cases, it may be necessary to extend the EXECUTE cycle to give time for the instruction to be completed.

Next Instruction

Before the next instruction can be started (with another FETCH instruction cycle), the program counter must be updated to give the address of the next instruction to be executed. If this new address is the one following that of the previous instruction, the program counter has simply to be incremented by 1 (from 0 to 1, using the example quoted above). However, during a JUMP instruction, the program counter must be preset to a new value specifying the address to which the jump is to be made. This new address may be derived from part of the JUMP instruction word, and placed in the program counter as part of the execution of the JUMP instruction.

When the current instruction has been fully executed and the program counter contains the address of the next instruction, the control logic restarts the control sequence by initiating the next FETCH instruction cycle.

Only a superficial description of the operation can be given here, and in some types of microprocessors more complex instructions (for example, using indexing and indirect addressing) are possible.

Where the main program contains a sequence of operations that is used several times, it is economic to store the sequence once only and to divert the main program flow to this so-called *sub routine*, whenever it is required. When the jump is made to the sub routine the current address of the program counter is stored in another register, and the program counter is loaded with the START address of the sub-routine. After completing the sub-routine, the program counter is reloaded with the RETURN address, so returning the microprocessor to the correct place in the main program. A sub-routine can be initiated either by a special JUMP instruction in the main program or, in some microprocessors, by an external *interrupt* from a peripheral needing urgent attention. In the latter case, the sub-routine would contain a program to deal with the peripheral.

CONCLUSION

Microprocessors differ widely in their architecture and instruction sets and, in some cases, the registers and other blocks mentioned in this article may be either omitted altogether or used for purposes other than those so far described. Some microprocessors allow the user to specify the instructions available to him using a technique known as *microprogramming*. In other microprocessor systems, a program store is contained on the CPU chip and the program is mask-programmed by the manufacturer. The size of the store in such devices is obviously restricted, and they are at present limited to relatively simple applications. An interesting development recently announced is a single-chip microprocessor containing its own reusable program store on a chip.

When long programs are involved, or large amounts of data are to be processed, it is often preferable to build up a more versatile microprocessor system by adding peripheral components around the CPU chip. Special interface circuits such as serial transmitter-receivers, memory controllers and interrupt controllers for input/output devices such as teleprinters and relays can be connected to the system as required.

The microprocessor system may be purchased in component form, or as a complete development system on a printed circuit board, or in a metal cabinet complete with power supplies and control panel. The availability of suitable development aids, both software and hardware, is a major factor in the economics of using microprocessors.

It is important to note that whereas the use of custom-designed LSI circuits is restricted by the high chip-design costs, so the use of microprocessors is likely to be limited by the cost of the program (or *software*) development. It is intended to describe the significant topics of programming and microprogramming of microprocessors in the next article in this series.

ACKNOWLEDGEMENTS

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Optical-Fibre Transmission Systems: Overview of Present Work

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UDC 621.391.63:677.521

The concept of optical-fibre transmission systems has now matured to the reality of operational systems carrying telephone traffic. This article provides a general survey of the present activities in the field of optical-fibre transmission systems, and is an introduction to a series that will describe the detail of the construction, installation and performance of the experimental British Post Office systems now in operation.

INTRODUCTION

A series of articles on the properties of fibre components and optical-fibre transmission systems was presented some years ago in this *Journal*[1-6]. This present article is the first of a new series of articles that will report on the progress that has been made since then and, in particular, on the experimental systems that have been installed by the British Post Office (BPO) Research Department in the Martlesham area with the assistance of Eastern Telecommunications Region staff.

The systems work has been implemented to gain experience of working with fibres in the field. Consequently, complete systems have been built and installed that are currently carrying telephone traffic although, throughout the project, the emphasis has been on flexibility of design and implementation to allow rapid evolution to occur and the maximum experience to be gained. As a result of this, the technical limits for the first systems have become much more clearly defined, and the components to be used and the "trade-offs" associated with each are better understood. While the equipment has been constructed using BPO 62-type equipment practice and is thus compatible with existing transmission equipment practice, it is not intended to serve as a field trial system suitable for subsequent production.

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RANGE OF ACTIVITIES

The major work to be described in this series of articles centres on 2 line transmission systems, operating at 8·448 Mbit/s and 139·264 Mbit/s. These systems are oriented primarily at junction and main network applications respectively, and the cables associated with those networks. Both systems have been demonstrated to operate over multimode graded-index fibre cables, installed in duct emanating from the BPO Research Centre at Martlesham. In total, 20 km of cable has been installed to give, after jointing, one link of 13 km from the Research Centre to the group switching centre (GSC) at Ipswich, via the Kesgrave telephone exchange, and a second link of 5·75 km from the Research Centre to Kesgrave.

The 13 km link to the Ipswich GSC is primarily reserved for 8·448 Mbit/s studies, while the 5·75 km link is to be used initially for the higher bit-rate system. All of the cables in use on the Martlesham-Kesgrave-Ipswich route were manufactured by BICC Telecommunications Cables Ltd., using Corning fibre, this type of cable being commercially available at the outset of the study early in 1976.

A number of other cables are being studied or will shortly be studied, notably 2 km of STC 8-fibre cable, 6 km of BICC cable using BPO fibre, and a 1 km length of GEC cable. These cables will all make use of the same route from the Research Centre so that detailed comparative measurements will be possible.

In support of these activities, a field measurement capability has been established which has allowed the precision measurement of fibre cables (installed in duct) before and after jointing operations. This has highlighted both strengths and weaknesses in the jointing techniques, but has demonstrated beyond doubt that fibres can be taken out of the laboratory and that jointing in the field can be done effectively. This experience is now being translated into tested techniques that can be implemented by technicians after a few hours' training.

In the laboratory, intensive activity has continued on all the components of these systems. Foremost has been the laser development, where substantially reduced drive currents, increased lifetimes and better temporal and spatial stability have been achieved, to the point where it has become entirely feasible to design systems around them. Lasers manufactured by STC have been used in the systems demonstrations described above, and BPO manufactured lasers are being tested with simpler and more-efficient drive circuits for later use.

Fibre connectors have been developed that allow fibre cable to be connected to a repeater in a similar manner to that for an electrical cable, and these connectors are now widely used. Equipment and techniques for preparing fibre ends and splicing them have been developed and demonstrated in the field, although the objective of developing a fully-automated splicing tool has not yet been achieved.

MAJOR RESULTS OF WORK

Perhaps the most important result to note at this time is that, in all, some 58 km of fibre have been installed in 23 km of cable of various designs without any fibre breakage. All the cable has proved to be stable under conditions of drawing-in and temperature-cycling tests, and approximately 40 field splices of fibres have been completed without difficulty.

All 4 fibre links from Martlesham to Kesgrave (5·75 km each) and the 2 links from Kesgrave to Ipswich (7·25 km each) are suitable for unrepeatered operation at 139·264 Mbit/s. Two of the former links are also suitable for higher bit rate operation over their full length, since they have 3 dB bandwidths in excess of 140 MHz over the total length of 5·75 km, with a baseband optical insertion loss of about 25 dB.

On the systems side, it has been demonstrated that an 8·448 Mbit/s system can be operated over 12–13 km without an intermediate repeater, and the 139·264 Mbit/s system has been operated without an intermediate repeater over 6 km, with sufficient margin to allow at least another 1 km of cable to be inserted. In each case, these distances represent a very substantial increase in the possible repeater separation over any comparable system, and thus promise savings in installation capital costs and reductions in maintenance liability.

ACTIVITIES IN INDUSTRY

Development of both components and systems is well advanced in the UK telecommunications industry, and demonstration systems are now emerging from the laboratory. The first complete system to be seen is a 140 Mbit/s link of 9 km from Stevenage to Hitchin, manufactured by STC/STL. It uses the STC fibre cable and includes 2 intermediate buried repeaters. The installation was completed recently and the system has commenced operation successfully under test conditions. Both Plessey/BICC and the GEC groups also have systems under development.

CONCLUSION

Later articles in this series will describe the components used in the transmission systems outlined in this article and their interactions within the system environment. In particular, the design, construction and performance of the systems built by the BPO Research Department for operation at 8·448 Mbit/s and 140 Mbit/s will be examined; the techniques used for field measurement, installation and jointing of the fibre cables, and the properties of the fibre cable as a transmission medium, will also be included.

It seems certain that these experimental systems will bear a close resemblance to the first systems that will one day enter operational service, and the underlying principles are most unlikely to undergo major change. Therefore, the articles to be published in this *Journal* (the first of which appears on p. 146 of this issue) should serve as a first introduction to the principles and technology of optical-fibre transmission systems, and will provide a basis for understanding how the system works, and what limits or controls its performance.

The timing and sequence for introducing optical-fibre transmission systems into the network has yet to be agreed and a number of problems have to be overcome. In addition, being a totally new technology, there has to be time for production to build up and operational experience to be gained. Since it appears that the systems cost will be highly volume sensitive, the first systems are likely to be expensive and it may be sensible therefore for early installations to concentrate on routes where the small fibre-cable size or long repeater-section length is particularly advantageous. These and other factors are being actively studied and it is expected that some preliminary targets will soon be established.

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Optical-Fibre Transmission Systems: The 8·448 Mbit/s Feasibility Trial

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UDC 621.391.63: 666.2

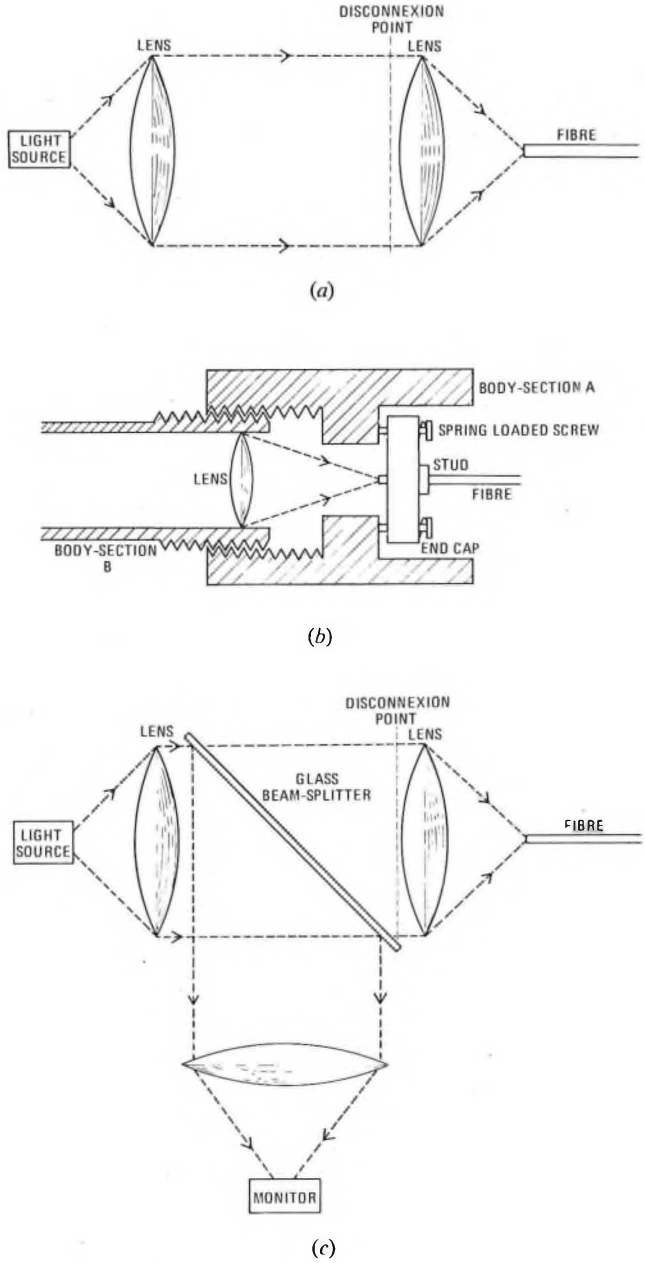
This article describes the feasibility trial of an optical-fibre transmission system developed by British Post Office (BPO) Research Department staff. The system operates at 8·448 Mbit/s between the BPO Research Centre at Martlesham Heath, and Ipswich, a distance of 13 km. The commercially-produced fibre cable was installed by Colchester Telephone Area staff, and the system now provides telephone circuits connecting the BPO Research Centre and Ipswich.

INTRODUCTION

Great strides have been made over the last few years in the development of optical fibres suitable for use as transmission media for the telephone network. Optical-fibre cables having losses of less than 5 dB/km are now readily available and, of significance, the improvement in the profile control of the graded-index fibre has made available transmission bandwidths suitable for operating at information rates of 140 Mbit/s and above. It was timely, therefore, to plan and develop an optical-fibre transmission system on an experimental basis to gain experience in the installation of an operational system.

To emphasize the scale of progress in this field of work, the 8·448 Mbit/s feasibility trial, described in this article, had been originally planned during the latter part of 1975 to use step-index fibres and light-emitting diodes (LEDs). However, early in 1976, a graded-index type of fibre[1] became available as a commercial product and lasers followed shortly afterwards. The use of these component parts enabled the originally proposed Martlesham–Kesgrave route trial to be extended to Ipswich, a total distance of 13 km. The fibre used in the experiment is of high-purity silica produced by the Corning Glass Company using the chemical vapour deposition process[1]. The loss of the fibre as a function of wavelength gave the optimum operating point at about 840 nm, which could be met by the use of Ga(Al)As sources[2]; near-optimum sensitivity at this wavelength was achieved by using silicon avalanche photodiodes (APDs)[3] to provide a system which, as a whole, could function with the most favourable parameters. For a system 10 km in length, the graded-index fibre was required to have a bandwidth of 200 MHz when measured over a length of 1 km. This allowed adequate performance margins to operate an 8·448 Mbit/s transmission system, assuming that the bandwidth decreased proportionately with the length of the fibre. In practice, the performance of the fibre was considerably more promising than expected, and has enabled more extensive experiments up to 140 Mbit/s to take place; these will be described in a subsequent article in this series.

To install an optical-fibre cable, permanent joints are required between cable lengths but, to provide rapid replacement of equipment modules, a demountable coupler is also necessary for both transmitter and receiver. In the case of the transmitter, monitoring facilities are needed to provide supervision and feedback to control the optical output. A number of couplers designed on optical principles were developed at the BPO Research Centre to satisfy the needs of the experiment. Fig. 1 illustrates the principles of 2-port and 3-port demountable lens couplers and alignment and focus facilities, the details of which are described later.



(*a*) 2-port demountable lens coupler
(*b*) Alignment and focus facilities of lens coupler
(*c*) 3-port demountable lens coupler

Fig. 1—Lens couplers

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TABLE 1

Relative Performance of Optical Sources

Source	Available Power in Fibre (dBm)	Spectral Width (nm)	Information Rate (Mbit/s)	Threshold Level (mA)	Mode of Operation
LED	−12	20–100	up to 34	0	Return-to-zero
Laser	0	1–2	up to 300	50–180	Non-return-to-zero (140 Mbit/s) Return-to-zero (8 Mbit/s)

An optical-fibre system can be regarded as a carrier system in which incoming signal information is translated into the optical spectrum, propagated through the glass-fibre medium and then reconverted to the basic information, which may be in digital or analogue form. Unlike most carrier systems, data is translated directly to the optical spectrum while, at the receiving end of the system, it is reconverted without intermediate-frequency amplifying stages. The carrier is not a discrete frequency since optical energy is generated in this case; electrons release their energy on recombination in a forward-biased semiconductor junction, and the frequency generated depends upon the conditions prevailing at the particular time of recombination of each carrier. An extension of the LED is the laser, in which the optical radiation in the junction is trapped between the end faces of the device which provides positive optical feedback within the cavity thus formed. When sufficient optical power is generated the stimulation of further radiation occurs, and a rapid build-up of optical emission takes place. The lasers which are now available provide an output power of about 1 mW into the fibre, while LEDs provide about 50 μW. The LED emission occupies a very broad spectrum in the range 20–100 nm, at a mean wavelength of about 850 nm. In terms of frequency, the mean value is $3 \cdot 5 \times 10^{14}$ Hz, and 20 nm spectral width gives a frequency spread of about 8×10^{12} Hz. However, the laser emits more coherent radiation, giving a spectrum width of about 2 nm. The spectral spread of a source introduces transmission distortion when dispersion is present in the glass fibre—such as is evident in glass prisms over the full optical range. For example, if the dispersion due to a fibre is 75 ps/km/nm, then the pulse-spreading produced with a source spectral width of 40 nm is 3 ns/km. However, the LED can be used satisfactorily at bit rates of at least 8 Mbit/s (the period of an 8 Mbit/s signal operating at a line rate of 10 Mbit/s is 100 ns).

The performance of available light sources is summarized in Table 1.

At 8·448 Mbit/s, it is possible to operate the laser directly from zero to full output, particularly the low-threshold devices. This method allows reduced pulse-width operation, and has the effect of reducing the duty cycle and perhaps enhancing the operational life of the laser.

At the receiving end of the system, a semiconductor junction is used to convert the optical energy back to its original electrical form. The p n junction is reversed-biased to produce a high-intensity field, so that electron-hole pairs, which are generated by the impact of incident optical energy, move in opposite directions under the influence of the field, thereby creating a flow of current. As a reverse-biased device, the photodiode has a high output impedance. It operates as a constant-current generator, and the load applied to the device requires special consideration for optimum performance. Typical sensitivities of photodiodes available for optical-fibre systems operating at 8 Mbit/s are −61 dBm for an APD and −49 dBm for a p i n diode giving error rates better than 1 in 10^9.

FEASIBILITY TRIAL

The 8·448 Mbit/s feasibility trial has been undertaken on a 13 km route between the BPO Research Centre at Martlesham and Ipswich. Two modes of operation have been used: non-

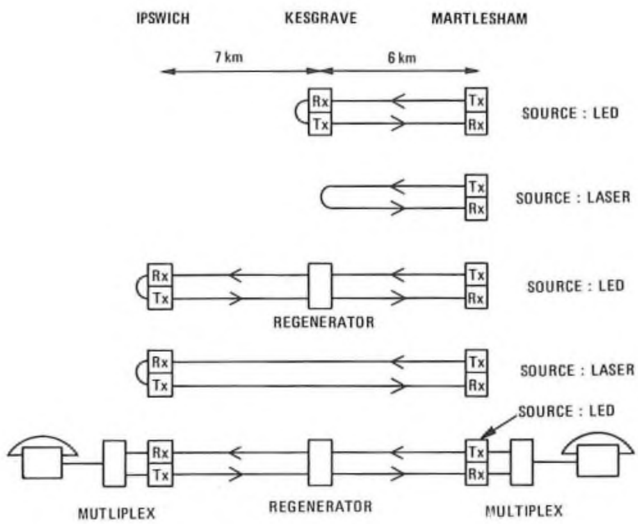


FIG. 2—System arrangement

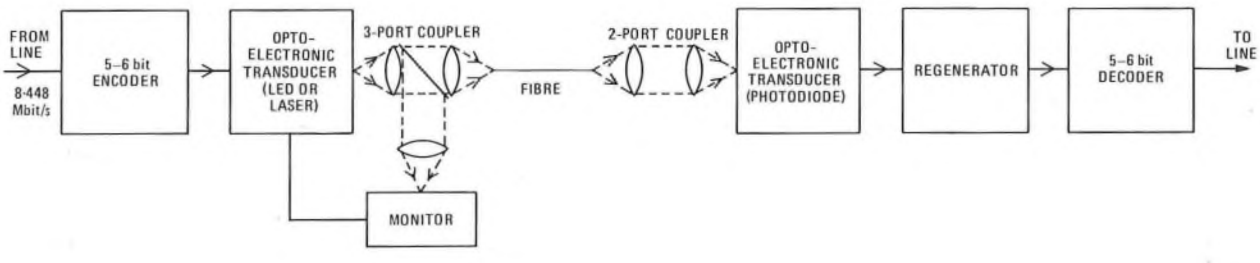


FIG. 3—Block diagram of 8·448 Mbit/s optical-fibre system

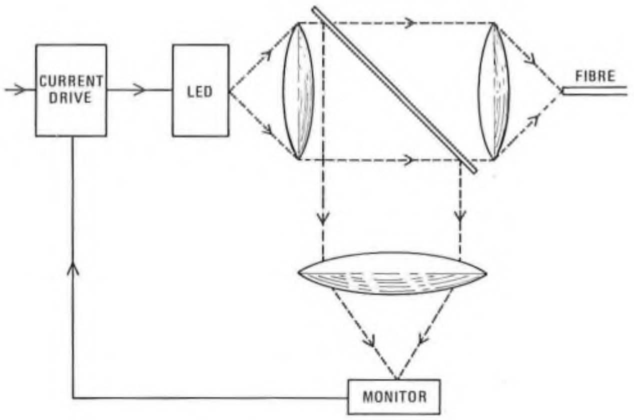


FIG. 4—LED control

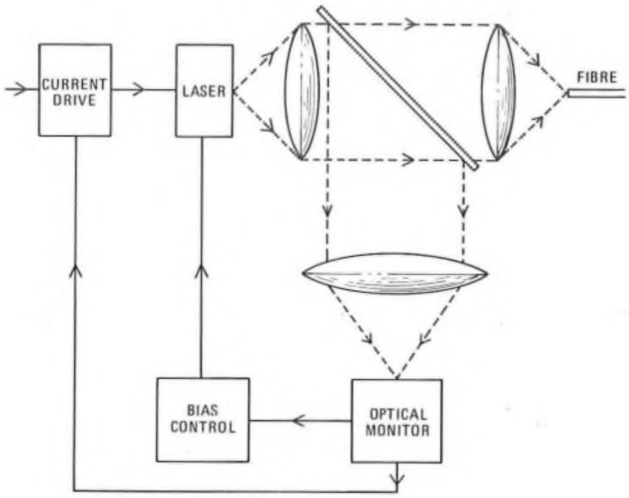
repeatered operation over 13 km using laser sources, and repeatered operation via an intermediate surface station at the Kesgrave telephone exchange using LEDs as sources. System arrangements adopted to date are shown in Fig. 2. A block diagram of the basic 8·448 Mbit/s optical-fibre system is shown in Fig. 3. The individual blocks are discussed separately.

Optical Transmitter

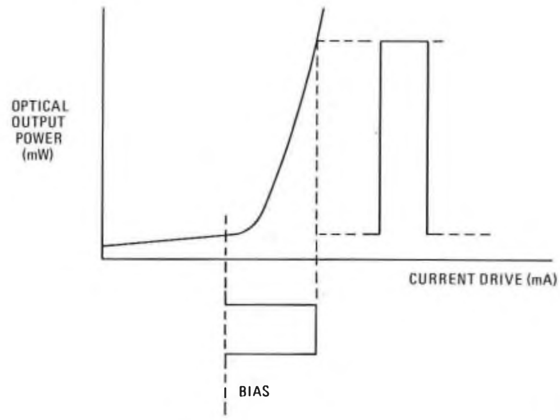
Only LEDs were available initially and, although relatively easy to control, these have limitations in coupling the optical output to the fibre since their radiation pattern is almost isotropic. The advent of lasers, with their well defined, small, (even though assymetrical) output beam, enabled more power to be coupled into the fibre. However, the initial requirements for maintaining the laser about threshold demanded fairly complex control circuits.

The control of the LED is illustrated in Fig. 4. A sample of mean optical output energy is employed, and is applied as feedback to adjust the current drive, such that if the diode characteristic changes, a suitable change in current drive is produced.

One technique used for controlling a laser is illustrated in Fig. 5(*a*) and (*b*). It can be seen from Fig. 5(*b*) that the laser has a non-linear optical-output-power/current-drive characteristic in which the spontaneous non-lasing light output increases very gradually with drive current until a threshold is reached at which lasing action occurs and results in a very rapid increase in light output. The laser control circuit is required to cater for a range of characteristics, governed by such factors as temperature, ageing and variations from sample to sample. A cautious approach was taken, catering for thresholds between 200 mA and 350 mA, and optical outputs, above threshold, between 0·2 mW/mA and 0·8 mW/mA. The laser control circuit therefore needed some form of automatic control.[4]



(*a*) Laser control unit



(*b*) Typical laser characteristic

FIG. 5—Laser control

One method that has been adopted is peak and trough detection, in which the optical output bit stream is monitored and the signals derived are separately used to change the current drive on the one hand and the bias condition on the other. For lasers with lower thresholds, that is about 50 mA, and using half-period pulses, it is possible to use a less complex method, and a control similar to that of the LED given in Fig. 4 has been used. This provides switching directly from zero and thus controls only the mean power emitted. Voltage rails of ±6 V are adequate for both techniques. The operating conditions for typical optoelectronic transducers are given in Table 2.

TABLE 2

Operating Conditions for Optoelectronic Transducers

Type	Emission Wavelength (nm)	Bias Current (mA)	Threshold Current (mA)	Drive Current (mA)	Optical Power (Note 2) (μW)	Feedback
LED BNR40/3/30/2	820	0	–	300	65	Mean
Lasers: STL } (Note 1)	840	150	160	30	1000	Peak and Trough
BPO } (Note 1)	860	0	50	80	300	Mean

Note 1: The Standard Telephone Laboratories (STL) laser was developed under a contract placed by the BPO, and the BPO laser was developed at the BPO Research Centre
Note 2: Optical power measured at output of 1 m of graded-index fibre

Fig. 6—A bulkhead-mounting 3-port coupler and fibre-terminated half-coupler

TABLE 3

Lens Focal Length for Coupler Arrangements

Half-Coupler Application	Focal Length of Lens
LED–Laser	4 mm
Fibre–LED	8 mm
Fibre–Laser	15 mm

Lens Couplers

Fibre-to-transducer connexions are made by means of demountable lens couplers[5]. A complete coupler comprises 2 half-units, each of which contains a convex lens used to focus the optical energy on the fibre and/or transducer (see Fig. 1(*a*)). Disconnexion of the coupler is possible at a point between the 2 lenses where there is a parallel beam of energy. Fibre ends or devices are fixed into position by use of end caps. In the case of fibre ends, the cap has a central hole, into which a fibre is fixed with fast-setting adhesive. Lateral alignment and fixing is facilitated by means of spring-loaded screws (Fig. 1(*b*)), while rotation of the coupling body-section A, in relation to body-section B, ensures that the fibre end is at the focus of the lens. Similar facilities ensure the correct location of devices mounted on end caps.

The lenses used were of 6 mm diameter, convex and were available with focal lengths to suit the 3 applications listed in Table 3.

A fibre–fibre coupler assembly has a 1 : 1 imaging ratio and, typically, an insertion loss of 1 dB. An LED–fibre coupler assembly has a magnification of 2 : 1, so an LED with a 50 μm diameter emissive area produces a 100 μm diameter image. Although this image overfills a 62·5 μm core diameter fibre, it relaxes the tolerances for lateral and angular alignment of the coupler assembly. A laser–fibre coupler assembly produces a magnification ratio of about 4 : 1 and, although the resultant image (which is not circular) would underfill a 62·5 μm core fibre, it also relaxes alignment tolerances.

A 3-part coupler (Fig. 1(*c*)) is available for use where monitoring facilities are required. Ten per cent of the energy in the parallel beam is diverted to a third lens by a beam splitter and is focussed on a photodiode. A bulkhead-mounting 3-port coupler and fibre-terminated half-coupler are shown in Fig. 6.

Cable

The optical-fibre cable used for the feasibility trial was manufactured by BICC Telecommunications Cables Ltd., and used 2 Corning graded-index fibres, having a core diameter of 62·5 μm and a transmission loss of about 4·5 dB/km. The cable construction (Fig. 7) comprised 2 parallel steel strength members, each about 1 mm diameter and spaced about 6 mm apart, sheathed in polyethylene. Between the steel wires were situated 2 cavities, each of which contained one fibre.

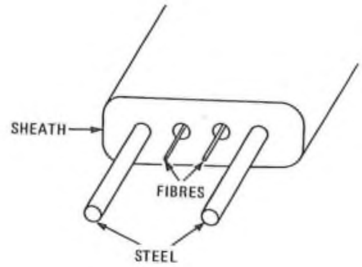


Fig. 7—Two-fibre cable construction

Cable Installation

The cable was installed (Fig. 8) in fourteen 1 km lengths by Colchester Telephone Area staff. The cable ducts used varied in their age, condition, depth and fill, and none of the ducts was empty. A 20-pair copper-conductor cable was also installed to provide supervisory facilities for the trial.

Fibre-to-fibre joints were made using a V-groove technique.[6] Close tolerance alignment of the fibre-ends to be joined was achieved by placing the 2 fibre-ends in a V-shaped groove formed in a rectangular copper plate (5 mm × 10 mm). The joints were housed in standard BPO Sleeves No. 31A. Jointing was undertaken by BPO research staff in a specially equipped vehicle used also for field measurements of transmission performance. Sufficient optical cable was provided at each jointing station to facilitate access to the test vehicle, and to provide maximum possible fibre lengths between terminals, the cable lengths were not trimmed to size.

Fig. 8—Installation by Colchester Area staff of optical-fibre cable

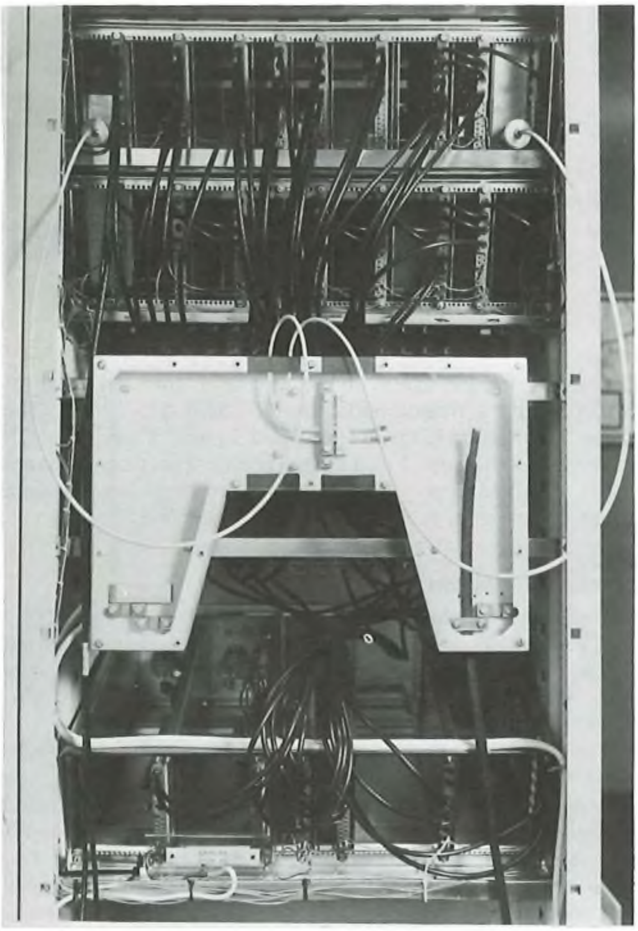


FIG. 9—Termination of optical fibre cable

Before fibre–fibre or fibre–transducer joints are made, it is essential that the end face of the fibre be perpendicular to the axis of the fibre. This can be achieved by breaking the fibre under controlled conditions. A jig has been devised by the BPO Research Department which clamps the fibre onto a curved table, thereby subjecting the fibre to differential stress. A tungsten-carbide blade is then lowered onto the fibre causing a scratch to be made on the fibre surface. The stress condition causes the scratch to develop into a clean break and results in a rapid fracture perpendicular to the axis of the fibre.

At the surface station the optical cable was terminated directly on the rear of the equipment racks (see Fig. 9).

Optical Receiver

Before considering the detection of optical energy, it is worth reviewing the 3 most significant sources of noise[3].

Thermal Noise

Thermal noise has a mean square current value of

$$\frac{4kTBN}{R},$$

where k is Boltzmann's constant, T is the absolute temperature, N is the noise factor of the following amplifier, R is the load resistance and B is the bandwidth.

Quantum Noise

When a photodiode is subjected to optical energy, electron-hole pairs are liberated, giving rise to current in an external circuit; that is, the photodiode acts as a current generator. However, the received optical energy arrives in discrete "packets" (*quanta*), rather than a continuous wave. The random nature of the arrival of the quanta produces a quantum noise having a mean square value of $2qI_pB$, where q is the electron charge, I_p is the photocurrent and B is the bandwidth.

Dark-Current Noise

Dark-current noise has a mean square value of $2qI_dB$, where I_d is the dark current (a function of the bulk material and reverse-bias voltage). By the use of selected silicon devices, it is possible to reduce the dark-current noise to insignificance.

Two types of photodiode are worthy of consideration here, the p n junction and the APD.

Using a p n junction diode with associated preamplifier, the dominant noise is thermal. Therefore, stringent requirements are placed on the following amplifier since minimum noise conditions demand minimum acceptable bandwidth, low noise factor and maximum load resistance. The latter, together with stray capacitance, results in integration of the pulse, and this can be corrected by differentiation in the later stages when the signal-to-noise ratio is acceptably high. However, it is desirable to minimize stray capacitance, and thus p n junctions are best suited to applications where the signal-to-noise ratio is relatively high, for example, monitoring. A particular type of p n device has been used for the trial in which an intrinsic layer is sandwiched between the p and n materials thus creating a p i n diode. In this device, the electric field can be made to extend across the intrinsic layer when the junction is reverse biassed, giving a depletion region much greater than in a p n junction and hence improving *responsivity* (current generated per unit optical power). Devices have been used with bias voltages of 30 V and responsivities of 0·5 A/W.

When an APD is used, an additional noise effect is introduced. Since the avalanche effect is essentially multiplication by a factor M, the noise current is also multiplied by the same factor. Furthermore, the random nature of the avalanche process introduces yet more noise (N_e) which is also a function of M. The resultant quantum noise, therefore, has a mean square value of $2qI_pBM^2N_e$. It can be seen from Fig. 10, how the signal and total noise varies with M, and how an optimum value of signal-to-noise ratio occurs when thermal and quantum noises are about equal.

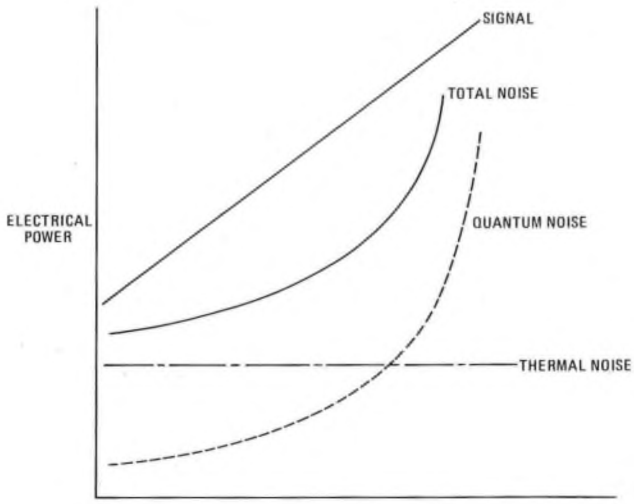


FIG. 10—Variation of signal-to-noise levels with change of multiplication factor for an APD

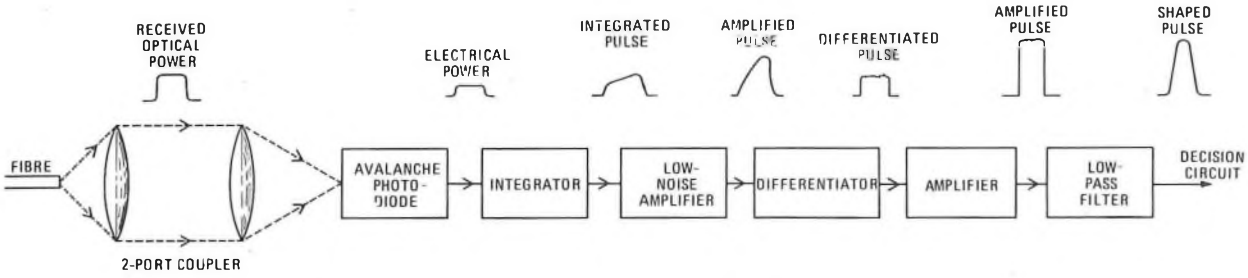


FIG. 11—Block diagram of optical-electrical receiver

An APD operating at its optimum gain, therefore, exhibits a best signal-to-noise ratio and allows the tolerances on the following amplifier to be relaxed, since the thermal noise no longer dominates. The APD is thus more suited to applications where the signal-to-noise ratio would be inadequate for p n devices, for example where low-level signal detection is required.

For the 8·448 Mbit/s system, APDs have been used for the main receiver; in particular, a type known as a *reach-through* device has been used. The reach-through device has a greater depletion region than a conventional APD giving a similar advantage to the p i n over the p n diode. A reach-through APD is used which has a responsivity of 0·4 A/W at unity gain, and is operated with stable bias voltages in the range 180–400 V and, ideally, an optimum gain of about 40. A block diagram of the receiver module is shown in Fig. 11. The APD is followed by a high-impedance stage, for maximum transfer of power, and can use AC coupling since the encoded received signal now has no DC content.

The load impedance (1 MΩ) and capacitance (6–12 pF) have the effect of integrating the pulse stream, but this is compensated after the first amplifier by the inclusion of a differentiator stage. The loss introduced by the differentiator is compensated by further amplification, and the pulse shape required for minimum noise bandwidth (for example, raised cosine) is obtained by a low-pass filter. The gains of both first amplifier and APD are controlled by a composite feedback circuit, providing a dynamic range of 25 dB with a minimum detectable optical power of less than 1 nW at the diode for a signal-to-noise ratio of 26 dB.

Decision Circuit and Timing Extraction

The regenerator is illustrated in Fig. 12. The amplifier accepts raised-cosine pulses from the receiver module and provides a controlled output of 2 V peak–peak for an input in the range 10–40 mV peak–peak. The amplified raised-cosine pulse stream feeds a Schmidt trigger circuit to produce definable pulse edges of nominally square waveform, with amplitudes comparable with transistor-transistor logic (TTL). The square waveform is fed to the decision gate, while, a sample is

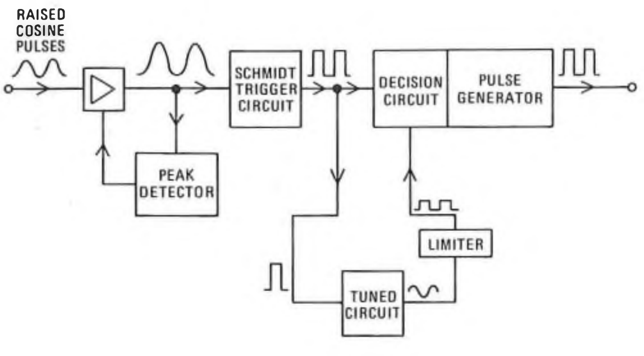


FIG. 12—Block diagram of regenerator

diverted to a resonant circuit, having a Q-factor of 50, to maintain a substantially continuous output.

The sinusoidal output of the tuned circuit is clipped to produce a square waveform, the leading edge of each pulse being used to trigger the gate of the decision circuit. On operation of the gate, a TTL level one or zero is generated, depending on the presence, or absence, of a received signal from the Schmidt circuit. A data stream is therefore regenerated at a rate governed by the tuned circuit.

Coding

Factors affecting the design of an optical-fibre transmission system for digital applications include:

(*a*) the mode of operation (for example, binary or ternary),
(*b*) the provision of adequate timing information,
(*c*) the provision of error-rate monitoring facilities, and
(*d*) the need to minimize detectable optical power.

The simplest mode of operation for an optoelectronic transducer is binary, in which the ON/OFF conditions of the transducer correspond to levels one and zero respectively. This mode of operation has been used for the early experiments at 8·448 Mbit/s. However, the provision of adequate timing information cannot be guaranteed with a simple binary system since it is quite possible that long sequences of zeros could be produced during which time no trigger pulses would be available for a timing recovery circuit. The problem can be overcome by recoding the binary signals prior to optical transmission so that, irrespective of the incoming data, there is a maximum number of zeros possible before the recurrence of a one.

Methods of recoding the information are, for example, coded mark inversion (CMI), scrambling or $NBMB$ coding. Although all have merits, CMI requires a line rate of twice the information rate, and hence twice the bandwidth; scrambling does not provide a defined code structure and so cannot guard against long sequences of zeros. Amongst the various $NBMB$ codes, depending on whether N is even or odd, are *zero*, *unity*, *paired* and *balanced-disparity* codes. The respective merits of these codes revolve about redundancy and convenience in error detection, and the code selected for the 8·448 Mbit/s trial was a balanced-disparity code[7] with $N = 5$ and $M = 6$.

The incoming binary digits are examined in groups of 5 and are retransmitted in the same time interval in groups of 6 bits. Since each of the originating bits can have one of 2 states, the number of possible combinations is $2^5 = 32$, this being the number of unambiguous combinations of ones and zeros required for the recoded group. Twenty of these are easily established by the following rule: if a 5 bit group contains 2 ones it is retransmitted followed by a one; if the group contains 3 ones it is retransmitted followed by a zero. This leaves only 12 combinations to be established, each of which is given 2 combinations, one the inverse of the other, which are used alternatively; some examples are given in Table 4.

TABLE 4

Recoding of Binary Signals

5 bit group	6 bit group
11000	110001
10100	101001
10010	100101
- - - -	- - - -
- - - -	- - - -
11111	111010 or 00101
11110	110110 or 001001

A sequence of groups therefore produces as many ones as zeros (that is, zero disparity) which provides a convenient characteristic to facilitate error detection, while the maximum number of sequential zeros is 6, thereby ensuring regular triggering of the regenerator clock. The penalty paid for using this 5 bit–6 bit coding process is that the line rate increases by 6/5 to 10·1376 Mbit/s.

Ancillary Equipment

To provide facilities for partial or full loading of the system with simulated and some live demonstration traffic, the system was extended to secondary and primary multiplex equipments at Martlesham and Ipswich. The primary multiplex had a line rate of 2·048 Mbit/s and 30-channel capacity.

Error measurements were obtained by applying a pseudo-random pattern at the transmit end of the system at 8·448 Mbit/s and comparing the output of the system with an identical pattern, any discrepancy constituting an error. The output from the pattern comparator can be coupled to a digital-error counter and data-evaluation system, which prints the date and time of any fault occurrence. Alternatively, a pseudo-random pattern can be applied at 2·048 Mbit/s via a secondary multiplex at the transmitter and compared with the pattern from a secondary multiplex associated with the receiver. In-service monitoring is provided by parity checking at the regenerator, any discrepancy being monitored by a selective detector. The detector can be regulated to respond to error rates in the range 1 in 10^1 to 1 in 10^{11}, and raise URGENT and NON-URGENT alarms as appropriate.

System Construction

The practicality of installing optical-fibre transmission systems in typical BPO engineering environments has been demonstrated; furthermore, the terminal equipments have been constructed in standard BPO 62-type equipment. The 2-rack terminal installed at the BPO Research Centre is shown in Fig. 13. A complete optical system including coding, decoding and regenerator equipment is contained on one shelf, and 8 systems can be accommodated in all. A U-link panel provides test and monitoring facilities and a convenient means of converting a system from terminal to regenerative operation. For convenience of use at a later stage of development, the transducer modules are each mounted on individual equipment cards (Figs. 14 and 15). The right-hand rack shown in Fig. 13, contains one 30-channel primary multiplex (2·048 Mbit/s) that feeds one port of the secondary multiplex (8·448 Mbit/s). The remaining 3 ports of the 8·448 Mbit/s multiplex may be fully or partly loaded with signals from pseudo-random pattern generators operating at 2·048 Mbit/s. Also in this rack are contained error and signal-level monitoring equipment, alarm panel and engineering-speaker facilities. The alarm system is compatible with those at Ipswich and Kesgrave telephone exchanges, and provides local and extended alarms for urgent and non-urgent conditions. Both racks are powered by 240 V mains supply.

The terminal equipment at the Ipswich exchange is similar to that at the BPO Research Centre, and is situated within a repeater station in an operational suite, and the equipment is powered from a 24 V supply. At the Kesgrave exchange, only a repeater rack is used, situated in the main apparatus room and powered by the 50 V exchange supply.

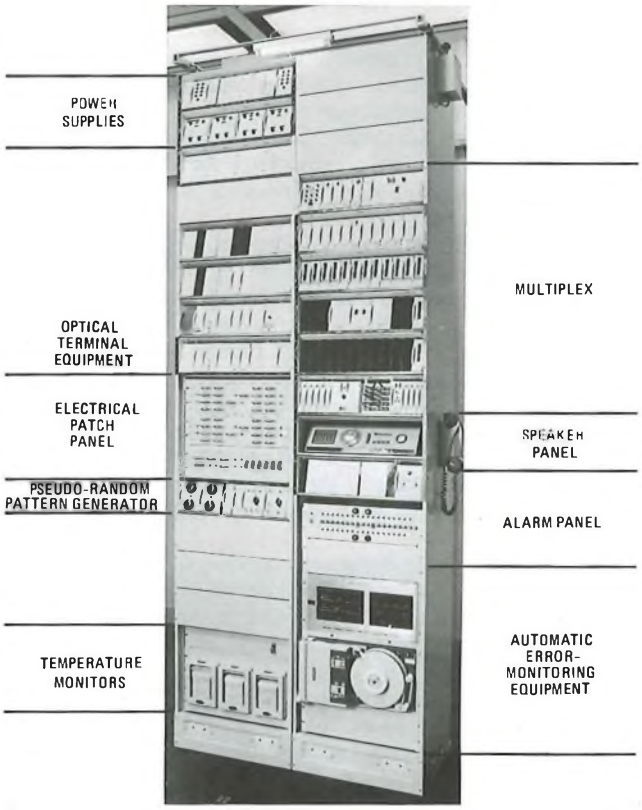


FIG. 13—8·448 Mbit/s optical-fibre system terminal equipment

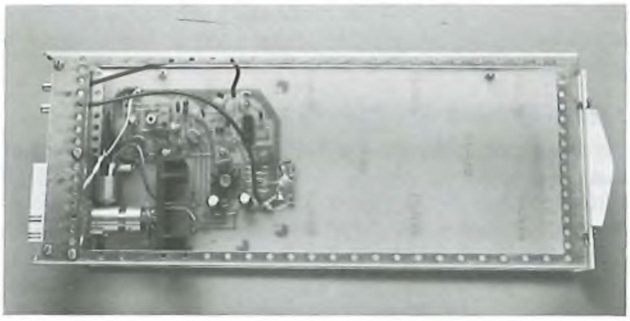


FIG. 14—8·448 Mbit/s electrical-optical transmitter

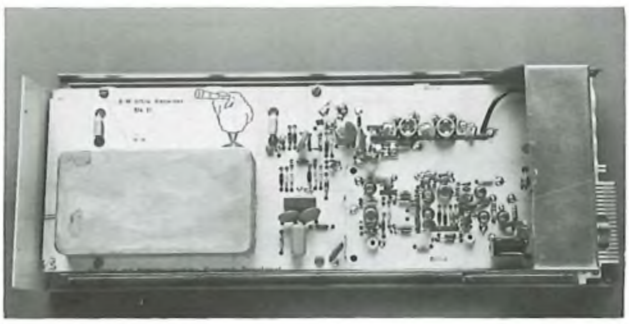


FIG. 15—8·448 Mbit/s optical-electrical receiver

Power Consumption

The power consumption (watts) of the equipment modules currently used is as follows.

Optical Transmitters:	LED	1·0
	Laser (using reduced width pulses)	0·5
Optical Receiver:		1·1
Electrical Modules:	HDB3–Binary Coder	2·1
	5B6B Coder	3·0
	Regenerator	0·7
	5B6B Decoder	6·5
	HDB3–Binary Decoder	2·0

An intermediate repeater consisting of receiver, regenerator and laser drive, would, therefore, have a power consumption of 2·3 W.

SYSTEM PERFORMANCE

The error-rate objective for a 2500 km hypothetical reference circuit is 2 in 10^7 so, for a repeater section length L km, the maximum permissible error rate is $8L$ in 10^{11}. Error rate versus received power characteristics have been obtained (Fig. 16) for the system arrangements shown in Fig. 2. The 8·448 Mbit/s system has been tested between Martlesham and Ipswich over the full 13 km using laser sources, and both the Martlesham–Kesgrave and Kesgrave–Ipswich sections using LEDs; substantial performance margins were achieved. Study of Fig. 16 suggests that the use of the laser source apparently resulted in lower sensitivity, but this was because the lasers were biassed near threshold and were thus emitting during the level zero conditions. The use of zero-bias lasers would provide results at least comparable with those obtained with LEDs.

In each case, the optoelectronic transducer was modulated with a pseudo-random pattern generator at 8·448 Mbit/s having a sequence length of $2^{15}-1$ and the received pattern was compared with an identical pattern, any discrepancy constituting an error.

Variations of received optical power were achieved by means of an optical attenuator using neutral-density filters. The filters were inserted into the optical path by means of small plungers and provided losses in the range 1–30 dB.

To establish the exact power launched into the fibre is a complicated matter because

(*a*) not all the power radiated from an LED is collected by the coupler,

(*b*) loss is introduced by the coupler,

(*c*) some energy which enters the fibre at too high an angle from the axis of the fibre will be radiated,

(*d*) some energy entering the fibre has a complex phase coefficient which produces a damped oscillatory effect (Evanescent modes),

(*e*) some energy is coupled into the outer cladding (leaky modes), and

(*f*) some energy is initially propagated at high angles which gradually change until a steady state is reached.

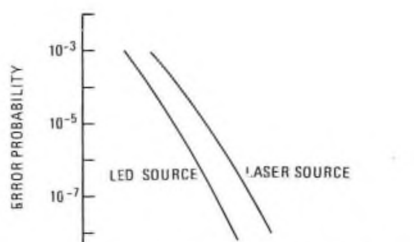


FIG. 16—8·448 Mbit/s feasibility trial experimental results of error-probability/received-power

Effects (*a*) and (*b*) can be defined; effects (*c*), (*d*) and (*e*) become insignificant beyond a very short length of fibre, and effect (*f*), although present for about 2 km, is insignificant for lasers and is defineable for LEDs. For these reasons the effective launched power is taken as that measured at the end of a 1 m length of fibre of the same type as that under test, and using the same source.

From the results (see Fig. 16), it is possible to determine the maximum length of cable that can be used before the introduction of a regenerative repeater. Assuming a minimum received optical power of −60 dBm, for an error rate better than 1 in 10^{10} and an effective fibre loss of 4·5 dB/km, the repeater spacings (with a small margin) would be: for an LED and assumed launched power of −12 dBm, a maximum of 10 km; for a laser and assumed launched power of 0 dBm, a maximum of 13 km.

CONCLUSIONS

The performance of the system as tested indicates the feasibility of operating optical junction systems at 8 Mbit/s with repeater spacings of at least 10 km. This means that about 80% of circuits on the junction network[8] could be catered for by non-repeatered optical-fibre systems.

Apart from the obvious attraction of no buried repeater, there are the equally attractive benefits of reduced underground plant congestion resulting from the absence of repeater cases; there would be no requirement for power feeding and consequently no need for a metallic strength member—a polymer strength member would be adequate and result in a 20% lighter cable, although the existing cable is less than 40 kg/km. However, a light metallic member, for example braid or foil, may still be included for location purposes.

The installation of the cable in 1 km lengths was achieved without difficulty and it is considered that even longer installations will be feasible. The ease of installation will undoubtedly prove attractive in urban areas.

The 8·448 Mbit/s optical-fibre transmission system has been in operation now for several months and has been extended via the primary multiplex to provide at Martlesham a number of out-of-area exchange lines off the Ipswich exchange. Immediate plans include connexion of 10 of the Martlesham–Ipswich channels to the experimental stored-program-controlled exchange (Pathfinder[9]) to provide incoming and outgoing junction facilities for levels 0, 1 and 9.

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Developments in Maritime Satellite Communications

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UDC 621.396.946:656.6

The range of communication services available to commercial shipping has recently been extended by the introduction of the USA MARISAT system and, in 1978, the European MAROTS satellite is to be launched. Experience gained from the design, development and operation of the MARISAT and MAROTS systems will be used in the planning and design of an international maritime satellite system to be known as INMARSAT. This article describes the technical and operational aspects of the progress being made in the field of maritime mobile-satellite communications.

INTRODUCTION

Long-range communication services for commercial shipping rely to a large extent on the use of radio links operating in the medium-frequency (MF) and high-frequency (HF) bands, but increasing traffic demand, adverse propagation effects and the need for watch-keeping all too often result in congestion on radio channels, poor communication quality and long delays in obtaining service. It is therefore becoming more difficult to provide a service of adequate quality and reliability to meet the increasing needs of the shipping community.

The inherent limitations of the long-range MF/HF services have been recognized for some time, as have the advantages to be gained from the use of communications satellites to provide an alternative to MF/HF transmission. A maritime satellite system has the capability of providing reliable communications of good quality, both for public correspondence and for safety and distress services. It could also cater for services which are not easily provided within the bandwidth limitations of MF/HF; for example, high-speed data transmission, which is of particular significance in view of the increasing level of automation on modern ships.

The development of 2 maritime satellite systems has been undertaken in the USA and in Europe; these systems are known as *MARISAT* and *MAROTS* respectively. Two operational MARISAT satellites were launched successfully in 1976 for use primarily by the US Navy, but having additional limited commercial capacity; a third satellite is also available as an in-orbit spare. The MAROTS satellite, which is being developed by the European Space Agency (ESA) with considerable UK involvement, was originally conceived as part of an experimental system which was to be used to acquire pre-operational experience, but ESA has since offered the MAROTS satellite for operational use after its scheduled launch in 1979.

Within the CEPT* organization and in co-operation with ESA and the associated European administrations, the overall characteristics of a future maritime satellite system have been defined, based on the use of the MAROTS space segment.

The means by which a maritime satellite service could be provided on an international scale by the 1980s have been actively studied by the Intergovernmental Maritime Consultative Organization (IMCO), a specialized agency of the United Nations Organization responsible for maritime safety. Constitutive and operating arrangements for a global maritime satellite system, to be known as *INMARSAT*, were agreed at an intergovernmental conference held in 1976. A technical panel has been set up within the INMARSAT organization to define the technical parameters of a first-phase INMARSAT system, taking into account the need for transition from the pre-INMARSAT systems and subsequently to later phases of the international system.

TECHNICAL CHARACTERISTICS OF A MARITIME SATELLITE SYSTEM

The immediate object of a maritime satellite system is to provide reliable telephony and telegraphy services of good quality for connexion with international public switched networks. The performance requirements of the telephony service form the basis for the system design because it is this service that uses the most satellite power and radio-frequency (RF) bandwidth. Because of call-charging limitations imposed by many inland public telephone networks, fully-automatic operation for calls set-up in the shore-to-ship direction is not foreseen for several years and hence semi-automatic operation is required for this direction of transmission. However, for ship-originated telephone calls and for Telex calls set up in either direction, fully-automatic operation is feasible from the outset.

It is envisaged that, once the system has become established, a much wider range of services will be available: high-speed data operating up to about 9·6 kbit/s for ship operating information; facsimile (weather maps, newspapers); broadcast messages (news, fleet messages); distress service; search and rescue facilities; radiolocation and radionavigation.

Frequency Bands

The operating frequencies of radio links between satellites and ships have been allocated[1] in the frequency range known as the *L-band*; 7·5 MHz of bandwidth is available at both 1·5 GHz (satellite–ship) and at 1·6 GHz (ship–satellite) for exclusive maritime use. An additional 1 MHz bandwidth is available in each band for shared use by maritime terminals and aircraft. The use of L-band frequencies for satellite/ship links has necessitated development of satellite and ship terminal hardware for the MARISAT and MAROTS systems, particularly with regard to satellite power output stages.

The frequency band to be used for satellite/shore links for the INMARSAT system is a matter for international discussion and agreement, but frequencies in the fixed-satellite service bands can be used. The MARISAT system uses frequencies in the 6/4 GHz bands for the satellites/shore links, whereas MAROTS is designed for operation at 14/11 GHz.

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* Conference of European Postal and Telecommunication Administrations

Maritime Traffic

A total of three operational satellites in geostationary orbit, one each over the Atlantic, Pacific and Indian Ocean areas, is the minimum required to provide global coverage. The IMCO has estimated that, based on present levels of MF/HF traffic growth, 7000 or so ships will eventually operate to INMARSAT and that 80 channels will be required by 1995 in the busiest ocean area, the Atlantic.

With a bandwidth of 50 kHz allocated to each channel, the total RF bandwidth requirement by 1995 would be only 4 MHz out of a total allocation of 7·5 MHz. However, when allowances are made for the fact that frequencies could not easily be re-used in overlap regions between satellite coverage areas, and the possible effects of additional services such as data and communications to exploration oil rigs, it is foreseen that the current 7·5 MHz bandwidth allocation will be used up by 1995. Initially, however, the traffic capacity of maritime satellite systems will be power limited, rather than bandwidth limited.

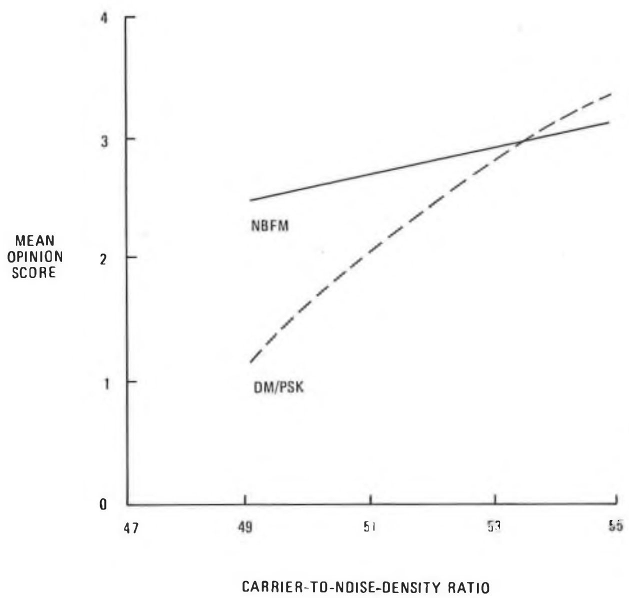
Modulation and Multiple-Access Methods

Traffic demand to and from the vast majority of ships will rarely require more than one communications channel at any time. A simple and efficient mode of operation for telephony services under these conditions is single-channel-per-carrier (SCPC) in frequency-division multiple access (FDMA).

The efficiency of operation of a modulation method can be judged from the satellite power per channel required to achieve a given performance objective. An indication of satellite power requirements is the carrier-to-noise-density ratio (C/N_0) at the demodulator input[2]. Satellite power requirements per channel, and hence total space-sector power and costs, may therefore be minimized by using a telephony modulation method which enables the performance objective to be met with the lowest possible value of C/N_0, thereby ensuring that the available satellite capacity is used efficiently. A firm performance objective has yet to be finalized, but initially the allowable subjectively-equivalent noise power in the hypothetical reference circuit for maritime satellite systems is seen as 25 000 pW0p under clear-sky conditions when there are no adverse propagation effects (that is, non-faded conditions). This quality of performance, while lower than that recommended for the fixed-satellite service, should provide a significant improvement over that available from the present MF/HF service and should be adequate for interconnexion with public switched networks. When more satellite power becomes available with future maritime satellites, there is the possibility of improving the noise power objective to 10 000 pW0p.

The telephony modulation method adopted for MARISAT is narrow-band frequency modulation (NBFM), which is an efficient method providing good speech quality with 50–51 dBHz C/N_0 at the demodulator input. Such a system would occupy about 28 kHz of RF bandwidth at about 7 dB carrier-to-noise ratio (C/N). Threshold extension demodulators, such as extended-range phase-locked loop devices, would therefore be required to operate effectively with these low C/N values. Speech processing using syllabic compandors is also essential to bring the subjective performance up to the equivalent of a circuit with 25 000 pW0p of noise or better.

Delta modulation using 2-phase phase-shift-keying (DM/PSK) is an alternative to NBFM for maritime satellite applications; in 1976, subjective evaluations and studies of both modulation methods (DM/PSK and NBFM) were carried out to determine the optimum method to be used for the MAROTS system. With the co-operation of the Netherlands administration and ESA, subjective tests were performed by the British Post Office (BPO) and the administrations of France and Norway. Each administration used its own language tapes, but adopted the same listening method of quality assessment as the BPO.[3] One result of these subjective tests is shown in Fig. 1 for a speech input level of −16 dBm0 corresponding to a median talker level; similar results were obtained for soft and loud talker levels. From Fig. 1, it can be seen that DM operating at 32 kbit/s with 2-phase PSK provides a better speech quality on the mean opinion score (MOS) scale at C/N_0 values in the range 53–55 dBHz, whereas NBFM has an advantage at lower C/N_0 values down to 49 dBHz which is within the range of immediate interest. Furthermore, NBFM exhibits a more graceful degradation in performance as the C/N_0 is reduced, a condition which may be experienced with severe propagation effects when ships are operating at the edge of the satellite coverage area with low angles of elevation. Similar results were obtained by all 3 administrations independently. Following these tests, it has been concluded that NBFM is the preferred modulation method for the MAROTS system.



Note: Speech input level = −16 dBm0
NBFM—narrow-band frequency modulation
DM/PSK—delta modulation using phase-shift-keying

FIG. 1—Subjective assessment of telephony modulation methods

To conserve satellite power, the optimum modulation method for digital services, such as telegraphy and data, is 2-phase PSK; a bit error rate of 1 in 10^5, exceeded for less than 1% of the time, is the tentative objective for the satellite link to achieve an acceptable performance for an overall connexion. To achieve maximum efficiency in the use of the satellite power and bandwidth available, time-division multiple access (TDMA) operation for telegraphy is preferred to FDMA operation. In the shore–ship direction, a number of telegraph channels can be multiplexed on the TDMA carrier during the shore-station burst time.

Channel Assignment and Signalling

The assignment of satellite telephone channels will be on a demand basis under the control of individual shore stations. Telex channels may be pre-assigned to each shore station in time-division multiplex (TDM), enabling blocks of channels to be transmitted during each station's TDMA burst. Co-ordination of the channel-assignment process and other necessary system control and supervisory functions can be carried out via satellite shore–shore channels.

At a shore station, there must be a suitable interface between terrestrial network signalling and satellite signalling procedures so that, to the customer, there will be little or no difference between the setting-up and supervisory functions of a maritime call and those associated with inland network calls. Signalling from shore to ship is required to establish contact with the ship and to allocate working channels and carry supervisory information. In the ship–shore direction, a random-access calling channel will be required for ships to request the use of working channels and for supervisory procedures.

Ship Terminal Configuration

The most critical element of the system is the satellite–ship L-band link, which requires over 90% of the total satellite power. This uneven power distribution arises because of the limited space available aboard a ship for installing a satellite communications aerial compared with that available at an earth station: limited space leads to small aerial diameter, low aerial gain (G) and, hence, low receive sensitivity, which is related inversely to satellite power requirements. It has been assumed that, for ships down to about 8000 (gross registered) t, the space available for a fairly unobstructed ship terminal location above decks limits the aerial diameter to 1·2 m, corresponding to a net gain of about 23 dBi (gain relative to an isotropic radiator). A suitable first-stage receiver would be a transistorized amplifier with an overall receive system noise temperature (T) of 500 K (about 4·3 dB noise figure), resulting in a gain/noise temperature (G/T) sensitivity of −4 dB/K.

Both the MARISAT and MAROTS systems will operate to ship terminals with a G/T of −4 dB/K. Typical costs for a complete ship terminal would be 3 or 4 times as much as those for conventional MF/HF equipment. There is also interest in other values of G/T, varying from about + 5 dB/K for special applications such as mobile platforms, to −17 dB/K for small ships.

Stabilization of the aerial mount in elevation may be achieved by the use of gyroscopes and level sensors to indicate movement of the aerial caused by ship roll, pitch and sway, and then to drive conventional servomechanisms to compensate for this movement. Typical ship motions of 30° roll and 10° pitch under heavy sea conditions would be reduced by the stabilization unit to produce an effective aerial pointing accuracy of about ±1°. Aerial movement in azimuth may be controlled from the ship's gyrocompass to compensate for changes in heading. The final pointing direction of the aerial towards the satellite may be achieved by means of a simple step-track system, which senses a satellite tracking signal and effectively causes the aerial to step round in azimuth and elevation until the received signal level is maximized.

Ship terminal equipment needs to operate efficiently, have a high reliability and be easily maintained by the ship's crew. Adequate protection of the above-decks equipment is achieved by the use of a fibre-glass radome to shield the aerial and the associated drive mechanisms and RF equipment from the effects of winds and salt spray. An impression of the ship terminal equipment is given in Fig. 2.

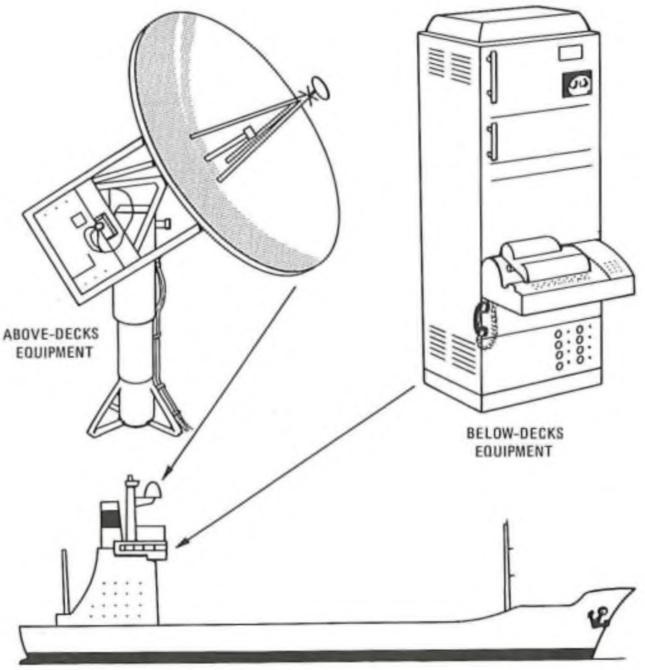


FIG. 2—Artist's impression of ship terminal units

MARISAT SYSTEM

Development of the MARISAT system resulted from a request made in 1972 by the US Navy for the provision of temporary satellite communication facilities, following delays in their FLEETSATCOM programme. Initial design studies indicated that US Navy requirements would not make full use of the capacity of the envisaged satellite configuration, and it was therefore decided to develop an integrated system meeting the requirements of the commercial shipping community in addition to those of the US Navy.

Three MARISAT satellites were launched in 1976; one is positioned over the Atlantic Ocean area and another over the Pacific to provide operational coverage to the areas shown included in Fig. 3. The third satellite has been positioned initially over the Indian Ocean area and is available as an in-orbit spare, although the capability exists to use it in an operational role if required. Shore stations serving each operational satellite have been built in the USA at Southbury, Connecticut (Atlantic satellite) and Santa Paula, California (Pacific satellite), and are connected to a control centre at Washington DC. Aerials of 13 m diameter are used to provide communication links in the 6/4 GHz frequency bands between each shore station and its satellite.

Operation of the satellite commercial capacity is separate from the US Navy operation and is controlled by a consortium of USA common carriers. Some 250 ship terminals with a G/T of −4 dB/K have been procured by members of the MARISAT consortium, and these terminals are gradually being leased out to interested shipping companies at an annual rent of around $15 300. Basic call charges for the satellite network have been fixed at $10/min for telephony and $6/min for Telex; additional charges are made when the call is extended outside the contiguous USA.

The MARISAT satellite illustrated in Fig. 4 is of conventional spin-stabilized design based on the INTELSAT IV spacecraft; stabilization in orbit is achieved by spinning the cylindrical body of the satellite at about 1 revolution/s, and then de-spinning the aerial platform to achieve earth pointing. Five repeaters are incorporated in the satellite communication equipment: 3 ultra-high frequency (UHF) repeaters for the US Navy, who use most of the available circuit capacity and power (300 W), and 2 repeaters (translating from 6 GHz to 1·5 GHz, and from 1·6 GHz to 4 GHz) for commercial use. Initially, to enable US Navy requirements to be met fully, the specified commercial capacity of each satellite was limited to one telephony both way carrier and 2 multiplexed Telex carriers (44 Telex circuits). It was expected that the naval requirements would decrease and that the commercial telephony capacity would be increased to 5 carriers as an intermediate stage; 9 telephony and 5 Telex carriers were planned for commercial use when US Navy requirements finally terminated by about 1978. However, since launch, the DC and RF power capabilities of the satellites have exceeded the specified values to the extent that

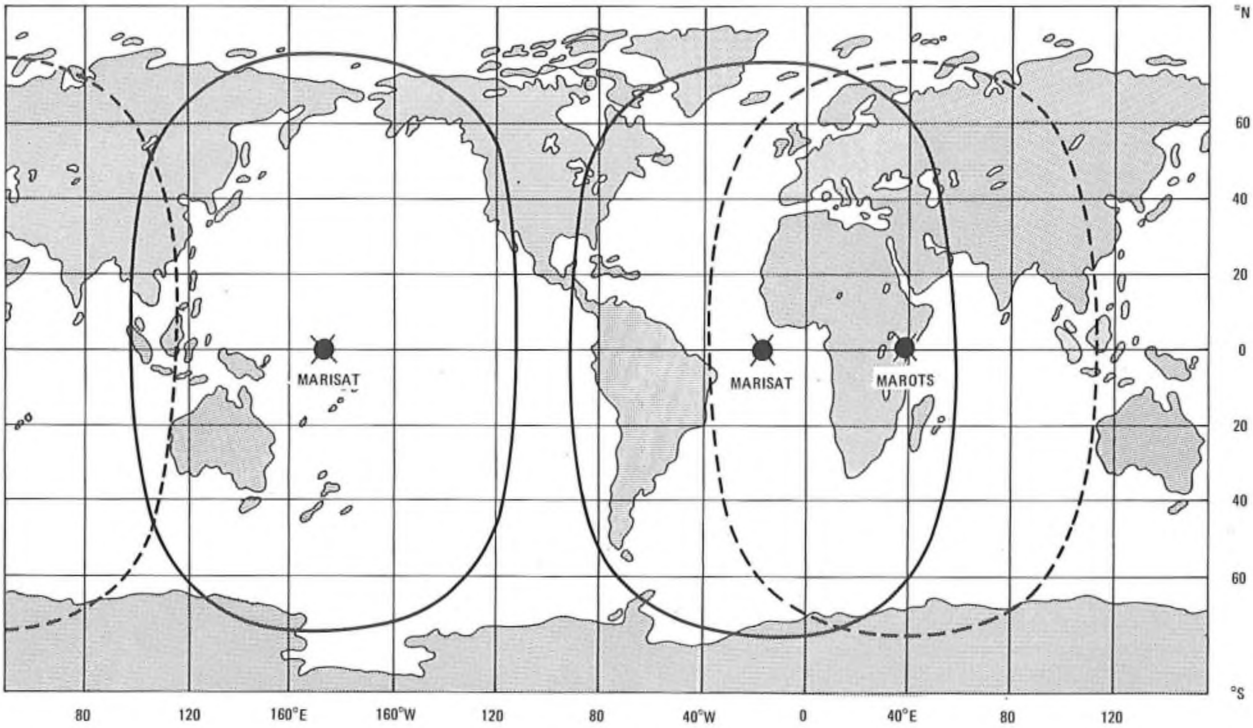


FIG. 3—MARISAT and MAROTS satellite coverage area contours to 5° elevation

a considerable increase in commercial capacity is now envisaged: the intermediate stage capacity now available is 8 telephony and 2 Telex carriers, while still maintaining full US Navy capacity, and the final capacity for commercial use is estimated at twice that of the intermediate stage.

To achieve these alternative output powers, a 3-level travelling-wave amplifier (TWA) has been developed specifically for MARISAT operation at L-band frequencies. Such a complex device is not required in the ship–shore direction because the minimal satellite output power requirement enables the full commercial capacity to be provided at all times.

In the shore–ship direction, the satellite is severely power-limited at L-band frequencies, and so an irregular Babcock-type[4] channel frequency spacing has been adopted to minimize the effects of intermodulation products arising in the TWA. This form of channel plan results in a substantial RF bandwidth requirement of 4 MHz to accommodate only about 20 carriers, each of which requires a nominal channel bandwidth of 50 kHz.

Telephony carriers operate in the SCPC/FDMA mode using NBFM with compandors. Telex operation in the shore–ship direction uses TDM and provides 22 channels per shore station carrier at 1·2 kbit/s; one channel is used for channel-assignment purposes. Telex information from ship to shore is transmitted on a TDMA channel at 4·8 kbit/s; a separate 4·8 kbit/s random-access channel is provided for signalling.

Despite some inherent disadvantages and the low satellite capacity, user reaction to the MARISAT system has been favourable and encouraging to those involved in planning the future INMARSAT system. Although call charges are relatively high, they must be judged against ship operating costs, which can approach £5000/d per ship; in such an environment, the proved availability and reliability of satellite communications are the more important factors.

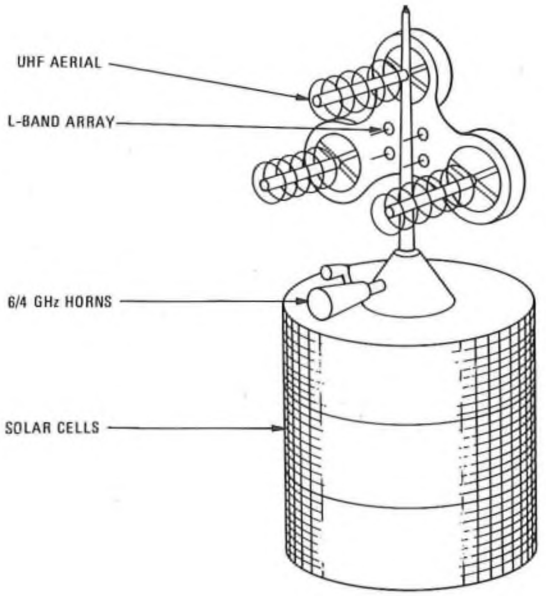


FIG. 4—Illustration of MARISAT spacecraft

MAROTS SYSTEM

At the 1973 European Space Conference held in Brussels, the European Space Research Organization (now ESA) was instructed to undertake the development of the MAROTS satellite which was intended to provide experimental and pre-operational data in the field of maritime satellite communications. However, the needs of the shipping community and the subsequent development of the MARISAT system have raised the possibility of MAROTS being used in an operational role, once the satellite has been launched in 1979.

The satellite development programme has been funded by the administrations of Belgium, France, the Federal Republic of Germany, Italy, the Netherlands, Norway, Spain, Sweden and the UK (the largest contributor with about 56% of the total capital investment). These nations between them own some 36% of the world's shipping tonneage, and the provision of a high standard of maritime communication services is therefore of considerable importance.

The MAROTS spacecraft now being built consists of 2 basic modules: a service module based on the ESA Orbital Test Satellite (OTS), and a maritime communication module. Both modules have been developed by European consortia headed by British companies. Following launch by a National Aeronautical and Space Administration space vehicle from Cape Canaveral (USA), it is planned to position the satellite in orbit at a longitude of 40°E (see Fig. 3.) This will provide coverage to the Indian Ocean and part of the Atlantic Ocean area, yet minimize interference with the Atlantic MARISAT satellite.

Satellite control facilities will be provided by an earth station in Spain which is connected to an operations control centre in West Germany. Shore station facilities will be provided initially at the BPO satellite earth station at Goonhilly Downs. Shore/satellite links will operate in the 14/11 GHz frequency bands, which will require the provision of an up-path power-control system at shore stations to compensate for fading effects on shore–satellite links.

A 19 m diameter, dual-purpose aerial is being built at Goonhilly.[5] This is intended to operate initially to OTS for experimental purposes and subsequently to MAROTS, either to enable experiments to be carried out or to fulfil an operational role. This aerial is over-sized for purely maritime-satellite applications, for which a diameter of less than 15 m would be sufficient at Goonhilly. A feature of the Goonhilly aerial will be the beam-waveguide feed arrangement[6], which allows the 14 GHz transmit and 11 GHz receive equipment to be situated within the base building. This avoids the need for a high-level receive-equipment cabin behind the reflector, and the need for long waveguide connexions to the transmitter.

An illustration of the MAROTS spacecraft is shown in Fig. 5. Although smaller, it is similar in some respects to the new generation of INTELSAT V satellites,[7] since it incorporates deployable solar panels and 3-axis body stabilization. This configuration makes more efficient use of the available spacecraft mass and can provide more power than a conventional spin-stabilized satellite, and also avoids the need for a de-spun aerial platform. Within the communications equipment, which uses most of the 460 W of DC power available, there are 2 broadband repeater stages (see Fig. 6): one receiving at 14·5 GHz and transmitting at 1·5 GHz for shore–ship communications, using a transistorized power amplifier (TPA) output stage at L-band, and the other operating at 1·6/11·7 GHz for ship–shore channels, with a more conventional TWA output stage. Cross-strapping is also provided for shore–shore (14·5/11·7 GHz) communications between shore stations for network control and co-ordination purposes.

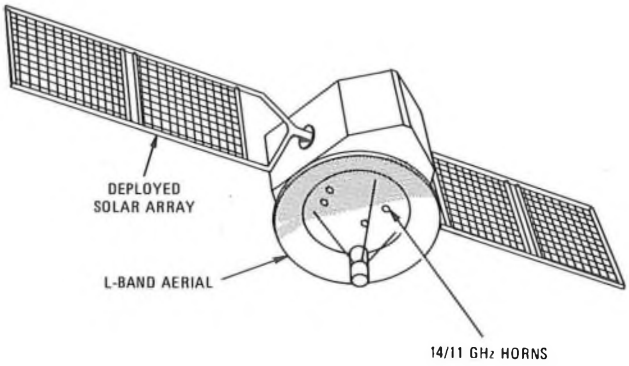
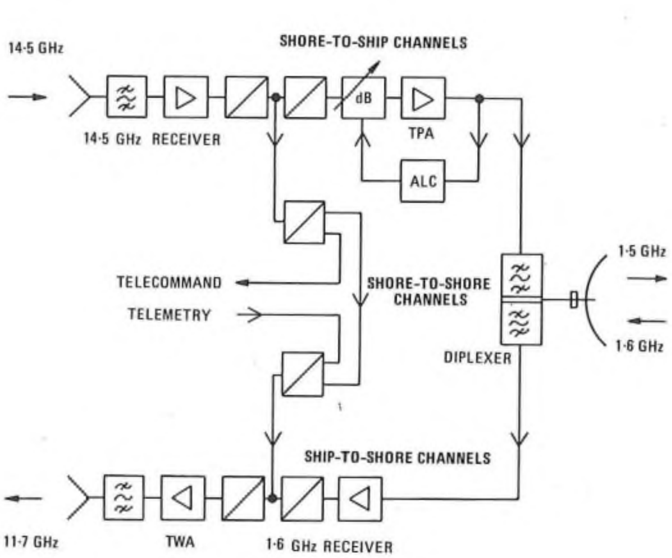


FIG. 5—Illustration of MAROTS spacecraft

The TPA has required considerable development effort to achieve a relatively high RF output power of 60 W at L-band, with adequate linearity and intermodulation characteristics. The design incorporates a modular cluster of transistorized stages, which provide high flexibility in matching satellite primary power to output power, inherent redundancy, good reliability and lower equipment mass requirements compared with an equivalent TWA. Automatic level control at the input of the amplifier enables output power to be maintained constant regardless of the satellite channel loading, so that with a small traffic demand the output power, and hence C/N_0 per carrier, is relatively high.

Further power advantages are gained by the use of a specially shaped profile on the L-band parabolic aerial which, while



ALC: automatic level control

FIG. 6—Block diagram of MAROTS communications equipment

still providing an earth-coverage beam pattern, gives nearly 2 dB more gain at the edge of the coverage area compared with a conventional earth-coverage aerial. This allows the power flux density received at ship's terminals to be fairly constant for all elevation angles, thereby compensating to some extent for propagation effects, which are at their most severe at low angles of elevation.

The RF bandwidth used by MAROTS for communications is restricted to 2·5 MHz. Satellite power limitations result in a capacity equivalent to about 40 telephony channels when operating to ships' terminals whose G/T is -4 dB/K although, in an operational system, voice-activated switching techniques could be used to increase capacity to 50 channels with 50 kHz spacing if traffic demand indicates this requirement.

For the forward-looking system configured around the MAROTS satellite, SCPC companded NBFM telephony operation in FDMA has been adopted as with MARISAT, but the Telex multiplexing and signalling modes of the 2 systems differ significantly, particularly in the shore–ship direction. Signalling and telegraphy transmissions for up to 30 shore stations are contained within one integrated TDMA carrier, with each shore-station burst containing only 4 Telex channels. In the ship–shore direction, separate random-access signalling carriers and TDMA telegraphy carriers are used, as with MARISAT. The Telex capacity per equivalent telephony channel in both directions of transmission is 120 Telex channels, which is about twice the corresponding MARISAT capacity. Bit rates for digital signalling and telegraphy carriers also differ, with MAROTS using a standardized bit rate of 9·6 kbit/s throughout the system in order to maximize Telex capacity per telephony channel and calling capacity on the random-access channel.

CONCLUSIONS

The successful inauguration of the MARISAT system has demonstrated that maritime satellites represent an efficient alternative to the long-range MF/HF service, and an attractive method of meeting the increasing communication requirements of the commercial shipping community, both in terms of capacity and the developing demand for new maritime services. Work on this system, together with the development effort on MAROTS, has led to the solution of many of the problems that had been foreseen in formulating a future international INMARSAT service. Before the end of 1978, the technical parameters of a first-phase INMARSAT system are expected to be defined, and these are likely to be influenced to a considerable extent by the experience gained and studies undertaken on maritime satellites over the last few years.

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Book Review

Electronics from Theory into Practice. J. E. Fisher and H. B. Gatland. Pergamon Press. xxxix + il + 445 pp. 429 ills. £8·75 (also available in 2 volumes at £4·75 each).

While engineering courses usually include some applications work (in the form of projects), emphasis is necessarily placed on the physics and analysis of behaviour of devices. But engineering includes turning specifications into working circuits, and the difficult step of turning theoretical knowledge into design practice has often been left to periods of industrial training, or even experience, outside of the academic course.

The authors' intention is to show how to develop a methodical approach to practical design work, and this they do by formalizing design procedures, giving hints and presenting model design cases.

By way of an introductory revision, the book deals with the main features, characteristics and parameters of semiconductor devices, including an informative summary of field-effect transistors and integrated circuits (ICs). The uses of each device are then dealt with from a circuitry point of view, with some advice on the selection of devices and use of data sheets.

The book then proceeds to its main purpose. Starting with amplifiers of all types, and going on to cover power supplies, oscillators, waveform generators and digital circuits, it describes the major design considerations, the order of tackling them, and gives detailed examples, from specification to final circuit. The design steps are dealt with in a practical manner: commonly-used approximations, reductions and assumptions are given. In many cases, the designs are also related to the use of packaged ICs and operational amplifiers—very relevant to modern needs.

Although the book is not meant to teach electronics, the introductory section on negative feedback, although brief, is so well presented that one can learn the basics of the subject from it (unlike the section on semiconductor devices, where previous knowledge is essential). The introduction given to operational amplifiers is also extremely useful.

The designs given in the book are not very sophisticated; they arrive at a working circuit rather than a refined design. But neither is the treatment elementary. Laplace transforms are used freely, and a useful appendix acts as an *aide-mémoire* for the mathematics involved.

There are some minor criticisms of the book. Although careful reference to British Standard recommended letter symbols and abbreviations is made, the effect is spoiled by the use of non-standard diagram symbols (particularly for logic elements, which is confusing) and unit symbols (for example, nS for ns).

Besides acting as a bridge between academic and working environments, this book will also be useful to those whose engineering activities since they qualified have not included much circuit work. It is, obviously, not a substitute for practical work, but a useful manual for initial exploration of the design bench.

B. S.

The Eighth International Teletraffic Congress, Melbourne, 1976

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UDC 621.395.31:061.3

This article gives a brief review of the Eighth International Teletraffic Congress and its activities.

The Eighth International Teletraffic Congress (8th ITC) was held in Melbourne from 10–17 November 1976, under the sponsorship of the Australian Telecommunications Commission and the Australian Telecommunications Development Association, and was opened by the Hon. Eric L. Robinson, Minister for Posts and Telecommunications in the Australian Federal Government.

The ITC is a triennial institution with no continuing existence except for its permanent international advisory council. Recognized by, but not part of, the International Telecommunication Union, the ITC provides a venue where important work in every branch of teletraffic theory and engineering is presented to, and discussed by, a body of knowledgeable and experienced mathematicians and engineers. The value of an ITC lies not only in the physical meetings and discussions that take place between the participants, but also in the fact that the *ITC Proceedings* represent a forum for publication. Some countries possess journals wherein their teletraffic research can be published readily: others, like the UK, do not, and for them the ITCs are doubly important, since the *Proceedings* may be the only published and generally available* record of their nationals' endeavours.

The 8th ITC was attended by some 230 delegates from 28 countries, ranging from Australia to Finland, Thailand to Brazil. From the UK, 12 delegates attended; drawn from the British Post Office, the telecommunications manufacturing industry, the University of Strathclyde, and Cable & Wireless. Between them they contributed in whole or in part to no fewer than 10 papers. Some of the UK delegates had previously attended the International Switching Symposium held in Kyoto, Japan, immediately prior to the ITC, and some participated in a programme of lectures given in developing countries before and after the congress.

The 131 technical papers presented at the congress covered a very wide variety of topics in all branches of teletraffic theory, including, in particular, such fields as basic probability theory of telephone traffic, analysis of delay systems, reliability theory, link systems and connecting networks, simulation methods, automatic alternative routing (AAR) and overflow traffic, traffic aspects of modern switching systems, network design, subscriber behaviour, traffic measurement and data collection, and forecasting. As at previous congresses, papers were divided into read and non-read categories. Authors were allocated about 10 min to present their papers, and the non-read papers were summarized at the end of each session by a discussion leader, whose task it was also to co-ordinate the questions and discussion on all the papers in that session. For the second time in the history of the ITCs, the great number of read papers necessitated the limited introduction of parallel sessions; participants had, therefore, to make a choice between attending the sessions on subscriber behaviour and attending those on delay systems. However, to mitigate this disadvantage, these sessions were video-taped and those who wished could view them afterwards.

It is impossible to summarize in a few words the range of material covered, and so this article is confined to a few areas of greatest interest and activity. Of these, perhaps the most significant is the problem of AAR and overflow traffic; papers on this topic ranged from techniques for describing overflow traffic more appropriately, to computer programs for the economic design of AAR networks. It is fair to say that there was a certain amount of controversy regarding the value of the latter.

The analysis of queueing systems received much attention. One interesting development was the increasing degree of interest shown in approximation techniques, as the complexity of the systems became greater. The methods of operational research and optimization theory are increasingly being used to treat some of the more difficult problems. Little progress, however, seems to have been made in the analytical treatment of modern stored-program-control systems, even allowing for natural reticence due to commercial security.

Much interest was shown in subscriber behaviour and traffic characteristics although, unlike the 7th ITC, there was little mention of the contentious subject of repeat attempts. Many papers described large-scale measurement activity, now rendered feasible by electronic collection apparatus; and there was particular interest shown in such topics as losses due to called-subscriber busy, or the response of traffic to changing tariff structures.

Other subjects which evoked interest, or where new ideas emerged, included reliability theory, packet-switching networks, and link systems; although there was less activity on this last topic than in previous years. The subject of dynamic network management, by contrast, which was of such interest at the 7th ITC, was scarcely mentioned.

It would be an act of discourtesy to fail to mention the excellent organization of the congress itself, or the varied and successful social programme arranged for delegates and their wives, which included, *inter alia*, visits to concerts and art galleries and demonstrations of opal cutting, and culminated in the the farewell banquet for all delegates and their companions in the Great Hall of the Victorian Art Gallery.

A one-day colloquium was held at the Institution of Electrical Engineers in London on the 27 April 1977, at which the achievements and activities of the 8th ITC were reviewed for the benefit of the large number of interested people who were unable to attend the congress personally. The opening address was given by Professor Arne Jensen, the chairman of the international advisory council of the ITC. The audience of approximately 240 was given personal views of the Congress by speakers chosen from those who attended from the UK.

The Ninth International Teletraffic Congress will, by invitation of the Spanish authorities, be held in Spain in 1979.

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* The papers presented at the ITCs are held by the Science Reference Library, 25 Southampton Buildings, Chancery Lane, London WC2A 1AW

Automatic Testing of Complex Integrated Circuits

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UDC 621.3.049.7:621.38.001.4

Large-scale integrated circuits are likely to be used extensively in British Post Office equipment in the next few years, and this article gives an insight into the problems of testing and assessing these "systems on a chip". Developments in the automatic testing of large-scale digital integrated circuits are described, with particular reference to random logic, memory and microprocessor circuits. The generation of suitable test sequences, both in software and hardware, is discussed.

INTRODUCTION

Because of their small size, high speed, low power consumption and reliability, digital integrated circuits will form a major part of the telephone network of the future. Their uses will be varied: a typical 10 000-line TXE4A exchange may contain 47 000 integrated circuits, whereas one integrated circuit, powered through the telephone line, could provide signal processing within a telephone instrument. A large number of the circuits currently used in exchanges are small-scale integrated circuits, containing fewer than 20–30 logic gates, which have been in volume production for more than 10 years and whose reliability has been the subject of extensive study.[1] As such circuits have a fairly limited logic capability and a correspondingly limited truth table, the detection of any faulty operation is relatively straightforward.

As circuits have become more complex, they have been readily absorbed into equipment with resultant savings in production costs, but with important implications for system reliability. The complexity of large-scale integrated circuits has reached the stage where a circuit only 4 mm square may include as many as 15 000 transistors. If a functional test for such a circuit were to mean the successful application of the entire truth table, as in the case of small-scale circuits, many of the circuits currently in telephone equipment would be untestable. In practice, a compromise is sought between the efficiency of the test procedure and the economically acceptable testing time.

A test on a digital circuit can be conveniently separated into 2 parts. Firstly, it is necessary to establish that the circuit performs its logic function (functional testing) and, secondly, the analogue properties of the circuit (such as the supply voltage, frequency and input and output voltages) have to be related to the manufacturer's specification. Functional testing of digital circuits requires a pattern generator to apply a sequence of binary words to the device under test, the output of which is compared with that of a reference device, as illustrated in Fig. 1. Any discrepancy indicates circuit failure. In the very simplest testers, the reference device may be a known good circuit, but this technique is useful only for circuits which have a truth table short enough for direct observation. Otherwise, when a discrepancy occurs between the outputs of the device under test and the reference device, it is difficult to establish which is in error. For large circuits, where long test sequences have to be applied, the expected reference data is normally generated within the pattern generator, as implied by the dashed line in Fig. 1. The other principal requirements of the tester are a system clock, buffer amplifiers to interface the device under test with the tester, and a controller, all of which are discussed in greater detail in this article. Firstly, however, the problems of generating test sequences for large-scale circuits are examined.

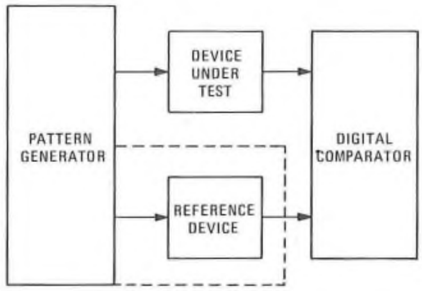

FIG. 1—Simplified functional tester

PRINCIPLES OF TEST-PATTERN GENERATION

The problem of test-pattern generation is demonstrable in principle by considering a circuit having 10 signal inputs, each of which may have logic 0 or 1 applied. If the circuit is truly combinatorial, meaning that the output at any instant is dependent only on the inputs, then there are $2^{10} = 1024$ input combinations, or *words*, which need be applied to test that circuit completely; regardless of the order in which they are applied, the output for a given input word should always be the same. If the circuit is sequential, implying the inclusion of memory elements, then the output depends not only on the word currently applied to the input but also on the words which have been applied previously, and on the order in which they were presented. The number of words which has to be applied to accommodate all possible word sequences is now factorial 1024, many orders of magnitude greater than for the combinatorial circuit.

In practice, there is no need to test a circuit so thoroughly, as is demonstrated by the circuit of Fig. 2, a 1 bit full adder comprising 10 gates. If inputs A, B and C are given weightings respectively of 1, 2 and 4, then there are 8 possible input words ranging from $A = B = C = 0$, corresponding to decimal 0, to $A = B = C = 1$, equivalent to decimal 7. Similarly, the outputs may be weighted SUM = 1 and CARRY = 2, giving an output word of decimal value from 0 to 3, corresponding to the range SUM = CARRY = 0 to SUM = CARRY = 1. By analysing the logic diagram, it is

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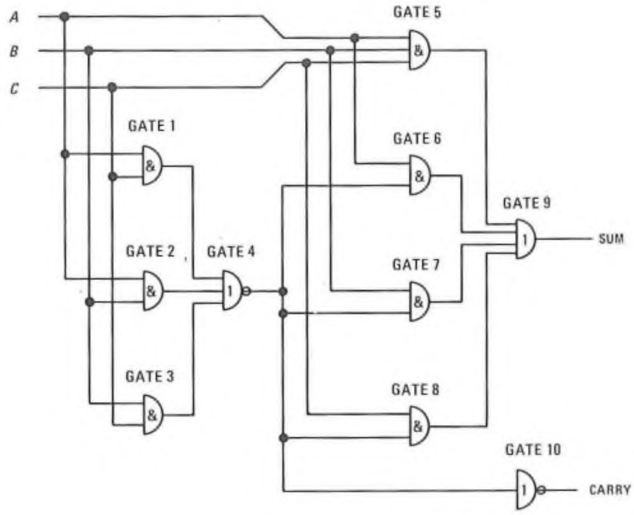


FIG. 2—Logic diagram of 1 bit full adder

TABLE 1

Truth Table for the 1 bit Full Adder of Fig. 2

Decimal Input	Input Word			Output Word	
	A	*B*	*C*	SUM	CARRY
0	0	0	0	0	0
1	1	0	0	1	0
2	0	1	0	1	0
3	1	1	0	0	1
4	0	0	1	1	0
5	1	0	1	0	1
6	0	1	1	0	1
7	1	1	1	1	1

possible to determine the expected outputs for all input words in the fault-free case, as shown in Table 1. Similarly, the outputs can be found for all possible fault conditions. The definition of *all possible faults* varies; it should certainly include the outputs of all the constituent logic gates stuck at logic 1 (SA1) or stuck at logic 0 (SA0) individually, and may also include combinations of these, as well as short circuits between gates and open-circuit interconnexions. There is some evidence that it is sufficient to consider only all SA0 and SA1 faults occurring singly. Table 2 shows the *fault "dictionary"* formed by simulating the circuit of Fig. 2 subjected to these faults; the column corresponding to each fault is called the *fault signature.*

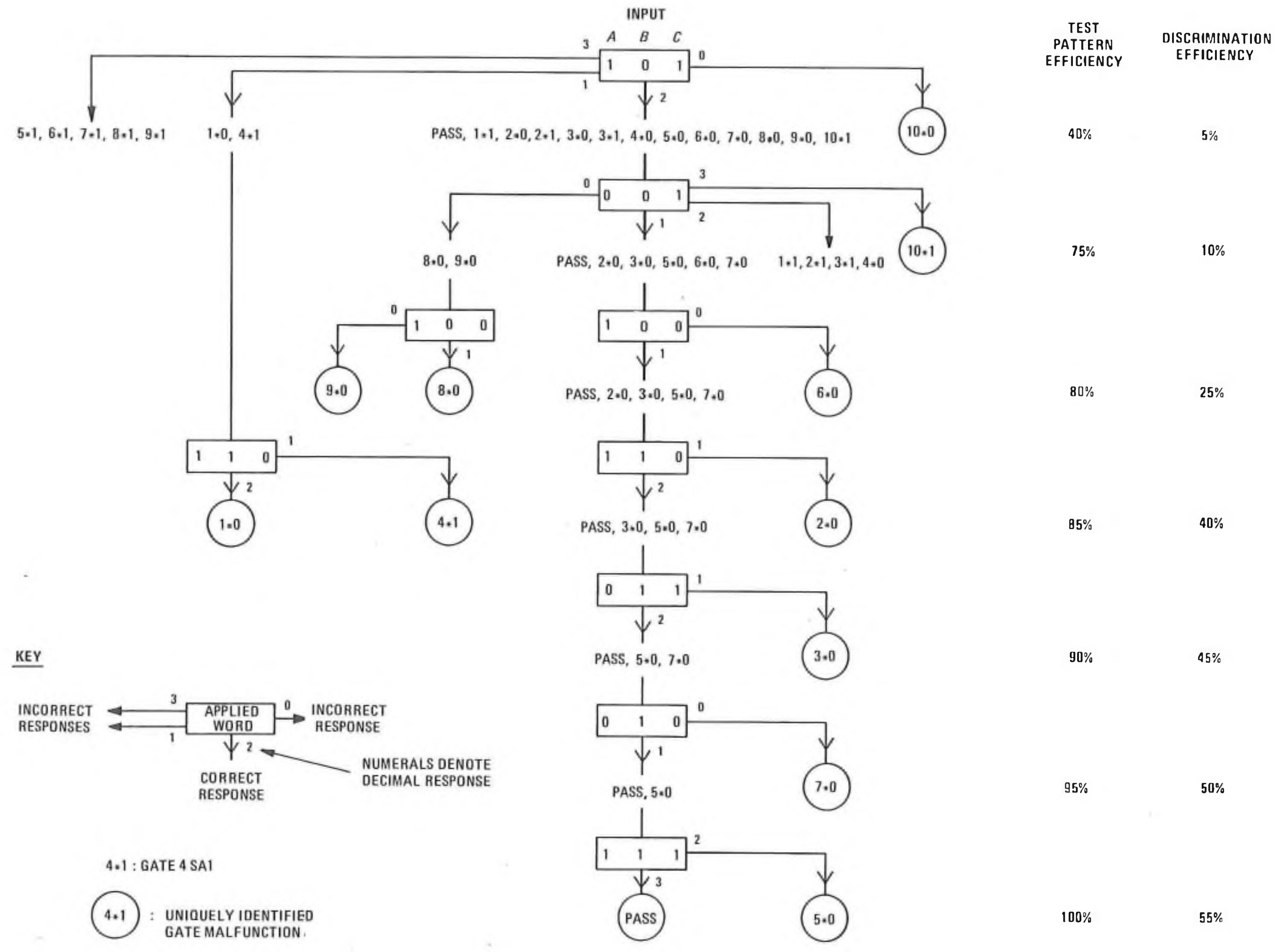
Suppose then that a 7-word input sequence is proposed and applied in the order 101, 001, 100, 110, 011, 010, 111. The first word, decimal input 5 in Table 2, immediately permits the detection of the fault conditions equivalent to gate 1 SA0, gate 4 SA1, gate 5 SA1, gate 6 SA1 . . . and gate 10 SA0 by yielding outputs of 1, 1, 3, 3, . . . and 0 respectively, when an output of 2 is expected. The full list of both detectable and undetectable conditions is shown by the topmost entry in Fig. 3. By counting the number of undetectable fault conditions after each successive input word, a *test pattern efficiency* (TPE) can be calculated as the fraction of all possible faults which the pattern would have found had they existed. Word 101 in Fig. 3 can detect 8 of the 20 possible faults, a TPE of 40%. When the next input word (001) is applied, a fraction of the previously undetected faults is revealed until, as shown in Fig. 3, the last word must be applied before all possible faults are detected, meaning that the TPE then reaches 100%. The test pattern reveals not only the existence of possible faults but has a limited ability to identify defective gates individually. Although an output of 1 in response to word 101 does not distinguish between the fault conditions gate 1 SA0 and gate 4 SA1, these conditions are positively separated when word 110 is reached. It is thus possible to define a *discrimination efficiency* as the fraction of all the faults which can be unambiguously identified. For the pattern used in Fig. 3, the discrimination efficiency reaches 55% because some malfunctions, such as gate 1 SA1 and gate 2 SA1, are not distinct from each other even after the entire pattern has been applied; that is, they have the same fault signature.

After only 2 input words, 75% of all faults can be found (with 2 of them being uniquely identified), yet 7 of the 8 possible input words are required to prove the fault-free case corresponding to a TPE of 100%. This asymptotic approach to a high TPE, illustrated in Fig. 4 for this example, is typical of the larger circuits. The time required to test a circuit, and hence the length of the test pattern, can add significantly to the circuit's cost, and manufacturers commonly achieve a TPE of only 60%. Thus, it is important to select the test pattern which achieves the required TPE after the fewest words have been applied. Normally, such patterns are compared by computer but, in the case of the example presented here, the pattern was selected by inspection of the fault dictionary. That this pattern is more efficient than at least one other (for small numbers of applied tests) can be

TABLE 2

Fault Dictionary for the Circuit in Fig. 2

Decimal Input	Decimal Value of Output for																				
	Fault-Free Condition	Gate 1		Gate 2		Gate 3		Gate 4		Gate 5		Gate 6		Gate 7		Gate 8		Gate 9		Gate 10	
		SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1	SA0	SA1
0	0	0	2	0	2	0	2	2	0	0	1	0	1	0	1	0	1	0	1	0	2
1	1	1	2	1	2	1	2	2	1	1	1	0	1	1	1	1	1	0	1	1	3
2	1	1	2	1	2	1	2	2	1	1	1	1	1	0	1	1	1	0	1	1	3
3	2	2	2	1	2	2	2	2	1	2	3	2	3	2	3	2	3	2	3	0	2
4	1	1	2	1	2	1	2	2	1	1	1	1	1	1	1	0	1	0	1	1	3
5	2	1	2	2	2	2	2	2	1	2	3	2	3	2	3	2	3	2	3	0	2
6	2	2	2	2	2	1	2	2	1	2	3	2	3	2	3	2	3	2	3	0	2
7	3	3	3	3	3	3	3	3	1	2	3	3	3	3	3	3	3	2	3	1	3



Note: The fault-free condition, shown as PASS, must pass each test

FIG. 3—Test pattern for the circuit in Fig. 2

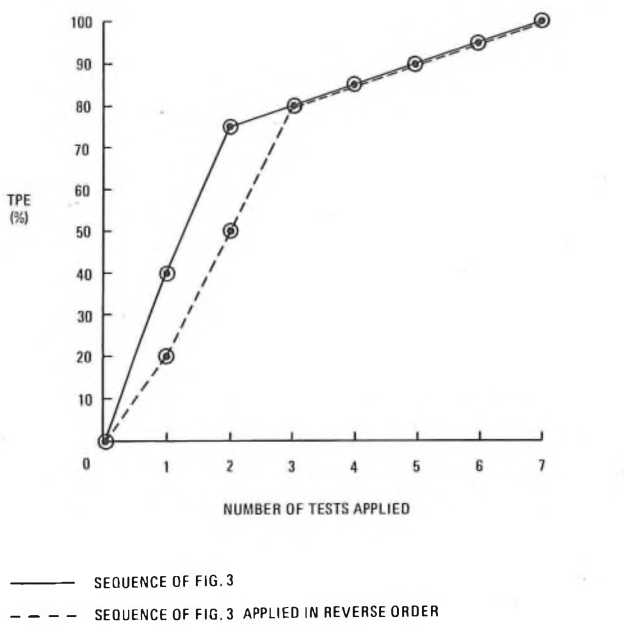


FIG. 4—Improvement in TPE with number of tests applied, showing effect of patterns formed from different test sequences

seen from Fig. 4, where the TPE is compared with that of the pattern formed from the same words applied in the reverse order.

The use of a fault dictionary to identify the faulty element of a circuit is more commonly applied to printed-wiring-board testers than integrated-circuit testers because of the problem of ambiguous fault diagnoses. In the adder circuit, for example, there is no word which can separate faults due to the outputs of gates 1 or 2 SA1. If the circuit were constructed of individual gates, the tester could instruct the operator to examine these outputs with a probe and, on the basis of the new test results, identify the faulty gate. Such an approach is clearly impracticable in integrated-circuit testing.

PATTERN GENERATION FOR MEMORY CIRCUITS

A random sequence of the possible input words, devised in the manner described for Fig. 2, can be applied to a circuit with a larger number of inputs; 20 inputs could necessitate over 1-million words. The highly sequential character of many modern large-scale integrated circuits requires the application of a substantial fraction of even longer word sequences. The preparation of patterns of millions of words would be extremely tedious if techniques had not been devised to simplify their generation. These techniques were developed principally for testing memories by taking advan-

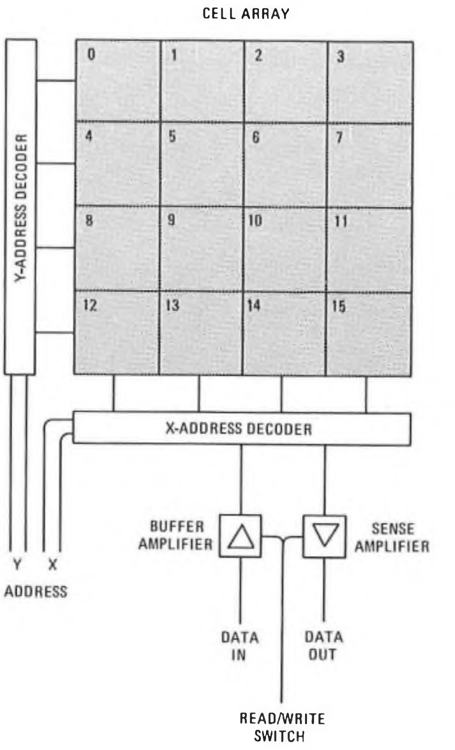


FIG. 5—Simple memory, showing constituent circuit elements

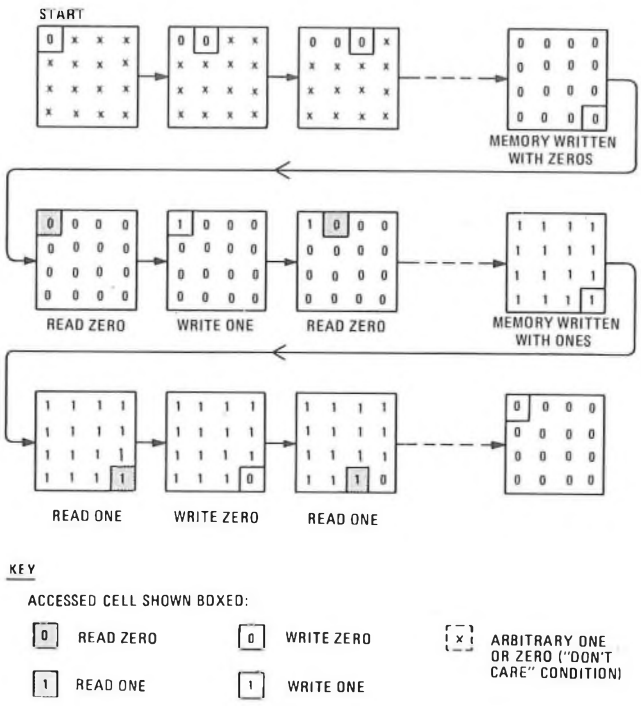


FIG. 6—MARCHPAT for 16 bit memory

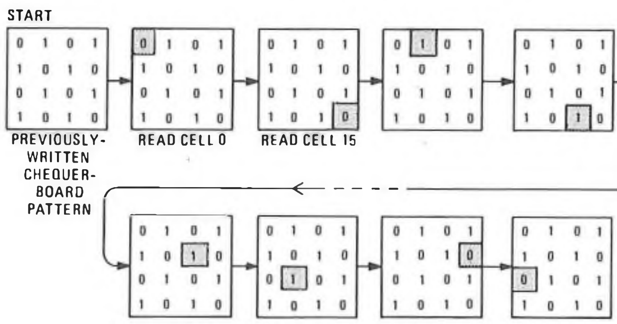


FIG. 7—ADDCOMP for 16 bit memory

tage of the highly ordered configuration of such devices, wherein the number of distinctive logic functions (such as memory cells and address decoders) and the number of inputs are comparatively small, although the memory capacity may be in excess of 16 kbit.

The principles can be illustrated by consideration of the highly simplified design for a 16 bit memory shown in Fig. 5. Each data bit is stored at a location in the cell array, the row being selected by the Y-address 2 bit decoder, and the required cell being accessed by selecting a column using the X-address decoder. The cell is switched to the input of the sense amplifier if its contents are to be read, or to an input buffer amplifier if data is to be written. The circuit elements which require testing are

(*a*) the memory array,
(*b*) the decoders,
(*c*) the sense and buffer amplifiers, and
(*d*) the READ/WRITE switch.

A simple test for the memory array consists of writing zeros in every cell. Taking each cell in turn, a check is made that the zero has been retained, and the zero is then replaced by a one, until the memory is full of ones. The test is then repeated, reading ones and writing zeros, working back through the memory from cell 15. The test ensures that each cell can store a one and a zero. In Fig. 6, the boxed cells are those accessed at a particular point in the address sequence; the unshaded boxes contain data being written and the shaded boxes contain data expected to be read. Successful READ operations show the memory to be operating satisfactorily. This pattern is standard throughout the semiconductor industry under the name *marching ones and zeros*, more frequently referred to as MARCHPAT.

A test for the decoders is to ensure that they can switch from one cell to another within the time allowed by the specification. In the worst case, each bit of the address is changed. Fig. 7 shows a memory written with a chequer-board pattern (alternate ones and zeros). Cell 0 (address 0000) is read, followed by cell 15 (address 1111), cell 1 (0001) and cell 14 (1110), the sequence being continued until every cell has been read. Because every second address is the complement of its predecessor, this pattern is called *complementary address*, or ADDCOMP.

The most stringent test of the output sense amplifier is whether it can recover rapidly enough to respond to a change of data after operation in one state for several address cycles, a characteristic easily verifiable by a modification of MARCHPAT. This modified pattern of *walking ones and zeros* (WALKPAT), shown in Fig. 8, starts with a background of zeros, and a one is written in cell 0. If all the other cells are then read in sequence, followed by cell 0, the response of the sense amplifier to a one after 15 zeros is determined. The original cell can be rewritten, and the test repeated throughout the memory, before writing and reading a zero on a background of ones.

The application of the various test patterns automatically checks the operation of the buffer amplifier and the READ/WRITE switch.

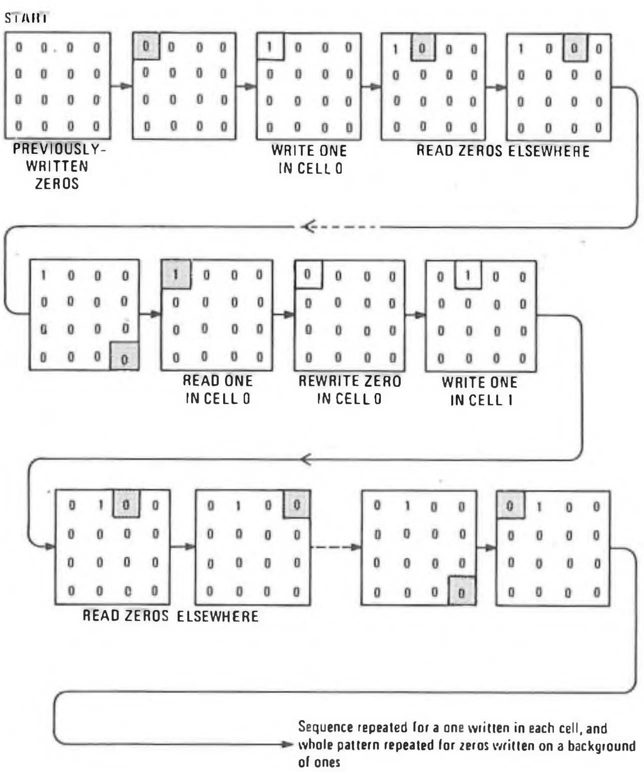


FIG. 8—WALKPAT for 16 bit memory

A very large range of standard test patterns for memories exists,[2] most probing a special weakness of a memory type, or of just one manufacturer's version of that type; some patterns depend on the particular properties of the test system available. Some of the test patterns can be very large, with up to 200-million words for a 4 kbit random-access memory, but the problem of generation is simplified by the orderly way in which the words occur. For example, a MARCHPAT for the memory shown in Fig. 5 can be generated from the following algorithm, or instruction set.

(*a*) Set cell address to 0000.

(*b*) Write a zero.

(*c*) Add one to the cell address and repeat step (*b*) until the memory is full.

(*d*) Repeat steps (*a*)–(*c*), but reading a zero in each cell and rewriting a one.

(*e*) Repeat steps (*a*)–(*c*), but decrementing the address from 1111, reading a one in each cell and rewriting a zero.

PATTERN GENERATION FOR COMPLEX CIRCUITS INCLUDING MICROPROCESSORS

The preceding sections have described 2 alternative forms of test-pattern generation. In the first, for large-scale sequential non-regular circuits, the requirement is a random selection of test words from the large number available. Memory circuits, however, can be tested using a well-ordered algorithmically-generated sequence of words. These 2 examples represent the extremes of circuit design but, in practice, there is a range of items which cannot be so conveniently tested, including counters, arithmetic units, calculator circuits and microprocessors. Microprocessors probably represent the most demanding testing problem because they contain examples of every type of digital circuit (random logic, memory, arithmetic units and counters). At present, there is no clear consensus of opinion on the testing of microprocessors, parallel with that achieved after 5 years or so of testing memories.

If the problem of ensuring that a microprocessor circuit can satisfactorily add 2 numbers is considered, the number of instruction words to be applied may well be in excess of 100, because the initial conditions of the device have to be set up (a process known as *initialization*), the data loaded and the circuit clocked while the addition is being performed. Many of these words can be generated algorithmically, particularly those for clocking and initialization. Only the 2 numbers being added, the microprocessor code for addition and the expected result represent random data. A more rigorous test may require 1-million input words of which only 1000 may be random. This requirement can be met by a tester which can interleave the action of algorithmic and random data-word generators.

PATTERN-GENERATION EQUIPMENT

The 2 major methods of applying test sequences have very different hardware implementations. Random-logic testing requires a means of applying a random sequence of test words to the device under test at high speed. Selection of the test words is normally made by computer at a maximum rate of several-thousand words per second, and they are likely then to be stored on a slow permanent medium, such as paper tape, with an even lower reading rate. This method of presenting words to the device under test is too slow for adequate testing, but a satisfactory solution uses a data-buffer store to accept test words at low speed and apply them to the device under test at a higher rate. Data-buffer stores are currently available manufactured either from semiconductor random-access memories or from shift registers, with maximum data delivery rates of 10 MHz and 20 MHz respectively. Both systems have their advantages. The shift register, in addition to its higher operating frequency, is cheaper than the memory, and can be considered viable for up to 80 kwords. A memory system is more flexible in that words can be accessed in any order, thus allowing jumps within the test sequence, and in their ability to transfer words to the device under test while new words are being stored in other locations. A buffer store organized in this way may accommodate only 1 kword and still have greater word-generation capability than a longer shift register. Memory systems are probably also easier to couple to the alternative pattern-generation system: the algorithmic pattern generator.

The WALKPAT indicates some of the features required of an algorithmic pattern generator. The word generator

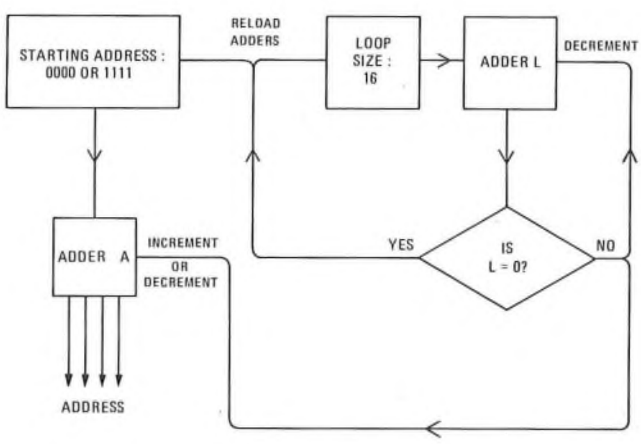


FIG. 9—Algorithmic pattern generator using adders

producing the addresses must accept a starting address and increment or decrement that address until all cells have been accessed. Fig. 9 shows how adders can perform this function. Adder L is loaded with the number of cells to be accessed (16 in the example) and decremented by one on every new word until it reaches zero, when it is ready to be reloaded for the next sequence. Adder A, which forms the addresses, operates in the same way except that it can increment or decrement, and it permits a choice of starting address to be loaded when adder L is reloaded. Algorithmic pattern generators like that in Fig. 9 can be constructed for real-time word generation up to rates of 10 MHz, allowing extensive test capability in a reasonable time. To provide more complex memory patterns, a practical generator offers many more facilities than those of the simple example described, but a design compromise must be reached between speed, complexity, ease of programming and cost.

AUTOMATIC TEST EQUIPMENT

Pattern generators are constructed from one of the standard logic families, normally transistor-transistor logic or emitter-coupled logic, and have to be buffered from the device under test. This may require, for example, drive voltages in the range +5 V to −12 V, and may provide corresponding output levels. The need for buffer circuits offering variable drive levels into a variety of input circuits at high speed requires that they be placed physically near the device under test. Similarly, the sense amplifiers must have a high input impedance, low capacitance and again be near the device under test so as to receive the output signals as accurately as possible. Both requirements are met by the concept of *pin-electronic* circuits of the type shown in Fig. 10, so called because the circuitry is arranged physically in a circle around the device-under-test pin (the circuitry is repeated for each pin). The circuit in Fig. 10 has sample-and-hold circuits to establish the high and low logic levels required of the drive buffer, and the acceptable logic levels for the sense buffer. In special cases, testers may be able to establish independent logic levels on every pin-electronic circuit. Typical high-quality pin-electronics might provide a ±15 V output with a slew rate of 1 V/ns, and a sense capability of ±15 V with 1 MΩ and 20 pF loading.

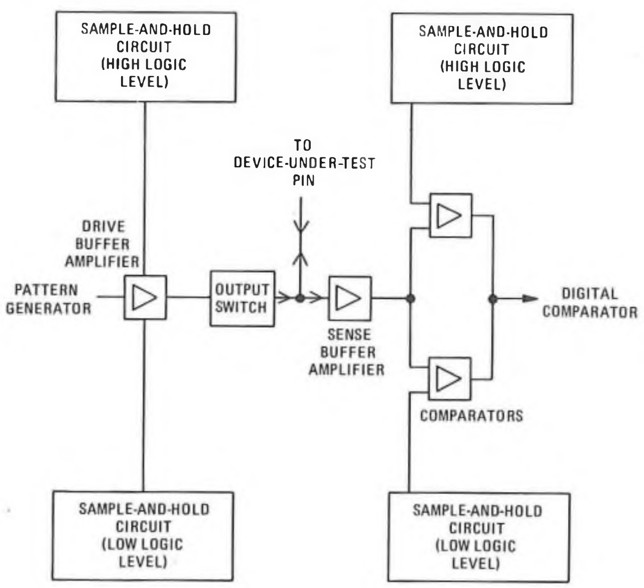


FIG. 10—Pin-electronic circuit

The device-under-test output data from the sense buffer amplifiers and the expected data from the pattern generator are not compared continuously but are strobed to assess the dynamic response of the device under test. For example, the strobe may be moved within the cycle period to measure propagation delay, the precision required being typically 1 ns in a system running at 10 MHz. This accuracy is achieved by using a 100 MHz system clock giving 10 ns tapped digital intervals with analogue delays provided in 1 ns steps.

The major elements of a complex large-scale integrated-circuit tester are shown in Fig. 11 in a typical configuration, resembling closely a normal computer installation with the peripheral equipment replaced by test circuitry. The practical system contains a computer, a programmable supply to power the device under test, supplies to provide the logic levels for the pin-electronic circuits, timing generators, pattern generator and a circuit known as a *formatter* which is used to apply the appropriate logic signals to each pin of the device under test and to make any timing adjustments necessary to match the unavoidable delay of each line to the test socket. The similarity to a computer installation extends to its acceptance of instructions in a high-level language (see Table 3) and operation in a time-sharing mode, in which program generation can run in parallel with circuit testing without apparent loss of performance to either user.

The simple program in Table 3 may be all that is required for the inspection of circuits and, with mechanical handling facilities, could test thousands of circuits every day. The tabular nature of the program also facilitates changes for different versions of the same circuit by, for example, changing a current limit in the bias table. Circuit characterization, using the computer to measure parameters by iterating values until a desired condition is achieved, would however require

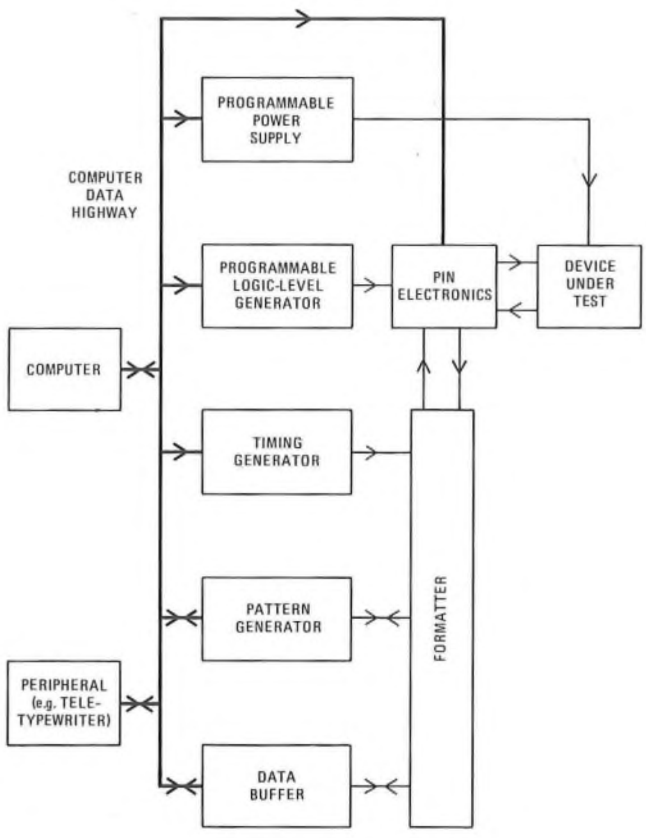


FIG. 11—Computer-controlled automatic test equipment

TABLE 3

Part of Typical Program for Commercial Tester

Program	Explanation
BIAS TABLE 1 V I +5.25 +20.0M	Power supply set to +5·25 V with 20 mA current limit
BIAS TABLE 2 V I +4.75 +20.0M	Power supply set to +4·75 V with 20 mA current limit
PIN TABLE 1	Input and output pins defined
PATTERN GENERATOR TABLE 1	Test-word sequence defined
INSTRUCTION TABLE	
1 PT 1	Set up pins according to Pin Table 1
2 RT BASIC RATE 1 PERIOD 100 = 1000 NS	Set repetition rate to 1000 ns
3 CE POSITION 650	Check for errors 650 ns after data transition
4 BT1	Use Bias Table 1
5 PG TABLE 1	Apply test sequence
6 JE 11	Jump on error to instruction 11
7 BT 2	Use Bias Table 2
8 PG TABLE 1	Apply test sequence
9 JE 11	Jump on error to instruction 11
10 S	Stop
11 ME 1	Print error message
12 S	Stop

Note: The language shown is used by Datatron Inc.

a very much more complex program and several minutes of testing time, corresponding to iterative numerical methods in ordinary computing.

CONCLUSION

To test a circuit satisfactorily, a test equipment must be capable of high accuracy in all its analogue functions, and be sufficiently powerful to generate patterns which probe the circuit's functional capability. With the advent of integrated microprocessor circuits, this task has become more difficult, requiring the fast, flexible pattern generators described. Currently, such a facility is available only in large computer-controlled systems, which will continue to be necessary for circuit characterization. Future trends in test equipment will be determined in part by the component industry, but it seems likely that microprocessors will be used increasingly to construct small bench-top testers capable of detecting a large proportion of faulty complex integrated circuits without the overheads of a large system. The situation is comparable with that of the computer industry, where the availability of complex circuits has given the calculator an enormous increase in computing power, but will never totally eliminate the need for large computer installations. This trend is already perceptible in the recent introduction by a calculator manufacturer of a small tester based on one of their more popular products. As in the past, the increased complexity of integrated circuits will provide solutions as well as posing problems for the test engineer.

References

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2 Huston, R. E. Proceedings of the 1973 Symposium on Semiconductor Memory Testing (IEEE), p. 27.

Book Review

Modern Wiring Practice (eighth edition). W. E. Steward and J. Watkins. The Butterworth Group. 286 pp. 213 ills. £5·00.

This book is essentially concerned with the more practical aspects of wiring practice. Great emphasis is placed throughout on the use of the IEE's *Regulations for the Electrical Equipment of Buildings*. Extracts are made from that publication in support of the content, and the authors give their interpretation, or practical illustration, of various aspects of installation work to comply with the regulations.

The book adopts the format of introducing the IEE's regulations at the outset, and proceeds to describe the distribution of supplies in buildings. Planning and arrangements of final sub-circuits are tackled, and this is followed by a survey of installation methods. The book goes on extensively to consider detailed aspects of installation work and techniques; for example, installing metal conduits. Finally, the content covers earthing and, of course, testing.

Although significant space has been devoted to the relationship of fuse types and ratings with respect to distribution conductors, a more detailed section on discrimination and fuse characteristics may have enhanced the value of the book.

In general, the diagrams and photographs are clear. In the case of the latter, however, it may perhaps be considered unfortunate that the opportunity has not been taken to place greater emphasis on aspects such as the use of safety helmets by personnel shown working on building sites. It is also doubtful whether a safety officer would applaud the picture of insulation being stripped from flexible cords using what appears to be a pocket knife.

No mention has been made of stand-by systems using engine-generator plant. Increasingly, many commercial organizations, even quite small ones, are conscious of the value of such plant in the event of breaks in normal mains supplies. Hence, recommendations on the interconnexion of such plant into an integrated building distribution system would be welcome.

Very little space is devoted to theoretical electrical engineering principles, and any student would have to look to other books if he wished to delve into background considerations. Clearly, from the fact that this book has now run to its eighth edition, the content and presentation has its appeal to the down-to-earth electrician, and no doubt, therefore, this updated volume will be found welcome by those with a need for emphasis on the practical aspects of wiring practice.

C. R. N.

The TXK5 Switching System at Mollison and Thames International Gateway Exchanges

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UDC 621.395.345

Mollison and Thames International Gateway Exchanges are equipped with the TXK5 crossbar switching system. This article, the third in a series on international systems, describes the functions of the TXK5 switching and peripheral equipments supplied at the exchanges.

INTRODUCTION

Before Mollison International Switching Centre (ISC) was brought into service in October 1974, Faraday and Wood Street ISCs handled all international calls to and from the UK. These latter ISCs are referred to as *full-facility* ISCs, because they can cater for all internationally-agreed facilities and all types of traffic. With the rapid growth of international direct dialling (IDD) in the UK and overseas, the amount of IDD traffic became large enough to warrant the provision of large unidirectional switching units solely for this traffic. These ISCs are termed *limited-facility* exchanges because they do not provide the complex operator and transit facilities described in previous articles.[1,2]

The first limited-facility exchange to be installed was Mollison ISC, which consists of 2 units each of 4000 erlangs capacity; one is dedicated to switching outgoing IDD traffic from the UK, and one to switching incoming traffic to the UK that does not require operator facilities. The switching system used for Mollison ISC is the L. M. Ericsson ARM20 crossbar system, which is designated *TXK5* by the British Post Office (BPO). The ISC is situated at Stag Lane, Edgware, some 19 km from central London, on a site that also accommodates the De Havilland TXK2 ISC[2] and a common repeater station. The exchange building is single storey and the switching equipment occupies an area of about 5000 m^2.

† Telecommunications Development Department, Telecommunications Headquarters.

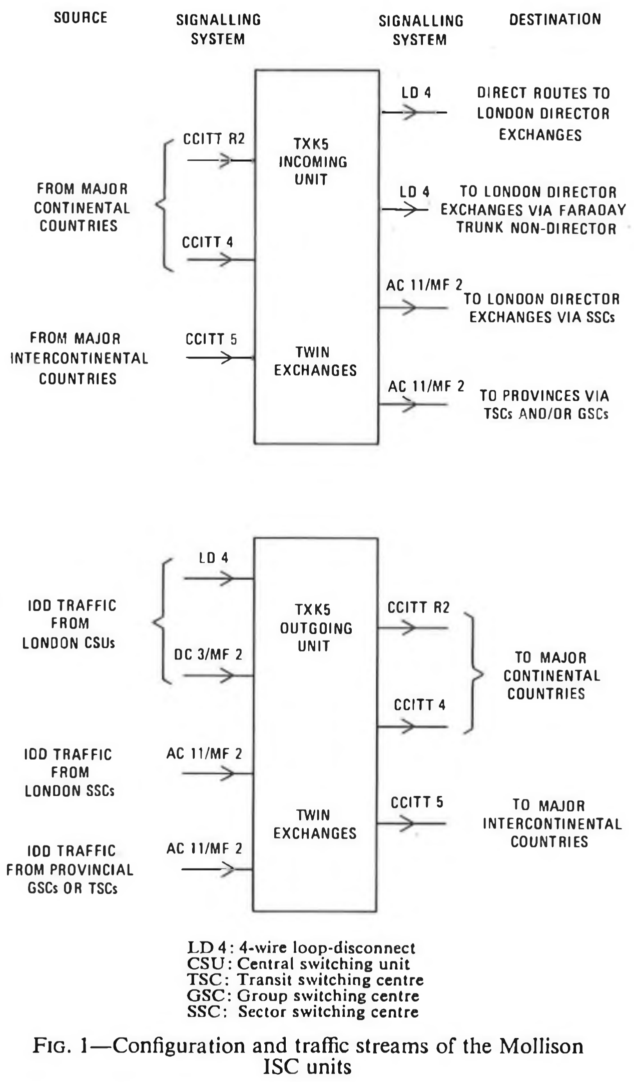


FIG. 1—Configuration and traffic streams of the Mollison ISC units

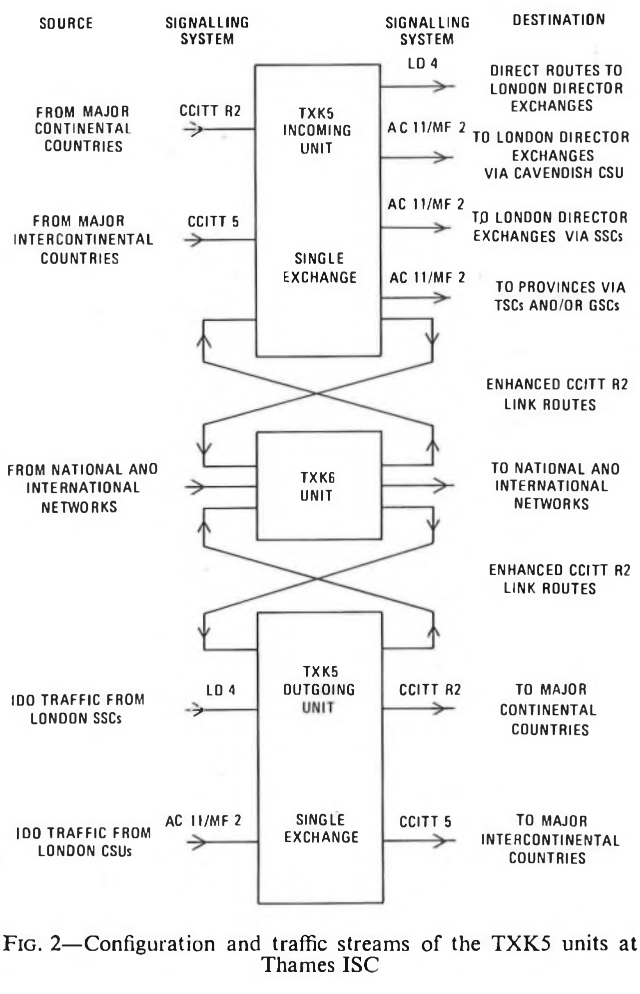


FIG. 2—Configuration and traffic streams of the TXK5 units at Thames ISC

A further 2 units of TXK5 equipment have been installed at Mondial House in the City of London, as the first phase of the Thames ISC. This will be ready for service in 1978. The second phase of Thames ISC will consist of a bidirectional unit of L. M. Ericsson AKE 132 stored-program-controlled equipment, which is designated *TXK6* by the BPO. Thames ISC will also be a limited-facility unit, but the TXK5 equipment has been enhanced to interconnect with the second-phase equipment over routes using CCITT† R2 signalling,[3] and provide the possibility of later adoption of certain facilities normally associated with full-facility units.

ISC TRAFFIC STREAMS

Mollison and Thames ISCs handle traffic between the UK and the 16 countries that have the highest levels of international traffic with the UK. Figs. 1 and 2 show the different traffic streams connected to Mollison and Thames ISCs respectively, together with the signalling systems used. As most of the traffic growth in Europe now uses CCITT R2 signalling, there is no provision for CCITT 4[4] signalling at Thames ISC. The CCITT R2 link routes at Thames ISC will use an enhanced form of this signalling system, using certain spare signals to pass information concerning the connexion of satellite and echo-suppressed circuits. This information is required to prevent the tandem connexion of the 2 satellite links, and to ensure the correct connexion of echo suppressors where these are necessary.

† International Telegraph and Telephone Consultative Committee

ISC SWITCHBLOCK DESIGN

The TXK5 switching system is a register-controlled system, providing 4-wire speech-path switching via 4 ranks of crossbar switches. Fig. 3 shows a simplified trunking diagram of the system. The incoming-unit design uses crossbar switches equipped with 10 vertical bars and 6 horizontal bars, to provide a basic 10-inlet, 20-outlet switch for 5 wires (4 speech wires and 1 holding wire). In the outgoing-unit design, the need for additional trans-exchange control functions influenced the choice of a 10-wire switching configuration, using a crossbar switch having 5 horizontal bars and providing 10 inlets and 10 outlets per switch.

The crossbar switches for both units are formed into 200-groups, which can handle a maximum of 200 incoming lines or 200 outgoing lines. Each 200-group comprises 2 ranks of crossbar switches, interconnected by links that provide a full-availability trunking arrangement. Link trunking is also used for the interconnexion of incoming 200-groups and outgoing 200-groups. The link routes so formed are dimensioned to suit traffic requirements.

Incoming and outgoing 200-groups are known as *GI* and *GU* respectively*. The 4 ranks of crossbar switches are known as *GIA*, *GIB*, *GUB* and *GUA*.

The normal maximum capacity of a TXK5 exchange is 4000 incoming circuits (20 *GIs*) and 4000 outgoing circuits (20 *GUs*). Each of the Thames units approaches this maximum

* The abbreviations are the initial letters of the Swedish equivalent names. Such abbreviations are in widespread use in the system and are indicated in this article by the use of italics

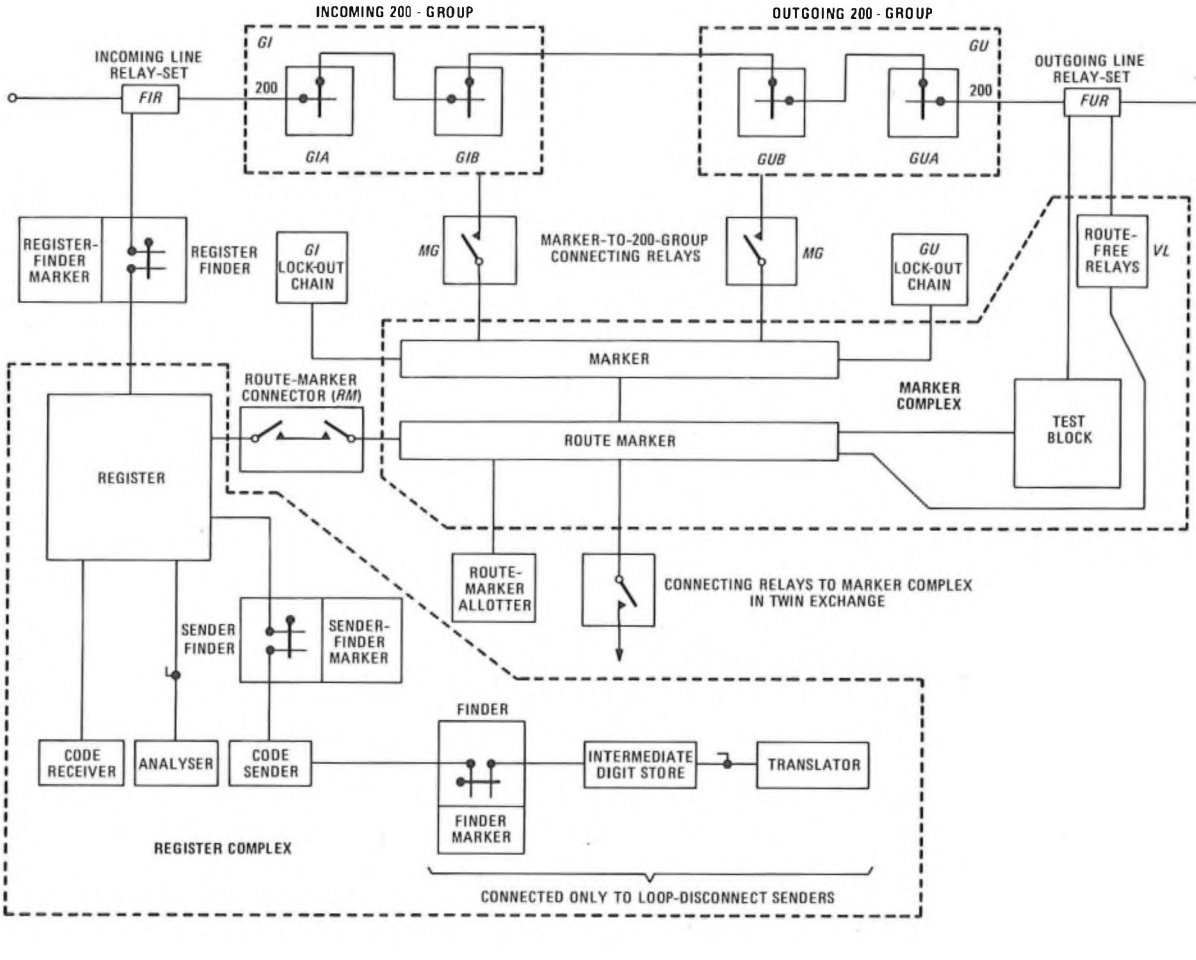
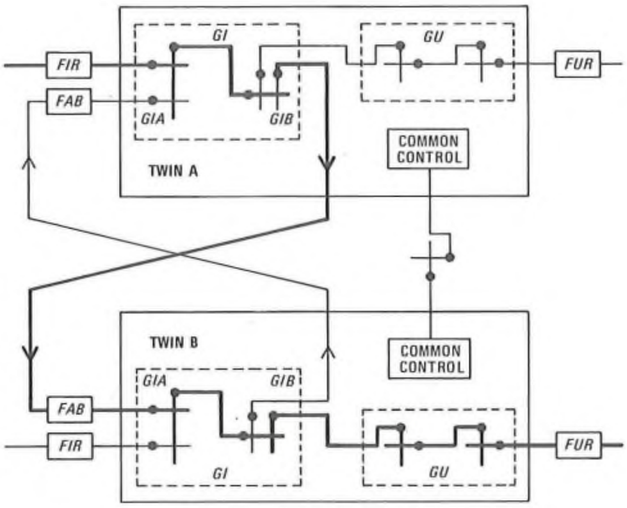


Fig. 3—Simplified trunking diagram of the TXK5 system



Thick lines show path taken by a twin call

FIG. 4—Interconnexion of the twin units in the Mollison ISC units

200-group capacity; however, at the earlier Mollison ISC, a larger capacity was required, so each of the Mollison units consists of 2 exchanges combined in a special way. This twin-exchange configuration still allows full availability between incoming and outgoing circuits by the use of special inter-twin trunks (known as *FABs*), as shown in Fig. 4. A special feature of calls needing to use these trunks (twin calls) is that the information needed for setting up the call in the second exchange is passed directly from the call-switching common controls of the first exchange to those of the second. There is no need to pass forward digital information over the trunks, nor to use a register in the second exchange.

Line Equipments

National and international circuits are terminated at the exchange on incoming and outgoing line relay-sets (Fig. 5), known as *FIRs* and *FURs* respectively. The main functions of the *FIR* are

(*a*) on seizure, to call the register-finder marker to connect a register,

(*b*) to provide the logic interface between the line signalling system and the internal exchange signalling,

(*c*) to provide transmission pads, transmission bridges and switchblock wetting currents,

(*d*) to provide all necessary signalling paths to and from the register,

(*e*) on receipt of signals from the register, to control the release of the register, the through connexion of the speech paths or return of tones, and

(*f*) to hold the forward connexion.

The main functions of the *FUR* are

(*a*) to provide the logic interface between the outgoing line signalling system and the internal exchange signalling,

(*b*) to provide suitable idle and marking conditions to the marker complex, and

(*c*) to provide transmission pads, transmission bridges and switchblock wetting currents.

Register Finder

The register finder is a crossbar switching stage providing a 20-wire connexion from 60 *FIRs* to a pool of 20 registers. It consists of 8 crossbar switches and one controlling marker, and occupies one rack of equipment. On teletraffic grounds, 60 *FIRs* do not warrant the exclusive use of 20 registers, so a grading arrangement is employed. Between 8 and 10 register finders are grouped together, and one pool of registers is provided for this register-finder group. In consequence, a register is graded over 3–5 register finders. There is no logical relationship between the 200-groups of *FIRs* that connect to the switchblock and the 60-groups in the register finder.

FIG. 5—TXK5 line relay-set and crossbar-switch racks with exchange tester trolley

Register Complex

The register complex comprises registers, code receivers, analysers and code senders. Its functions are to receive and store the numerical information, to control the calling of the marker complex after receipt of a suitable number of digits, to control the forward transmission of digits, and to direct the final through connexion or return of tone.

The register is the controlling part of the register complex. It is responsible for digit storage, interworking with all other parts of the register complex and overall supervision of the call set-up. All the registers in Mollison and Thames are of the same basic design. Groups of registers for each incoming register signalling system are formed by wiring the registers directly to appropriate code receivers. All the other facility requirements are achieved by strapping in the register and, to a lesser extent, in the code receiver. For multi-frequency (MF) signalling systems, the code receiver also includes an electronic receiver for decoding the MF signals.

Analysers are short-holding-time equipments, accessed by the registers. One analyser is provided for every 24 registers; its function is to determine, from the first 3 received digits, the point at which the marker complex should be called to route the call forward. The following indications can be returned by the analyser:

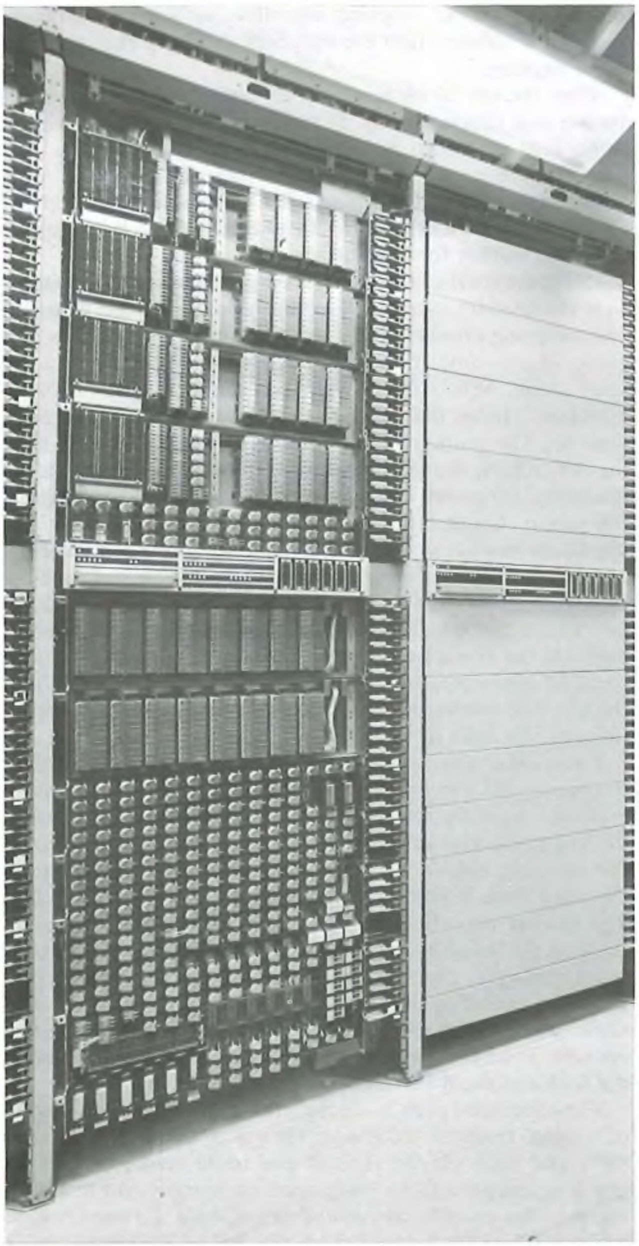


FIG. 6—TXK5 route-marker rack

(*a*) route after *N* digits,
(*b*) insert *stop* digit in digit store,
(*c*) determine routing point by 5 s digit time-out, and
(*d*) spare code.

Indications (*b*) and (*c*) are used in conjunction with calls using CCITT 5 signalling[5] when routing is delayed until all digits have been received.

The register can signal forward in all required signalling systems by calling a code sender of the appropriate type. Code senders are provided in pools and are connected to the registers by the sender finder. The sender finder is a crossbar switching stage, providing 20-wire switching from 16 registers to a group of 40 code senders containing a proportion of all required types. The sender finder has a marker and is similar, in many respects, to the register-finder stage.

On receipt of suitable sending-programme instructions from the register, the code sender requests digits from the register and transmits them in the appropriate code back via the sender finder to the outgoing circuit. For certain MF signalling systems, an electronic receiver is incorporated to decode backward register signals; suitable DC indications of their receipt can be extended to the register.

Special equipment has been provided in the register complex of the incoming units to provide the translation digits for loop-disconnect routes in the London director area.

Marker Complex

The marker complex is responsible for setting up the speech connexion through the switchblock. The main equipments are route markers, markers and test blocks. Route markers (Fig. 6) are assembled into groups of up to 5 and each group is accessed from a pool of registers by the route-marker connector (*RM*). The actual quantities and grouping of route markers, markers and test blocks are dependent on the size and traffic loading of the particular exchange, and are not discussed here.

FURs are connected to the marker complex via test blocks. Each circuit is connected to one test block but, for security, circuits of any one route are spread over 3 test blocks. The 3 route-parts so formed each have a route-free relay (*VL*), which has a connexion with each *FUR* in the route and provides the route markers with conditions that indicate whether there is at least one free circuit in each of the 3 route-parts.

The functions of the route marker are

(*a*) to receive up to 5 digits from the register and determine the outgoing route,

(*b*) to receive from the *FIR*, via the register, a signal indicating the identity of the incoming 200-group in which the *FIR* is situated,

(*c*) to select and connect to a test block containing free circuits in the required route, using information from the *VL* relays,

(*d*) to select a marker, and pass to it the identity of the 200-groups containing the incoming line and the selected outgoing line, and

(*e*) to send back to the register information relating to the type of signalling used on the outgoing route and other sending-programme information.

The test block can be connected to a maximum of 150 outgoing circuits. This capacity can be used in varying combinations. A maximum of 30 route-parts can be accommodated, but with severe restrictions on the size of these route-parts. Typically, groupings are arranged to enable fewer route-parts of a larger size to be handled. A maximum of 30 circuits in any one route-part can be accommodated, thus restricting each route to 90 circuits maximum, but this can be increased by an adaption of an alternative-routing facility. The function of the test block is to test and select an idle *FUR* in the route-part, which is indicated by the route marker. It also extends to the marker the marking conditions from the *FUR*, together with the identity of the 200-group in which it is situated.

The functions of the marker are to select a free path through the switchblock, operate the crosspoints and carry out a continuity check on the path. In contrast with many other switching systems, the marker is not functionally tied to any one area of the switchblock. A large number of connecting relays (*MG*) are therefore provided to connect markers to the incoming and outgoing 200-groups. This method of working allows end-to-end selection and rapid completion of the switched path under single marker control. The disadvantage lies in the large volume of common controls and their interconnexion.

Accounting Complex

The equipments provided for international call accounting at Mollison and Thames ISCs are significantly different from each other. Both systems are based on the use of active digital computers, but the facilities provided and the interfaces with the switching equipment are quite different. The Mollison accounting equipment termed the *AVR* requires a relatively large electromechanical interface. This interface, known as *AVRV*, forms part of the switching equipment and so it is described here; the general principles of the accounting equipment are, however, covered later.

The function of the *AVRV* is to switch a single accounting wire from each *FIR* to one of 198 accounting points. Each accounting point is assigned to a route destination, this being the combination of selected outgoing route and the ultimate destination ISC. The *AVRV* uses crossbar switches in a novel way to provide the required switching. Each *FIR* is connected to 2 vertical elements in different crossbar switches. Closing 3 crosspoints allows the selection of one of the 198 outlets. There are 64 *AVRV* units in the Mollison outgoing unit, each providing switching for 100 *FIRs*. Each *AVRV* unit has a single marker (*AVRM*), which receives information from the register and sets up the path to the accounting point. The 100-groups of *FIRs* are assembled in such a way that 6 *AVRV* 100-groups contain the same *FIRs* as the ten 60-groups of *FIRs* in the register-finder group. This configuration implies that each register will need access to only 6 *AVRMs*.

A TYPICAL CALL THROUGH THE ISC

The functions of the ISC equipments can also be described by considering a typical call through the Mollison outgoing unit. The call considered is an outgoing IDD call from a London sector switching centre (SSC),[6] using signalling system (SS) AC 11/MF 2,[7] to a continental ISC using CCITT R2[3] signalling.

On receipt of the seizure signal, the SSAC 11 *FIR* calls the register-finder marker, which selects and operates a path through the register-finder stage to a free SSMF 2 register. The *FIR* passes a *1-out-of-3 origin* signal to the register. The register acknowledges this signal and the *FIR* releases the register-finder marker. The *origin* signal is used in the Mollison outgoing unit as part of the identification of the *AVR* 100-group; at other units, the *origin*-signal procedure is either deleted or is used, as at Thames incoming unit, to indicate whether the incoming line is a link circuit or one via a satellite.

The SSMF 2 register seizes its associated code receiver and, in response to backward SSMF 2 signals, receives the *class-of-service* signal and the digit sequence; typically a country code of 2 digits and the distant national number of between 7 and 9 digits. After receipt of the third digit, the register calls the analyser and, on connexion, extends the 3 received digits to it. As the call is a continental call, the routing instruction received back will be *route after 7 digits*. Thus, on receipt of the seventh digit, the register calls for connexion to a route marker. All the route markers in one group receive the calling signal, but one is primed by the route-marker allotter to accept it. The route-marker allotter primes idle route markers in a rotational sequence to ensure they are evenly used. The called route marker identifies the calling register and operates the *RM* to establish a 48-way path between them. The route marker receives 5 digits from the register. For typical continental calls, the first 2 (the country code), and perhaps 1 or 2 digits of the national number, are examined to determine the required outgoing route.

In parallel with the digits, the route marker receives a DC-coded signal over a 2-wire path extended from the *FIR*; this signal indicates the incoming 200-group in which the *FIR* is situated, and is decoded and stored for later use by the marker.

When the outgoing route is determined, the route-free information is received from the 3 *VL* relays associated with the 3 route-parts. Test conditions from the 3 test blocks associated with the route are gated with the route-free information, and allow the route marker to select and seize an idle test block with access to idle circuits. At the same time, the identity of the outgoing signalling system and sending-programme information are sent back from the route marker to the register.

When the test block is seized, it identifies the calling route marker and connects to it. It receives from the route marker indications of which circuits it should test. When a free circuit has been chosen, the test block sends to the route marker the identity of the *FUR's* outgoing 200-group and also connects 2 marking wires from the *FUR* back through to the route marker for later use by the marker.

The route marker then selects an idle marker, and extends to it the identity of the 200-groups containing the incoming and outgoing circuits. Only one marker can work in a 200-group at any time; therefore, each 200-group has a lock-out relay chain. When the marker has an indication from the 2 lockout chains that both the 200-groups can be seized, it does so. The marker then connects to the 200-groups using the *MG* relays, thus establishing a 168-wire connexion to the incoming 200-group and a 96-wire connexion to the outgoing 200-group. Using the 2-wires via the route marker and test block, the marker now operates a marking relay in the *FUR*, and the horizontal bar in *GUA* corresponding to the *FUR*. The *GUA* switch to which the *FUR* is connected is also identified within the *GU*. Similarly, on the incoming side, using a path via the route marker and register, the marker operates the *GIA* horizontal bar and identifies the *GIA* switch within the *GI*. The marker then receives, via the *MG* relays, indications of idle links in the *GIA* switch.

The marker also applies test conditions over the *MG* relays to the idle links in the *GUA* switch, and these conditions are extended back through free links to the *GUB* and thence to the link route with the *GI*. The marker primes the *GI* to accept the marking signals from the particular *GU* and these are extended back from the *GI* to the marker via the *MG* relays. The marker uses this information to select a free path right through the switchblock. A high selection speed is achieved by using reed-relay chains. The marker closes the A-stage crosspoints by operating the *GIA* and *GUA* vertical bars and, at the same time, the respective *GIB* and *GUB* horizontal bars operate. The 2 B-stage crosspoints are then closed by operating the *GIB* and *GUB* vertical bars.

The completed path is checked for continuity by the receipt of a signal from the *FUR* over the HOLD wire of the switched path, and back via the register and route marker. When the check is completed, the route marker, marker and test block release, the speech connexion being held forward by the register. The time elapsed from the call of the route marker is about 500 ms.

In parallel with the path set-up procedure, the register receives the sending programme information from the route marker. In the chosen example, the information received is that:

(*a*) the outgoing signalling system is CCITT R2,

(*b*) the call is a terminal call requiring no transit indication, and the sending of address digits starts with the third stored digit; and

(*c*) the chosen route is the primary route; this information is required for accounting purposes.

The register calls the sender-finder marker, instructing it to connect a CCITT R2 code sender. When this is connected, the sending information in (*b*) above is sent to it. A signal is sent across the switchblock, instructing the *FUR* to transmit the seizing signal. The code sender transmits the first MF digit; which is the language (discriminating) digit zero. Zero is sent automatically by all code senders at Mollison because all the calls are subscriber dialled. On receipt of acknowledgement signals from the distant ISC, the CCITT R2 code sender sequentially reads each digit from the third store onwards, and transmits them forward. This compelled sequence of sending digits and receiving acknowledgements continues until the distant ISC returns a signal indicating that all digits have been received and the call may be connected through. The register instructs the *FIR* to switch through the speech paths after the code receiver has returned an SSMF 2 *number-received* signal. At this stage, the register would normally release, but at Mollison outgoing unit, the *AVRV* connexion between the *FIR* and the accounting point is now made. The register calls the *AVRM* over a path through the *FIR*. The *AVRM* identifies the calling *FIR* and returns an acknowledgement of seizure. This passes back through the *FIR* to the register over one of 2 paths. This received signal, together with the *1-out-of-3 origin* signal received at the beginning of the call, allows the register to determine to which of 6 possible *AVRMs* it should connect. When this connexion is made, the register extends the first 4 stored digits, together with the information from the route marker concerning whether the primary, or some alternative, routing was selected. The *AVRM* uses this information to determine the route destination to which the call should be accounted, and then operates the respective crosspoints to connect the *FIR* to that accounting point. When this has been done, the register and *AVRM* release, and the *FIR* holds forward the speech connexion and *AVRV* connexion.

When the called subscriber answers, the *FUR* returns the condition across the switchblock for retransmission by the SSAC 11 *FIR*. At the same time, a contact in the *FIR* allows accounting pulses to be forwarded to the accounting point for registration by the *AVR* computer.

EQUIPMENT PRACTICE

The equipment practice of the TXK5 system is based on a plug-in philosophy. The crossbar-switch racks are provided fully-equipped, each rack containing 10 switches, with electrical connexions being made by plugs and jacks at the top of the rack.

The common-equipment racks contain plug-in relay-sets, with electrical connexion from shelf jacks at the side of the rack to plugs and jacks at the top of the rack. A route marker or marker occupies a whole rack, while a register occupies one quarter of a rack. These are broken down into functional plug-in relay-sets of various convenient sizes. The line relay-sets are also plug-in, but there is no rack plug and jack, the shelf jacks being wired directly to intermediate distribution frames.

The plug-in relay-sets consist of a number of relay mounting strips, normally no more than 5, which may be used for mounting both relays or small printed-wiring boards. Both electronic components and reed relays can be mounted on these printed-wiring boards. Components can also be mounted by direct connexion to the tags on the back of relay coils or springsets.

In applications requiring electronic assemblies, such as MF receivers, larger printed-wiring boards are used. Assemblies of an older design and practice are based on a discrete-component technology, and are mounted horizontally on adapted relay strips. Those of a newer design, particularly equipment designed for the Mollison or Thames installations, make use of integrated circuits where applicable, and are mounted by vertical insertion in specially designed plug-in shelf units.

MAINTENANCE PHILOSOPHY

The maintenance philosophy applied in the TXK5 system is known as *controlled corrective maintenance*. This presupposes that the equipment is inherently reliable and that the service will not be significantly affected by a small percentage of faulty equipments remaining in the exchange. The philosophy relies on supervision and fault-indication techniques prior to fault tracing and repair. With the exception of a mobile artificial traffic equipment, known as the *exchange tester*, no automatic tester or routiner is used.

International Switching Maintenance Centre (ISMC)

The ISMC contains a number of equipments, described below, for the supervision and fault recording of the exchange common-control equipment and switchblock.

(*a*) *Centralograph Equipment* This is a printer that is automatically connected to route markers and/or markers whenever an abnormal condition arises during the setting-up of a call. A coded print-out gives details of the type of fault, the exchange equipments used and the attempted switch path.

(*b*) *Service Alarm Equipment* This supervises the quality of service given by all common equipment items, by monitoring the proportion of forced-released calls within groups of exchange equipment.

(*c*) *Traffic and Statistical Meters* These are connected permanently, or when required, to exchange equipments to provide data for statistical analysis.

(*d*) *Electronic Traffic Recorder* This is provided at Mollison ISC, and is known as *MET 2*.

International Transmission Maintenance Centre (ITMC)

The ITMC is responsible for maintaining all national and international circuits terminating at the exchange, together with their associated relay-sets. For this purpose, the ITMC (Fig. 7) contains the following equipments.

(*a*) *Supervisory Console* This provides lamps and keys for monitoring busy, blocking and fault conditions on incoming and outgoing routes and circuits.

(*b*) *Test-Jack Frame* This provides facilities for the connexion to, and monitoring of, all circuits terminating at the exchange.

(*c*) *Test Consoles* A number of test consoles are provided in the ITMC, each containing control panels and a comprehensive range of test equipment. Test consoles may be connected to national or international circuits via the test-jack frame or the access selector.

(*d*) *Access Selector* The access selector, which consists of a relay network, allows a test-access path to be made to any line relay-set in the exchange. Under the control of test-console keys, different forms of access are possible. The access selector is used for testing and monitoring circuits and may also be used for setting up test calls on outgoing circuits.

Ancillary Equipment

The following ancillary equipment is also provided for maintenance purposes.

(*a*) *Exchange Tester* This is an artificial-traffic generator, comprising a trolley and a fixed equipment rack. These are connected via an 80-wire highway, multipled round the exchange. Under the control of keys and lamps on the trolley, test calls can be set up from *FIRs* and *FURs*, and also from the ITMC test consoles.

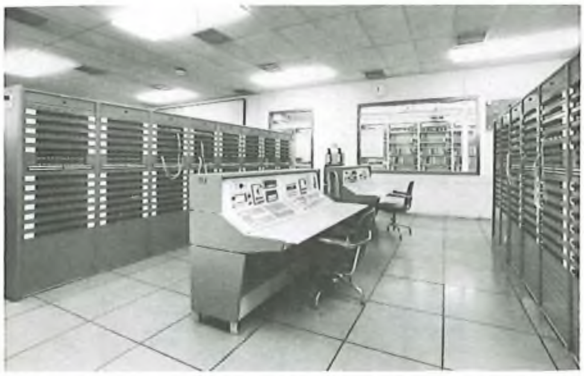


FIG. 7—Part of Mollison ITMC showing test consoles and test-jack frames

(*b*) *Automatic Transmission Measuring Equipment No. 2 (ATME 2)* This equipment, controlled by minicomputers, is used for the automatic routining of international circuits, in conjunction with responders in the distant ISCs. The access selector is used to connect the ATME 2 to the required circuit.

(*c*) *Service Observation Equipment* This can be connected to *FIRs* for monitoring live traffic.

INTERNATIONAL ACCOUNTING EQUIPMENT

As stated earlier, the international accounting systems at Mollison and Thames ISCs are significantly different from each other.

Mollison Equipment

The accounting-only *AVR* equipment at Mollison ISC comprises the following 3 sections, as shown in Fig. 8.

(*a*) *Computer Equipment* This is based on two UAC 1610 computers with associated peripheral equipment, together with a generator adaptor and a digital input unit.

(*b*) *Interface Equipment* This comprises a generator unit, check encoder and a number of receivers.

(*c*) *Switching Equipment* This consists of part of the *FIRs* and the *AVRV* switching network, the function of which has already been described.

The computer equipment is situated in a computer room, adjacent to the exchange equipment floor. The computer system accounting software scans all *FIRs* by generating a series of pulses during every 15 s period. These pulses are spread sequentially, via the generator and generator adaptor, over 1000 wires; each wire is multipled over 7 *FIRs*, allowing a maximum of 7000 *FIRs* to be scanned, as shown in Fig. 8. In addition, the wires are passed back to the computer via the check encoder and digital input unit, so that the generator output can be checked.

The pulses are passed, via contacts on the answer relay in the *FIR* and the *AVRV* switch network, to one of 198 accounting points, each representing a route destination. Hence, the computer receives pulses for each route destination from all *FIRs* that are carrying a call in the answered state. These are stored on counters in the computer store, according to the accounting point and the tariff applying at that particular time.

At the end of each month, the information is placed on magnetic tape and the counters reset. In addition, a daily dump of information on the counters to magnetic tape is performed for security reasons.

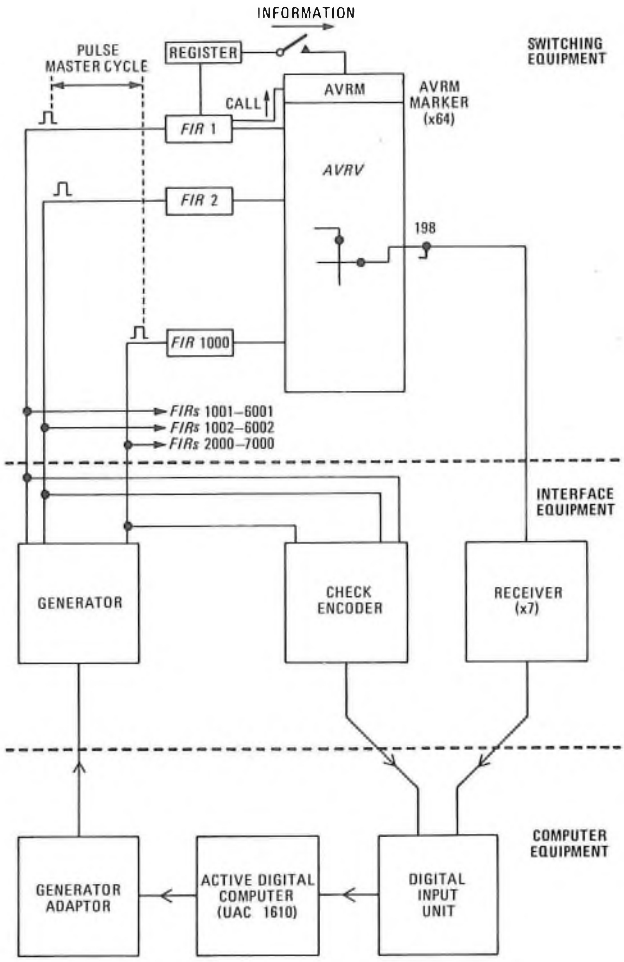


FIG. 8—Mollison ISC *AVR* system

Thames Equipment

The international accounting and traffic analysis equipment (IATAE) being provided at the first phase of Thames ISC provides many facilities that are not available on the Mollison *AVR* equipment. The following main functions are provided by the IATAE:

(*a*) international call accounting,

(*b*) traffic recording and performance monitoring, and

(*c*) processing of fault information collected by the centralograph.

The system is based on three UAC 1610 computers: one for accounting, one for traffic analysis and other facilities, and the third as a back-up. These are connected via interface equipment to the *FIRs* and the route markers for accounting purposes, and to *FIRs* and *FURs* for traffic-recording and performance-monitoring purposes.

The relationship between a *FIR* and a route destination, defined by the *AVRV* at Mollison, is established in the IATAE by software on the basis of information received directly from the route marker. All *FIRs* are continuously scanned and, when in the answered state, a counter is stepped for the route destination listed against the *FIR*.

CONCLUSION

The TXK5 equipment provided at Mollison ISC has played a vital role in expanding UK international switching capacity at a time of high demand for IDD service.

The provision of further equipment for the first phase of Thames ISC will ensure that switching capacity will continue to meet the expected growth of international telephone traffic.

ACKNOWLEDGEMENTS

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A Call Sender for TXE2 Exchanges

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UDC 621.395.345: 621.395.664

This article describes the facilities and operation of an automatic call sender for use in TXE2 exchanges. The call sender is designed to assist maintenance staff in the monitoring of exchange performance. The design was first conceived by the authors for local application, but it has since been adopted by the South Eastern Telecommunications Region and is in use in several TXE2 exchanges.

INTRODUCTION

The need for equipment monitoring devices to aid maintenance in a modern telephone system is well established. The principal fault-monitoring equipment in the TXE2 exchange design is the maintenance data recorder which, under the command of the common control, prints information concerning faults detected while the common equipment is in use. The maintenance data recorder and other fault-checking facilities within individual units of the common equipment can detect the majority of faults that may arise. However, there are certain areas of the exchange where faults can remain undetected; for example, faults within the exchange registers may cause serious loss of traffic, and faults in the network beyond the exchange interface can degrade outgoing service. It was the discovery of a particular register fault that stimulated the idea leading to the design and construction of an automatic call sender to check the setting-up of a call from a line circuit to a selected test number, thus bringing to attention previously undetected faults.

The unit is known locally as the *basic electronic automatic multi-test* (BEAM) call sender and is used in conjunction with an existing test-call unit which is built into the TXE2 exchange design. The call sender is designed to operate continuously, either attended or unattended and, on detection of a failed call, produces a PROMPT exchange alarm, or simply records on a meter the type of fault encountered, depending on the mode of operation.

DESIGN DETAILS

The physical design of the call sender is compatible with the standard form of TXE2 equipment practice adopted by TXE2 manufacturers. The sender is constructed as a double-width unit, and is mounted in the control rack or an auxiliary equipment rack, depending on the type of manufacturers' equipment installed. The call sender is shown in Fig. 1.

The circuit design is realized in printed-wiring-board construction and the unit is powered from the 50 V telephone exchange battery supply. A single printed-wiring board was used in the design of the call sender, connexions being made by means of edge connectors. This proved to be an economic design and has the added advantage that a fault on the unit can be localized by substitution of the printed-wiring board.

The call sender circuit design is formed of 3 sections: control logic, pulsing unit, and fault detecting logic. The circuit was designed using complementary metal-oxide semiconductor (CMOS) integrated circuits (ICs).

Facilities

A test number of up to 10 digits can be selected using thumb-wheel switches mounted on the front panel of the call sender. The number selected can then be dialled from the call sender, which can execute the following programme of checks.

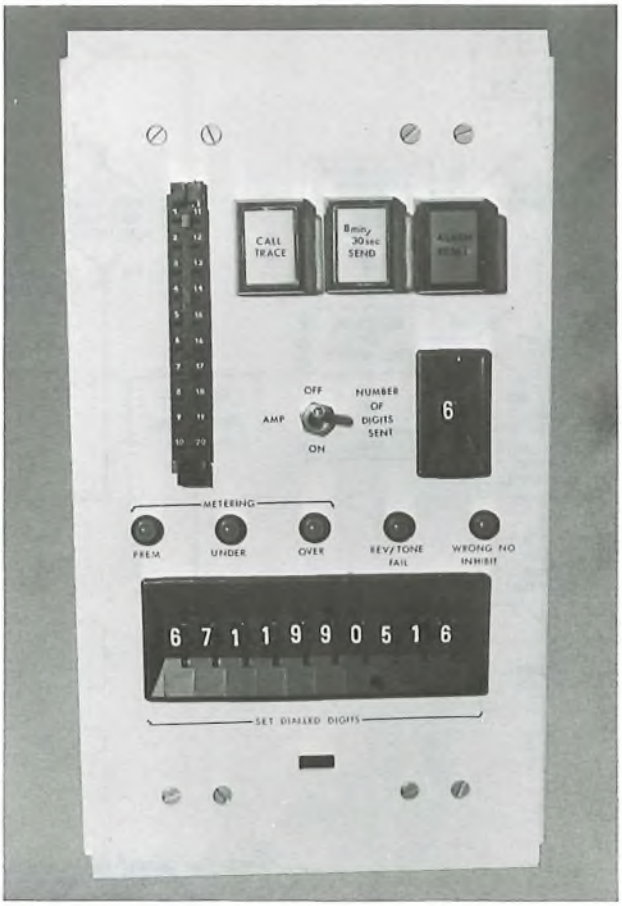

Fig. 1—BEAM call sender

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(*a*) *Premature Metering* The presence of a meter pulse received before the called-subscriber-answer (CSA) signal is detected.

(*b*) *Under-Metering* Under-metering is indicated if no meter pulse is received after the CSA signal.

(*c*) *Over-Metering* If more than one meter pulse is received in any 5 s period after the CSA signal, then an over-metering condition is indicated.

(*d*) *Tones of Polarity Reversals* If less than a predetermined number of tone bursts or polarity reversals (variable between 1 and 15, nominally 3) is received during a 35 s time-out, then a failure condition is indicated.

Including the principal circuit performance checks, the facilities offered by the call sender are:

(*a*) holding dial tone obtained by the test-call unit,

(*b*) dialling a number of up to 10 digits, selected by thumbwheel switches,

(*c*) operating a total-calls meter for each call initiated,

(*d*) starting test calls at 30 s or 8 min intervals as selected by a push button switch on the front panel,

(*e*) checking for

(*i*) premature metering,

(*ii*) under-metering,

(*iii*) over-metering, and

(*iv*) multiple-reversals or tone bursts,

(*f*) automatic resetting to the start sequence if all tests are successful,

(*g*) operating a meter each time a failure occurs,

(*h*) operating a meter that records the type of failure (as in (*e*)),

(*i*) holding a failed call and raising a PROMPT alarm when in LOCAL mode,

(*j*) indicating the type of failure by means of light-emitting diodes (LEDs) on the front panel, if the failure occurs when in LOCAL mode,

(*k*) manual resetting by a push-button switch on the call sender's front panel following a failure when in LOCAL mode,

(*l*) automatic resetting (no alarm raised) following a failure when in REMOTE mode,

(*m*) connecting call-trace pulses to the P-wire by means of a push-button switch on the front panel,

(*n*) inhibiting the call sender manually,

(*o*) inhibiting the call sender automatically should a non-test number be obtained more than once in a predetermined number of test calls, and raising a PROMPT alarm when in LOCAL mode,

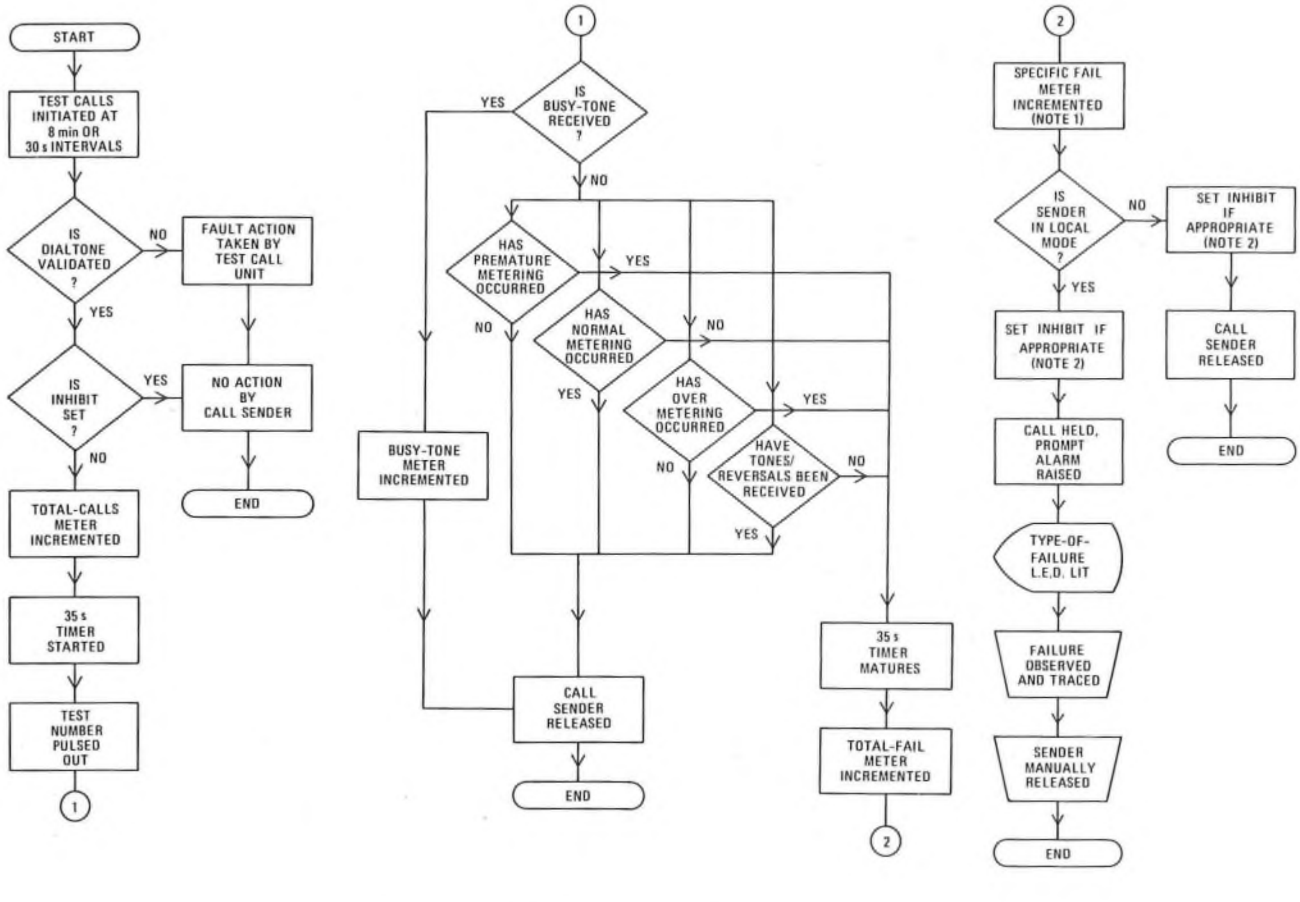
(*p*) audible monitoring of the line if required (an amplifier and speaker are provided as an integral part of the call sender, with an ON/OFF switch on the front panel),

(*q*) switching the dial pulse ratio between 2 : 1 and 1·6 : 1,

(*r*) switching the inter-digital pause between 300 ms and 800 ms,

(*s*) switching the dial pulse speed within the range 8–12 pulses/s,

(*t*) automatic switching to the REMOTE mode when the exchange ALARM EXTENSION key is operated, and



Note 1: The normal metering check is inhibited if a premature meter pulse is received or the TONE/REVERSAL check fails

2: Call sender inhibited if non-test number is called more than once in a predetermined number of test calls

FIG. 2—Flow chart of call sender operation

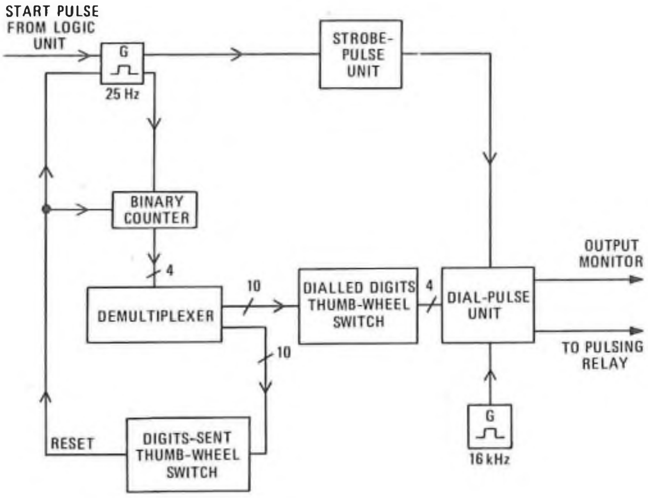


FIG. 3—Block diagram of dialling section

(*n*) on detection of busy tone, the call sender releases without raising any exchange alarm.

Because the call sender makes repeated calls to a given test number, certain faults in the routing process could possibly cause a customer's number to be rung continuously in error. Therefore, the call sender is inhibited should a customer be rung more than once in a predetermined number of test calls. The number can be varied between 1 and 15, but is nominally set at 10. Investigative action normally precedes resetting the INHIBIT alarm.

A number of the standard facilities of the TXE2 exchange design have been used to enhance the effectiveness of the call sender as described below.

(*a*) The line circuits associated with the test-call unit have been given test-telephone class-of-service, enabling calls to be continuously routed to a specific supervisory relay-set. This expedites the location of suspected intermittent faults.

(*b*) Switch-selected multiple line circuits are used, one associated with each A-switch major group.

(*c*) Rapid call-tracing is achieved by the connexion of call-trace pulses to the P-wire of the line circuit being used; the pulses are connected by a push-button switch on the front panel of the call sender.

The flow chart (see Fig. 2) shows the cycle of operation of the call sender.

Circuit Operation

It is not proposed to give a detailed description of the circuit operation, but some aspects are worthy of mention. All logic functions are implemented using standard CMOS 4000B logic-family parts. Interfacing with the 50 V supply is achieved in 2 ways: for operation of lamps, LEDs and meters, a high-current buffer feeds a transistor driver; for other interfaces (for example, the line and P-wire), use is made of dual-in-line reed relays, followed by bounce-elimination circuitry. The pulsing unit is built around a recently introduced large-scale integrated CMOS circuit and provides all the timing and output pulses required. In other respects, the circuit follows standard logic design procedures.

A block diagram of the dialling section is shown in Fig. 3. A START pulse from the control logic into the dialling section starts a 25 Hz oscillator. The derived clock waveform feeds a binary counter, the outputs of which are demultiplexed. The demultiplexer is used to provide a unique pulse to each of the 10 thumb-wheel switches. These encode the pulses into binary-coded-decimal (BCD) format for inputting to the binary-to-loop-disconnect-pulse dial unit. The decimal DIGITS-SENT thumb-wheel switch steers the appropriate demultiplexer output to reset the oscillator and the binary counter when the digits have been received by the dial-pulse unit. The BCD data is synchronously strobed into the dial-pulse unit by the strobe-pulse unit. The output pulses and timing are all derived from a 16 kHz oscillator.

CONCLUSION

A call sender has been developed which will assist the maintenance staff of TXE2 exchanges in monitoring total system performance. Test calls can be established over all types of junction routes serving the exchange, and the operation of distant exchange terminating equipment can also be tested. The call sender has the capability of generating 17 000 test calls per week. In newly-commissioned exchanges, this feature has been found particularly useful by providing a realistic traffic flow prior to public opening.

By making use of modern technology, a call sender has been developed that is inexpensive to manufacture, easy to maintain, and yet will fully integrate with the existing TXE2 system design.

Book Reviews

Physical Science for Technicians. W. Bolton, B.SC. McGraw-Hill Book Company (UK) Ltd. 135 pp. 135 ills. £2·25.

This paperback book has been written to cover the new Technician Education Council (TEC) level-1 unit in Physical Science (TEC U75/004). It is disappointing to find that the author, who is an advising officer to the TEC, in his apparent haste to be first in the market, has inadequately covered, or missed out altogether, topics in the syllabus which are most important to the telecommunications technician. Secondary cells, temperature coefficient of resistance and angular velocity are not mentioned, and some previous knowledge of magnetic fields seems to be assumed. In other areas, no force diagrams are given for components in tension, compression or shear; and no load/extension graph is given for a brittle material.

Numerous problems are set at the end of each chapter, but no answers are given. A novel idea is the inclusion of discussion points at the end of each chapter, which could be stimulating to the more enthusiastic student.

The figures have been kept simple and are well drawn; the printing is clear with few noticeable errors, and the writing style is well suited to students at this level. A telecommunication student using this book would have to supplement it with further reading to cover adequately the topics mentioned above.

R. H.

Hybrid Microelectronics. T. D. Towers, M.B.E., M.A., B.SC., C.ENG., M.I.E.R.E. Pentech Press. 254 pp. 143 ills. £7·50.

The author provides a useful general introduction to the use of hybrid technology in a wide range of applications. Emphasis has been placed upon the circuit and systems aspects of hybrid assembly techniques, rather than on the manufacturing processes used. Applications in the field of telecommunications are only briefly mentioned. Detailed design considerations, and the long-term reliability of hybrid circuits, are not discussed.

D. B.

Dual Polarization Technology

Part 2—The Introduction of Dual-Polarization Operation at UK Earth Stations

A. L. MARSH, C.ENG., M.I.E.E.†

UDC 621.3.095.1 : 621.37.029.6

The first part of this article[12] introduced and discussed the basic principles of dual-polarized microwave transmission and the requirements imposed on the design of reflector aerials. This second part of the article identifies and examines the practical significance of those aerial design requirements. The article outlines the development of aerial technology and discusses the technical and practical repercussions of a programme of modifications for the introduction of dual-polarization operation at the UK earth station at Goonhilly Downs.

The principles of a method for measuring the polarization purity of an earth-station aerial are also described, and an equation is developed (in the Appendix) that relates the polarization purity of the aerial and the isolation achieved between cross-polarized signals. The concluding part of this article will examine the influence of the earth-to-space propagation path on dual-polarization operation.

INTRODUCTION

The next generation of communication satellites, the INTELSAT V series[13], which is planned to be brought into service in 1979, has stimulated significant new developments in earth-station aerial technology. New frequency bands will be brought into operation at 11 GHz and 14 GHz requiring additional aerials and, at the same time, dual-polarization technology will be implemented in the 4 GHz and 6 GHz frequency bands, thereby considerably increasing system traffic-carrying capacity. Dual-polarization operation will require modification to existing earth-station aerials to meet a new and more stringent polarization purity performance, and this article describes how study and development work has brought about the practical realization of this new requirement.

The practical significance of dual-polarization performance is discussed with particular emphasis on the problems of modifying the present large steerable reflector aerials at the Goonhilly earth station.[14]

GENERAL BACKGROUND

Part 1 of this article indicated how the efficient use of dual-polarized waves at the same frequency depends on achieving high polarization purity in the satellite and earth-station aerial systems.

A fundamental requirement of a dual-polarized earth/space transmission link is to maintain a tolerable level of co-channel interference in the system between signals of the orthogonal* polarization. This interference is termed *cross-polarization interference* (XPI) and, in a practical earth–space link, both the earth-station and satellite aerials contribute to the overall system polarization purity.

To define the dependence between polarization purity and the resulting XPI, a coupling factor relationship derived from first principles has been used. Development of this relationship produces an expression for XPI as a function of the polarization purity at each end of the transmission link. A very useful linear-law approximation has been derived for circularly-polarized transmission systems, which enables the overall standard to be expressed as the vector sum of the individual polarization purities of the earth-station and satellite aerials. The Appendix to this article describes this process, and the discussion in this article explains how a minimum performance standard has been derived for the earth-station aerial from a knowledge of the polarization purity of the overall link and satellite aerial.

Dual-polarized satellite transmission links are designed to operate with an XPI of 27 dB, or better, under clear-sky propagation conditions. Satellite aerial polarization purity varies to some extent over the illuminated coverage area of the earth's surface, but a satisfactory performance has been achieved by careful aerial design. The overall polarization purity of all the transmission links within the satellite coverage area will vary in random fashion as the vector sum of satellite and individual earth-station aerial polarization purities, but an average case can be assumed in which the overall link polarization purity is divided equally between satellite and earth-station aerials, the vector resultant being calculated as the square root of the sum of their squares.

On this basis, a mandatory polarization purity standard has been set for new earth-station aerials, equivalent to an XPI of 30 dB, which is specified in the form of the aerial *voltage axial ratio* (VAR). VAR is a measure of the ellipticity of the circularly-polarized wave and is expressed as the instantaneous voltage ratio of the major and minor axes of the characteristic polarization ellipse. A mandatory VAR not exceeding 1·06 in the direction of the satellite, has been specified for new earth-stations. This, for reasons discussed in the Appendix to this article, is more conveniently expressed as a logarithmic power ratio of 0·5 dB. For existing earth-station aerials that are to be modified for dual-polarization operation, the specified minimum mandatory VAR has been relaxed to 1·09, equivalent to a logarithmic power ratio of 0·75 dB.

A further useful outcome of the linear-law approximation for cross-polarization interference is that the earth-station polarization purity itself can be considered as the vector sum of several individual contributions.

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* True orthogonality exists between polarized waves only when their polarization states are diametrically opposite each other on the Poincaré sphere[12]. In such cases, the cross-polarization interference ratio is infinite

STUDY AND DEVELOPMENT PROGRAMME

To assess the impact of the new earth-station performance requirement on aerial design, it has been necessary to undertake studies on the polarization properties of large reflector aerials. These studies have been divided into the 3 separate areas: reflector systems, feed-horn launchers and feed-assembly components.

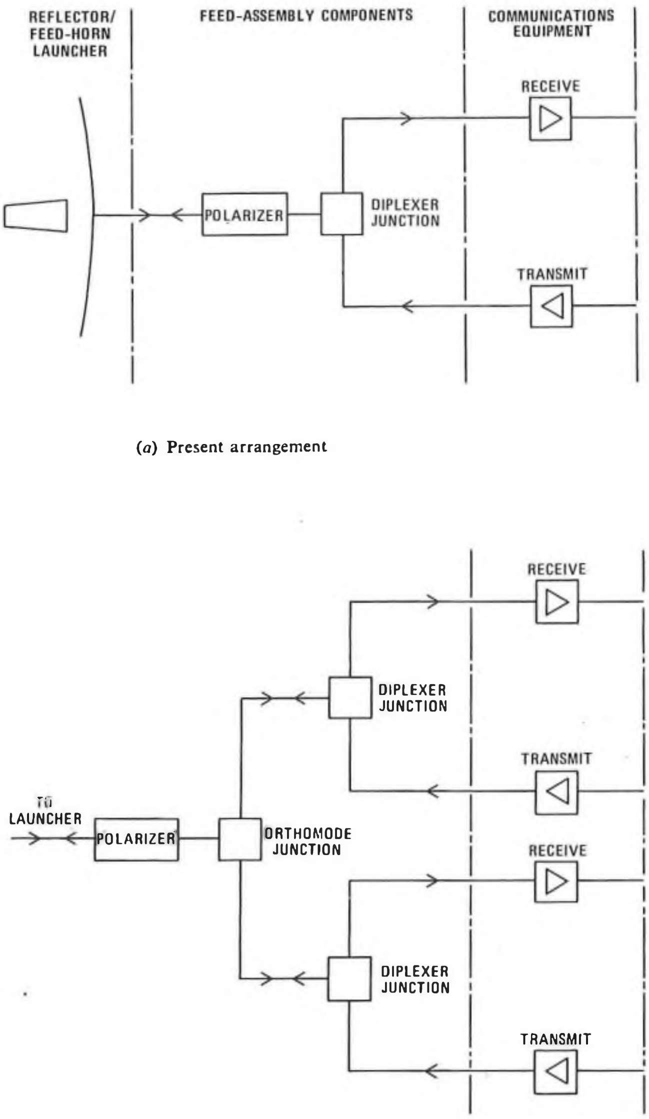
The results of the study and development work have enabled the nature and extent of modifications to the 3 aerials at the Goonhilly earth station to be established, and have highlighted possible repercussions on aerial technology for future installations requiring dual-polarization facilities.

Reflector Systems

Two forms of symmetrical reflector system are at present in common use: the conventional front-fed reflector and the Cassegrain 2-reflector configuration. It is now accepted that the latter gives greater aerial efficiency, particularly when reflector profile shaping is used. Specific computer calculations using Goonhilly aerial design data have shown the Cassegrain configuration to be suitable for dual-polarization operation. Cross-polarization contributions from reflector curvature, profile shaping and profile tolerances, are calculated to be several orders of magnitude below the overall requirement for the earth-station aerial.

Recent tests on a front-fed aerial used for experimental purposes have shown that cross-polarization contributions are also insignificant for this type of reflector configuration.

Improvements in aerial efficiency and layout of equipment accommodation resulting from the use of beam-waveguide feed systems are now accepted advantages for new earth-station aerials. The polarization performance of a variety of beam-waveguide reflector systems has been analysed and results show that there are no constraints on dual-polarization operation[12].



(*a*) Present arrangement

(*b*) Possible dual-polarization arrangement

FIG. 14—Progression of feed-assembly components

Feed-Horn Launchers

The feed-horn launchers used for the Cassegrain reflector aerials at Goonhilly are of the circular and square aperture multi-mode type, which are used to obtain circularly symmetrical amplitude illumination patterns. Improved feed-pattern symmetry, and therefore better aerial gain, sidelobe and polarization characteristics, can be obtained using recently developed corrugated horns.[12] However, replacement of existing feed-horn launchers with the superior corrugated-horn type requires that the existing sub-reflector be replaced and the main-reflector be reshaped if all the potential improvements in performance are to be realized. Fortunately, recent measurements on the multi-mode type of horn have indicated that they are marginally acceptable for the specified dual-polarization performance and that feed horn replacement is not essential where this design is in use.

Feed-horn launchers for earth-station aerials normally incorporate means by which satellite tracking information is derived in order that the earth-station aerial position is always optimum. In the multi-mode feed, the fundamental and higher-order waveguide modes present in the horn are augmented by off-axis waveguide modes, which are generated at the throat of the horn when the incident wave from the satellite is not on-axis. The off-axis mode signals are coupled out in 2 perpendicular planes by a tracking coupler. For dual-polarization operation, it is essential to preserve good rotational amplitude and phase symmetry in the feed horn to ensure high polarization purity. The tracking coupler must therefore be made to appear rotationally symmetrical by adding 2 false tracking ports, or by a tuning adjustment which balances out asymmetries caused by the tracking coupler.

Feed-Assembly Components

Feed-assembly components are waveguide devices which perform 2 functions basic to the correct operation of the earth-station aerial system. Firstly, the transmitted and received frequency bands are multiplexed to and from the feed-horn launcher and, secondly, the correct polarization for each frequency band is established. These functions are critical for dual-polarization operation in which both frequency bands are duplicated by the use of a polarization multiplexing network.

FREQUENCY MULTIPLEXING

Existing earth-station aerials operating in the 4 GHz and 6 GHz satellite communication frequency bands operate over two 500 MHz bandwidths. These frequency bands cover the transmit frequencies 5·925–6·425 GHz and the receive frequencies 3·7–4·2 GHz. Microwave signals in these 2 frequency bands enter and leave a common waveguide path to the feed-horn launcher at a diplexer junction, as shown in Fig. 14(*a*).

This bi-directional junction functions in 2 mutually perpendicular planes for transmit and receive-band frequencies. Satisfactory operation of the low-noise amplifier (receiving picowatts of signal in the 4 GHz band) depends on an

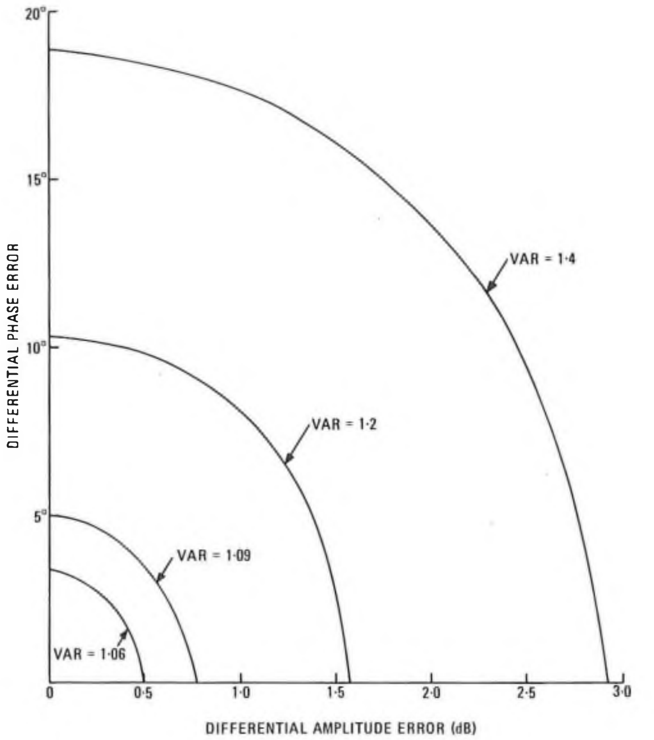


FIG. 15—Tolerable quarter-wave polarizer amplitude and phase errors for given VARs

isolation of the order of 80 dB from the 6 GHz band transmitted signal (the power of which is measured in kilowatts) present at the diplexer junction. Because transmit and receive-band signals are operated on mutually-perpendicular polarization planes and there is appreciable frequency separation between them, good inherent isolation exists, but the necessary 80 dB of isolation requires additional transmit-band rejection filtering. It is now common practice to provide transmit rejection filters in the low-noise amplifiers, thus reducing the required isolation at the diplexer junction to 40 dB or so.

The configuration of the 2 diplexer junctions necessary for dual-polarization operation is shown in Fig. 14(*b*). The orthomode junction is the "heart" of the polarization multiplexing function described in the following section.

POLARIZATION MULTIPLEXING

Transmit and receive-band frequencies are at present radiated and received on 2 mutually-perpendicular polarizations, and circular polarization is used on the earth–satellite link because it is relatively immune to Faraday rotation effects in the ionosphere.

Wave polarization was discussed in Part 1 of this article and the function of the quarter-wave polarizer was described. Fig. 14(*a*) illustrates the position of the quarter-wave polarizer in the common bi-directional waveguide path between the feed launcher and the transmit and receive equipment. The active plane of the polarizer is fixed at 45° to the mutually-perpendicular axes of the diplexer junction. Circularly-polarized signals in the receive frequency band are transformed into a linear polarization in the same plane as the receive-band frequency port of the diplexer junction, while linearly-polarized transmit-band signals leaving the diplexer junction in the perpendicular plane are resolved into 2 equal components, and form circular polarization after passing through the quarter-wave polarizer.

The introduction of dual-polarization operation requires duplication of the polarization multiplexing facility with the planes of polarization of transmit and receive frequency bands reversed for frequency re-use. Fig. 14(*b*) illustrates the function of the orthomode junction, which combines 2 sets of mutually-perpendicular transmit and receive-band polarizations at the diplexer junctions.

Feed-Assembly Development

It has been necessary to direct considerable development effort towards improving the polarization purity of feed-assembly components, the most significant being in the design of the quarter-wave polarizer, which until now has not been required to achieve a VAR better than 1·4. Poor polarization purity may be attributed to the fact that the quarter-wave polarizer is normally constructed from a series of frequency-sensitive reactive loading elements, which cumulatively produce a total phase shift of 90° over a bandwidth covering both 4 GHz and 6 GHz frequencies. The frequency-sensitive phase shift of the reactive loading elements proves to be a severe constraint to good VAR. To illustrate the scale of the problem of achieving a VAR of better than 1·06, the phase and amplitude error envelopes corresponding to given VAR specifications are shown in Fig. 15.

Feed-assembly development work has proceeded in 2 directions, namely:

(*a*) improvements in polarizer design to achieve the necessary VAR over the 4 GHz and 6 GHz frequency bands, and

(*b*) alternative feed-assembly configurations to allow the use of separate polarizers in the 4 GHz and 6 GHz frequency bands.

Although the new polarization purity specification has been achieved using a special development of the 4 GHz and 6 GHz frequency-band polarizer, considerable interest has also been centred on alternative developments with separate 4 GHz and 6 GHz quarter-wave polarizers. This interest arises mainly from the possibility of adjusting the polarization state of the earth-station aerial using a rotatable quarter-wave polarizer cascaded with a rotatable half-wave polarizer. This arrangement has the advantage that the satellite polarization vector can be cancelled by a polarization vector generated by the adjustable polarizers at the earth station. The theoretical advantages of this technique cannot be fully realized in practice because the polarization state varies with frequency, and the exact polarization states of orthogonal polarizations at the same frequency have an arbitrary dependence. An example of the developed hardware is shown in Fig. 16.

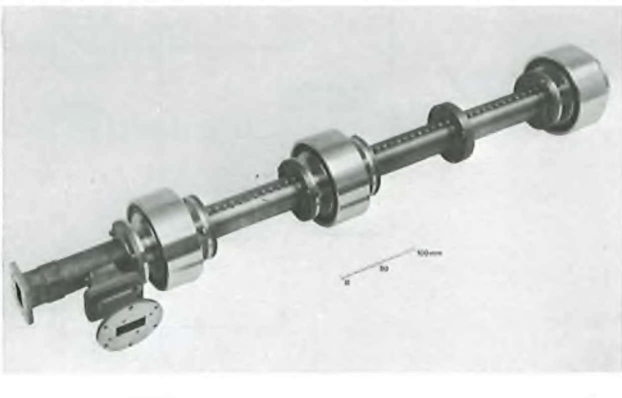
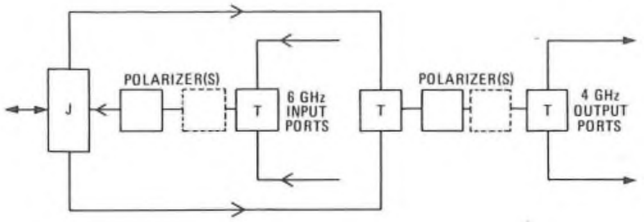
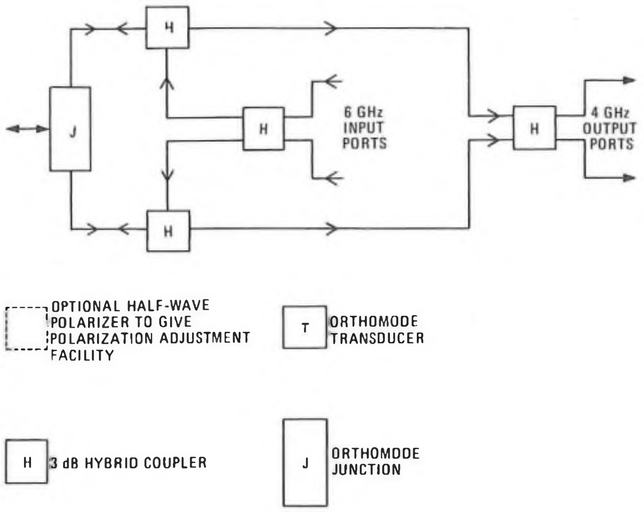


FIG. 16—6 GHz frequency band rotatable quarter-wave and half-wave polarizers and orthomode transducer junction
(Photograph by courtesy of COMSAT laboratories)



(*a*) Normal polarizer



(*b*) Hybrid polarizer

FIG. 17—Development of dual-polarization feed-assembly components

Block diagrams of 2 recently developed dual-polarization feed assemblies are illustrated in Fig. 17. Fig. 17(*a*) shows feed-assembly components having separate polarizers for each frequency band, with the option for inclusion of a half-wave polarizer to enable independent adjustment of transmit-band and receive-band polarization states. The waveguide junction, which incorporates the functions of both diplexer and orthomode junctions, is a critical component of this arrangement. Fig. 17(*b*) shows an alternative feed-assembly arrangement which dispenses with the use of waveguide polarizers and replaces them with hybrid-T junctions which possess an inherent differential phase shift of 90° between 2 of their ports.

An example of dual-polarization feed-assembly equipment using separate polarizers is shown in Fig. 18.

Results of Development Studies

Useful conclusions have been drawn as a result of the study and development programme, which have enabled detailed planning of modifications to the Goonhilly aerials to go ahead.

The conclusions are summarized below.

(*a*) Existing feed-horn launchers and reflector systems of good design are adequate to meet the relaxed specification for dual-polarization operation with existing aerials. The specification for new aerials is only likely to be met comfortably with the superior performance of the corrugated feedhorn.

(*b*) Earth-station polarization purity in the direction of the satellite is generally dominated by the contribution of feed-assembly components; the most significant contribution being from the quarter-wave polarizer.

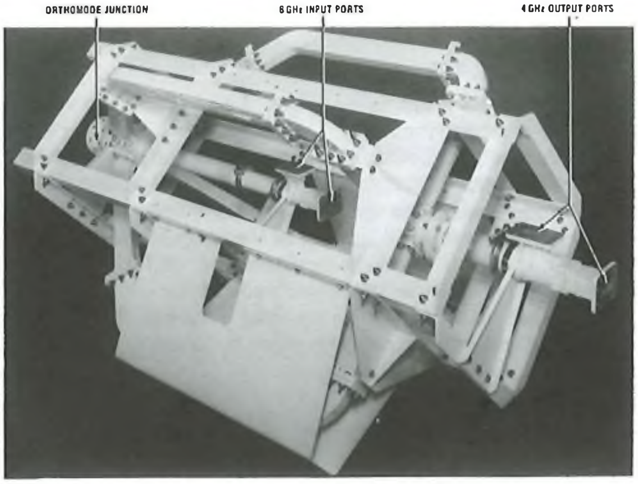


FIG. 18—Dual-polarization feed-assembly components

(Photograph by courtesy of GTE ISC)

(*c*) Adjustable feed components have been developed (usually involving rotatable polarizers) which enable the earth-station aerial polarization purity to be continuously varied. Overall link purity can then be optimized, either manually for clear-sky conditions, or adaptively to suit varying propagation conditions if necessary.

AERIAL MODIFICATION PROBLEMS

The practical aspects of a modification programme for the Goonhilly earth-station aerials are currently being studied. A variety of individual problems have been met during the planning stage, but the following have been found to be common to all the Goonhilly aerials.

(*a*) Increased signal attenuation between the feed-horn launcher and the communications equipment due to additional feed-assembly components results in a small degradation in the gain-to-noise-temperature ratio.

(*b*) Increased mechanical complexity of the feed assembly must be accommodated in a restricted space.

(*c*) The potential doubling of available radio bandwidth requires more communication equipment to be accommodated within physically restricted areas.

(*d*) An aerial must be taken out of operational service to complete the modification.

Each of the Goonhilly aerials is of a different mechanical design and electrical performance;[14] therefore, it has been necessary to deal with the modification problems in a different way for each aerial. Fortunately, it is possible to phase the dual-polarization modifications over a period of a few years, because dual-polarization operation will be introduced gradually after the launch of the first INTELSAT V satellite in 1979. This enables the out-of-service time required for modifications to be planned in conjunction with the provision of aerials at the new UK earth station at Madley, thus minimizing the loss of traffic.

Goonhilly No. 1 Aerial

Although it is technically possible to modify the Goonhilly No. 1 aerial for dual-polarization operation, the aerial lacks the necessary equipment accommodation, and its age is such that major structural modifications are considered uneconomic. The traffic presently carried by this aerial will be transferred to the first aerial at the Madley earth station, but the provision of a special feed assembly is being studied with the object of equipping the Goonhilly No. 1 aerial to operate in a limited stand-by role. This feed design is special in that it needs to be particularly compact and light in weight in order to be compatible with the front-fed configuration of the aerial.

Goonhilly No. 2 Aerial

Goonhilly No. 2 aerial is not needed to operate with dual-polarized transmissions until the early 1980s, but plans are now being evolved for its modification. Although the present feed horn is technically suitable for dual-polarization operation, longer-term plans are being considered to replace it for other reasons with a launcher of the corrugated-horn type. The efficiency and sidelobe performance of the Goonhilly No. 2 aerial need to be improved and, at the same time, the maintenance liability of the existing rotating feed can be removed. Opportunity may therefore be taken to accomplish these requirements simultaneously.

Goonhilly No. 3 Aerial

The first phase of plans to modify Goonhilly No. 3 aerial, the most recently constructed aerial, are now complete. The present multi-mode feed-horn launcher design will be retained and integrated with newly developed feed-assembly components, though for practical convenience the whole assembly will be replaced as a unit.

For the first phase of the modification, the aerial will be taken out of service, and it is planned to complete this phase during 1978. This time scale will enable contingency traffic support to be provided, and will allow the feed-horn manufacturer and installer to complete work before the peak of international demand for dual-polarization modifications is reached in 1979. The out-of-service time will be largely taken up by performance measurements, which are necessary before and after the modifications to ensure that any performance degradation can be accounted for.

MEASUREMENT METHODS

Before an earth-station aerial can be accepted into a dual-polarized system, it is clearly necessary accurately to ascertain its polarization purity performance, and a satellite source of near perfect purity is necessary to do this. However, it is found that due to design constraints purity varies within limits over the global coverage area.

The actual polarization purity of the satellite source aerial, which can be established before launch of the satellite, introduces a systematic error into earth-station purity measurement. This uncertainty error must be removed, especially when it is comparable in magnitude to that of the earth station to be measured and it can only be eliminated conclusively by rotating either the source or aerial under test.

Because of reflections and varying propagation from surrounding terrain, conventional aerial testing methods using a terrestrial measurement range are not normally considered accurate enough to measure high polarization purity. Several alternative methods have therefore been studied using satellite sources of known polarization purity and rotatable polarizers at the earth-station aerial.

One method, which has been devised and is currently favoured, is based on identifying the individual contributions to the overall purity of the measurement link, then making simple assumptions and calculations as to the earth-station aerial's overall vector sum, using a polarization diagram.

The Polarization Diagram

It can be seen from the Appendix that the polarization states generated by satellite and earth-station aerials can be represented by vectors, and that polarization purity has an approximately linear relationship with cross-polarization interference.

Cross-polarization interference can, therefore, be conveniently used to measure the overall polarization purity conditions existing on the earth–space transmission link. The individual contributions to the overall link purity are expressed by the following vector components:

$\bar{R}_s$ is the contribution to overall link purity from the satellite source aerial,

$\bar{R}_f$ is the contribution from the earth-station reflector and feed-horn launcher,

$\bar{R}_p$ is the contribution from the earth-station quarter-wave polarizer,

$\bar{R}_c$ is other earth-station component contributions, and

$\bar{R}_t$ is the overall transmission link polarization purity.

If the purity of the quarter-wave polarizer of the earth station is known, and the difference between the overall link polarization purity and the quarter-wave polarizer purity is designated $\bar{R}_x$ (that is, $\bar{R}_x = \bar{R}_t - \bar{R}_p$), $\bar{R}_x$ can be used in conjunction with the known contribution, $\bar{R}_s$, to establish earth-station purity $|R_E|$.

The cross-polarization interference is first measured with the quarter-wave polarizer positioned to generate circular polarization; that is, at 45° to the planes of the orthomode transducer ports. The cross-polarization interference ratio is reduced to the equivalent expression of polarization purity ($\bar{R}_{t1}$ decibels) using the linear law derived in the Appendix. The XPI is then measured with the quarter-wave polarizer rotated precisely 90° from its original position and reduced to the equivalent expression of polarization purity ($\bar{R}_{t2}$ decibels).

The procedure is illustrated in Fig. 19 in the form of a polarization diagram from which it is apparent that $\bar{R}_{t1}$ and $\bar{R}_{t2}$ are the vector sum and difference respectively of $|R_x|$ and $|R_p|$. By twice applying the cosine law, it can be shown that

$$|R_x| = \sqrt{\left(\frac{|R_{t1}|^2 + |R_{t2}|^2}{2} - |R_p|^2\right)}.$$

If the magnitude of $\bar{R}_s$ is known for the direction of the earth–space transmission link, a worst-case assumption can be made that the vector sum of earth-station purity components, less the quarter-wave polarizer contribution (that is, $\bar{R}_e = \bar{R}_f + \bar{R}_c$), is given by

$$|R_e| = |R_x| \pm |R_s|.$$

To obtain the overall purity of the earth-station aerial, including the polarizer, it can reasonably be assumed that $|R_E|$ is given by the square root of the sum of the squares of contributions $|R_e|$ and $|R_p|$.

Therefore, $|R_E| = \sqrt{(|R_p|^2 + |R_e|^2 \text{ dB})}$.

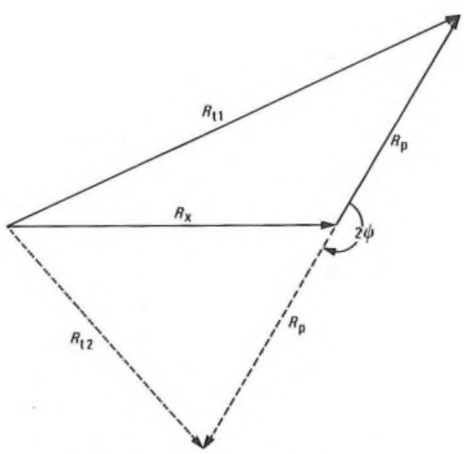


FIG. 19—Polarization diagram

CONCLUSIONS

Increasing demand for satellite communication circuits has put pressure on present-day technology to provide means of meeting this demand. Dual-polarization operation has been chosen as a relatively low capital cost method of increasing satellite system capacity, before the potential of higher frequency bands is fully developed.

Studies have shown that the necessary modification to existing 6/4 GHz aerials for dual-polarization operation need only involve feed-assembly components. However, the modification programme for dual polarization also provides a useful opportunity to review other advances in aerial technology. For this reason, the aerials at Goonhilly have each been considered on their own merit for modification. The modification work at Goonhilly will be phased over about 3 years, commencing in 1978; the new aerial under construction at Madley and future aerials will be provided with dual-polarization capability at the outset.

The use of dual-polarization technology should prove a profitable means of increasing the traffic capacity of present and future earth terminals with only modest additional expenditure by earth-station owners.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the help given by colleagues in Telecommunications Headquarters in the preparation of this article.

APPNEDIX

The Polarization Coupling Factor Equation

This Appendix introduces and develops a general expression describing the isolation between the cross-polarized signals of a dual-polarized transmission system as a function of their VARs (see Fig. 20).

The general expression, derived from first principles in a series of articles by Rumsey, Deschamps, *et al*[15], can be considerably simplified for circularly-polarized transmission systems to a good approximation of a linear law. This result considerably simplifies calculations and measurements of polarization purity.

The linear law approximation enables polarization states generated by an aerial to be expressed in vector form. This method of expression is a good approximation to the Poincaré sphere method[12] of representation over the polar regions of the sphere.

Coupling Factor Relationship

A general expression has been derived[15] which relates coupling loss (F) and polarization state. The expression is

$$F(\pm) = \frac{(1+r_1^2)(1+r_2^2) \pm 4r_1r_2 + (1-r_1^2)(1-r_2^2)\cos 2\psi}{2(1+r_1^2)(1+r_2^2)}. \quad \ldots\ldots (1)$$

Note: The positive or negative sign of term $\pm 4r_1 r_2$ is chosen depending on whether the polarization ellipses r_1 and r_2 have the same (+) or opposite (−) sense. The relative angle of tilt of the 2 polarization ellipses is given by $\psi = \tau_1 - \tau_2$.

The polarization state of a wave is uniquely defined by 3 parameters: voltage axial ratio (r), sense ($\pm$), and the angle of tilt (τ) of the principal axis of the polarization ellipse. The positive and negative sign convention is used to denote the sense of polarization rotation, either left-hand or right-hand, and r is expressed as a ratio less than unity.

Equation (1) can be expanded, rearranged and applied to the case of an elliptically-polarized aerial of axial ratio r_2 receiving an elliptically-polarized signal of axial ratio r_1.

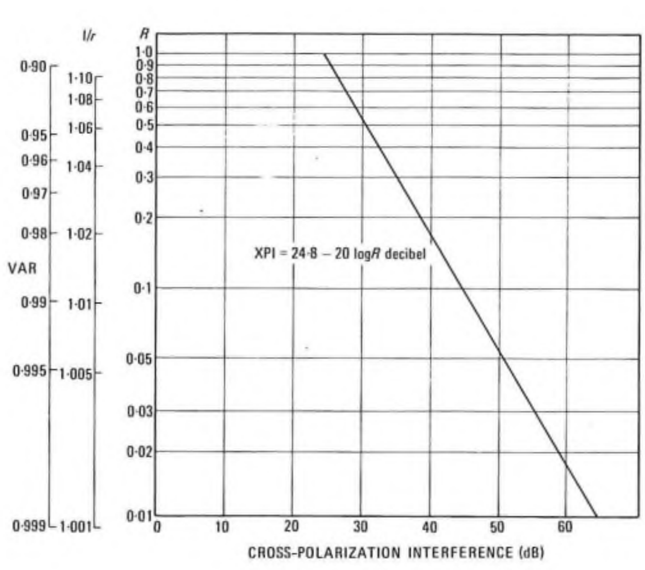


FIG. 20—Cross polarization interference as a function of VAR

If ψ is the relative angle between the major axes of the 2 polarization ellipses ($\tau_1 - \tau_2$), the coupling loss (F) between signal and aerial is given by

$$F(\pm) = \frac{(r_1 \pm r_2)^2 + (1-r_1^2)(1-r_2^2)\cos^2\psi}{(1+r_1^2)(1+r_2^2)}. \quad \ldots\ldots (2)$$

Note: The positive or negative sign of the term $(r_1 \pm r_2)^2$ is chosen depending on whether the polarization ellipses, r_1 and r_2 have the same (+) or opposite (−) sense.

In systems using nominally orthogonal polarizations as a means of signal discrimination, an important parameter in the determination of the quality of the system is the cross-polarization isolation ratio which, for the purpose of this Appendix, is assumed to be numerically equivalent to the cross-polarization interference ratio (XPI), and

$$\text{XPI} = \frac{\text{F}(+)}{\text{F}(-)}.$$

This is the ratio of the coupling factors of an incident wave, when measured at the port having the same polarization sense (co-polarized) to that measured at the port having the opposite polarization sense (cross-polarized). It can now be seen that double application of equation (2) enables the XPI to be determined from a knowledge of the polarization states of the incident signal and the aerial; thus

$$\text{XPI} = \frac{(r_1 + r_2)^2 + (1-r_1^2)(1-r_2^2)\cos^2\psi}{(r_1 - r_2)^2 + (1-r_1^2)(1-r_2^2)\cos^2\psi} \quad \ldots\ldots (3)$$

Vector Expression

Equation (1) can be simplified by substituting

$$r_1 = (1 - p_1), \text{ and } r_2 = (1 - p_2)$$

and expanding all terms to express $\text{XPI} = \dfrac{F(+)}{F(-)}$.

The expansion reduces to equation (4) for small values of p_1 and p_2 by removing insignificant terms (approximation is good to about 5% for $p = 0{\cdot}1$).

$$\text{XPI} \approx \frac{4}{p_1^2 + p_2^2 + 2p_1p_2\cos 2\psi}, \quad \ldots\ldots (4)$$

where $p_1 = (1 - r_1)$ and $p_2 = (1 - r_2)$.

In practice, VAR is expressed as a logarithmic power ratio, R, where

$$R = 20 \log_{10} \left(\frac{1}{r}\right) \text{ decibels.}$$

It can be shown, as follows, that R is approximately equal to $8 \cdot 686p$ for small values of p, where $p = (1 - r)$ (approximation is good to about 2% for $p = 0 \cdot 2$).

$$R = 20 \log_{10} \epsilon \log_e \left(\frac{1}{1-p}\right),$$

$$= 20 \log_{10} \epsilon \left(p + \frac{p^2}{2} + \frac{p^3}{3} + \ldots \frac{p^n}{n}\right),$$

$$\approx 8 \cdot 686p. \text{ (for small values of } p\text{).}$$

If $R_1 \approx 8 \cdot 686p_1$ and $R_2 \approx 8 \cdot 686p_2$, then equation (4) becomes

$$\text{XPI} \approx \frac{4}{\left(\frac{R_1}{8 \cdot 686}\right)^2 + \left(\frac{R_2}{8 \cdot 686}\right)^2 + \frac{2R_1R_2}{(8 \cdot 686)^2} \cos 2\psi}.$$

$$\text{XPI} \approx \frac{(2 \times 8 \cdot 686)^2}{R_1{}^2 + R_2{}^2 + 2R_1R_2 \cos 2\psi}.$$

From the cosine formula, $R^2 = R_1{}^2 + R_2{}^2 - 2R_1R_2 \cos 2\psi$.

Where R_1 and R_2 can be considered as vector quantities,

$$\bar{R}_1 = R_1\angle 2\psi_1 \text{ and } \bar{R}_2 = R_2\angle 2\psi_2 \text{ and } 2\psi = 2\psi_1 - 2\psi_2.$$

Therefore, equation (4) can be expressed as

$$\text{XPI} \approx \frac{17 \cdot 37^2}{R^2}$$

Hence, $\text{XPI} \approx 24 \cdot 8 - 20 \log R$ decibels.

Note: Overall approximation is less than 1% for R ⩽ 3 decibels.

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Book Reviews

Questions and Answers on Electric Motors (second edition). A. J. Coker (revised by P. Chapman). The Butterworth Group. 128 pp. 88 ills. £1·25.

The author of this little book must have sympathy for those students entering electrical engineering and nervously approaching the apparent incomprehensibility of AC motors, Most engineering courses embark at once on an analytical approach to AC machines, having of course already covered basic AC circuit theory, and some students never really recover from this shock treatment. The approach in this book is quite different. It contains no analysis and no theoretical mathematical work at all. Yet the author succeeds in persuading the reader that he understands how most of the commonly used forms of electric motor work (and there are a surprising number of them), and how they are controlled; that is, how they are started and how their speeds are regulated.

A question-and-answer technique is used throughout. The questions are simple, basic and non-mathematical, mostly of the type, "How is so-and-so achieved?" or "Why is a commutator used?" The answers are short and crisp, with good line diagrams to support them. By carefully selecting his questions, Mr. Coker has progressively built up descriptive accounts that explain the fundamentals of how motors work, so that, when a student meets the conventional basic theory in the course of his studies, he should already understand what he is dealing with.

There is less of a range of interest in DC motors than in AC machines, especially when 3-phase motors are included, as they are here. Induction motors, synchronous motors and methods of control of large machines form much of the matter in the book. But many light-current engineers will find the chapter on single-phase motors the most interesting, as it covers many of the principles of the small motors that occur so frequently in low-power applications. A few paragraphs on linear motors have been added in this second edition, but are less informative than the rest of the book and leave the reader with the impression that they were an afterthought.

This book is a useful contribution to helping students understand the basic principles of electric motors and how they are controlled.

C. F. F.

Elsevier's Telecommunication Dictionary (second revised edition). W. E. Clason. Elsevier Scientific Publishing Company. 604 pp. Dfl. 125·00 ($47·95).

This second revised edition (1976) is, as we have come to expect, clearly printed and well produced. Like the other dictionaries in the series, it embraces languages of the European economic community (with the exception of Danish), and the inclusion of American terminology underlines the intention that it should be used beyond the boundaries of Europe.

Apart from the wide range of vocabulary offered, it is good to see the inclusion of a number of abbreviations, as these so often prove difficult to interpret. In the case of PCM, the translations given are correct, but I wonder if there is a case for the more general acronym MIC (French: *modulation par impulsions codées*; Spanish: *modulación por impulsos codados*; Italian: *modulazione per impulsi codati*).

A disappointing omission is the term stored-program control and its abbreviation (SPC). This surely merits an entry in such a general dictionary of telecommunication terms. Eurovision is listed, but it would be helpful also to include the abbreviated names of large organizations, such as the EBU: UER (European Broadcasting Union: *Union Européene de la Radio*), and CCITT and CCIR, although the last 2 may be sufficiently well known by their initials not to need translation. I also failed to find *informatique*, which is now in common use, and is generally translated as data processing. There is not much of a vocabulary relating to submarine cables; terms such as sheath and armour could usefully have been included.

The book has the same drawback as other multilingual dictionaries, in that the word order is alphabetical in one language only; in this case, English. For any other language, one must turn to an index to find an appropriate reference number for the English word. Many translators would probably prefer to use a series of bilingual dictionaries rather than work by double referencing through a multilingual dictionary.

However, where a multilingual dictionary is needed or preferred, this one is very good, and has undoubted value as a work of reference in a technical library.

E. J. E.

A New Modem for the Datel 2412 Service: Datel Modem No. 12B

R. W. BIGG†

UDC 681.327.8

This article describes the facilities, construction and operation of the Datel Modem No. 12B, which is to be used to introduce the Datel 2412 service which will extend the range of 2400 bit/s data transmission facilities provided by the British Post Office.

INTRODUCTION

The Datel 2400 service was introduced by the British Post Office (BPO) in 1968; this offered transmission of serial binary data at 2400 bit/s on a 4-wire leased line that was equalized to the standard required by International Telegraph and Telephone Consultative Committee (CCITT) Recommendation M102 (equivalent to BPO tariff T circuits). If the leased line failed, alternative operation at 600 bit/s or 1200 bit/s was possible on a 2-wire telephone line connected to the public switched telephone network (PSTN). A 75 bit/s backward channel could be provided and used either on the leased line in conjunction with the 2400 bit/s channels, or on the stand-by PSTN line in conjunction with the 600 bit/s or 1200 bit/s channels. The Datel 2400 service was provided by the Datel Modem No. 7,[1] which conformed to the international recommendations for leased-line operation at 2400 bit/s given in CCITT Recommendation V26.[2] Stand-by operation on the PSTN at 600 bit/s or 1200 bit/s conformed to CCITT Recommendation V23.

In 1972, the Datel 2400 service was extended by the introduction of the Datel 2400 dial-up service, which offered transmission at 2400 bit/s on the PSTN, with fall-back to either 1200 bit/s or 600 bit/s. This service was provided by a modified Datel Modem No. 7, the main modification being the incorporation of a fixed attenuation/frequency and group-delay/frequency equalizer. It was recognized that not all PSTN connexions would support data transmission at 2400 bit/s using this modem, and the new service was offered initially on the basis of a period of free trial by the customer. More recently, with increased confidence through experience, the service is provided subject to satisfactory tests by the BPO, both from the customer's premises to the local Datel test centre and to distant Datel test centres close to the locations to which the customer wishes to operate.

CCITT Recommendation V26 allows 2 alternative, but incompatible, ways in which the line carrier signal is phase-modulated: type A and type B. Since the Recommendation is restricted to leased circuits, optional modulation methods, even though they were incompatible, were acceptable. However, when tests by various administrations showed that modems meeting this Recommendation would give an acceptable performance on switched networks, it became necessary for the CCITT to recommend a single modulation method to obtain compatibility. Although type A gives slightly superior performance, type B provides the possibility of full code transparency and the CCITT agreed that Recommendation V26 *bis*[3] (covering the use of this type of modem on switched networks) would standardize on type B after the 1976 Plenary Meeting.

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The Datel Modem No. 7 conforms to the type A modulation, and conversion to type B modulation was found to be impracticable. Also, advances in technology during the period following development of the modem made possible a smaller and more attractive unit. These facts led to the BPO decision to develop a new modem to succeed the Datel Modem No. 7.

Early in 1974, a development contract was placed for the new modem, which is coded the Datel Modem No. 12B and is described in this article. The Datel Modem No. 12B is to be used to introduce a new service entitled *Datel 2412*.

FACILITIES

Two versions of the Datel Modem No. 12B have been developed. The Model 1 version provides for transmission and reception of isochronous serial binary data (synchronous with a timing waveform) at a rate of 2400 bit/s (using type A or type B modulation) or 1200 bit/s, with a backward channel operating anisochronously at any rate up to 150 bit/s. The Model 2 version does not have the backward-channel facility. Both models can be operated via a PSTN line, or a 2-wire or 4-wire private circuit.

Incoming calls on the PSTN line can be answered automatically by the modem, and the equipment can be operated in conjunction with a Data Control Equipment No. 1[4] to provide an automatic-calling facility. Both automatic calling and answering procedures conform to CCITT Recommendation V25.[5] The modem is normally connected to the leased line whenever power is applied, but can be disconnected by means of a button on an associated telephone instrument. Once disconnected from the leased line, the modem can be connected to the PSTN line for stand-by operation by means of a button on the telephone instrument associated with the PSTN line. Alternatively, connexion to either line can be entirely under the control of the data terminal equipment (DTE).

Test facilities are provided which are accessible to the operator; these enable the modem to be tested locally in conjunction with the DTE or a Datel tester, or remotely from the distant terminal or from a BPO Datel test centre.

The equipment operates from the public AC mains supply and can be table mounted or, in larger installations, accommodated on 62-type equipment racks.

MODULATION SYSTEM

Forward Channel

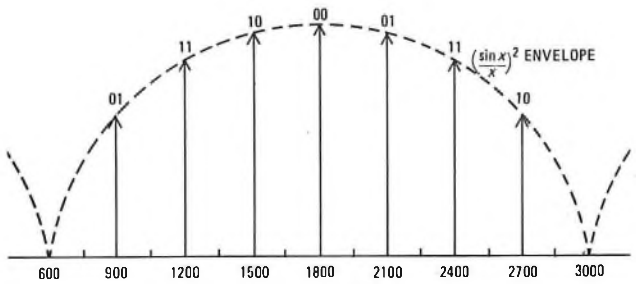
The carrier frequency of 1800 Hz is located where group-delay distortion is a minimum, approximately in the centre of the frequency band available on a typical telephone channel. When operating at 2400 bit/s, the carrier frequency

TABLE 1
Phase Modulation of Transmitted Carrier

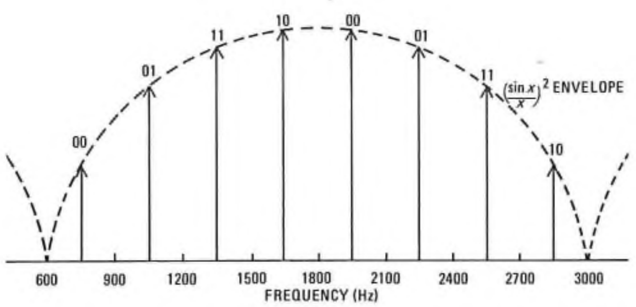
Bit or Dibit	Phase Change		
	Type A	Type B	1200 bit/s
00	0°	+ 45°	—
01	+ 90°	+135°	—
11	+180°	+225°	—
10	+270°	+315°	—
0	—	—	+ 90°
1	—	—	+270°

is differentially phase-modulated by pairs of bits (dibits) in the serial data stream to be transmitted. Table 1 shows the phase change that corresponds to each of the 4 possible dibits for both type A and type B modulation. When operating at 1200 bit/s, the modulation is differential 2-phase, as is also shown in Table 1. Thus, with type A modulation, a continuous binary 1 is transmitted as successive 180° phase advances of the carrier at dibit rate and, with type B modulation, as successive 225° phase advances. At 1200 bit/s, binary 1 is transmitted as successive 270° phase advances at bit rate. The line modulation rate is, therefore, always 1200 symbols/s (1200 baud). Type A modulation produces 4 absolute phases of the carrier signal, whereas type B results in 8 phases being generated.

A repetitive dibit gives rise to energy at a single spectral point in each sideband above and below the carrier. The frequency separation between these 2 points is directly proportional to the modulation rate and is 1200 Hz at 1200 baud. The precise frequencies at which energy appears is dependent upon the phase change; that is, upon the dibit. The relative level of the spectral energy is bounded by an envelope, symmetrical about the carrier frequency, and having a shape defined by the mathematical expression $(\sin x/x)^2$. Fig. 1 shows the spectra produced by repetitive dibits for both type A and type B modulation. When the modulating pattern is more complex, energy is spread more uniformly across the band, the number of lines of spectral energy produced being a function of the pattern length. The energy per line reduces as the pattern length increases, maintaining the total energy substantially constant. With random data, or with pseudo-random patterns several-hundred bits long, energy is uniformly present throughout the band; however, at any particular instant, a spectral line in the upper sideband is accompanied by a spectral line in the lower sideband, separated from it by a frequency equal to the modulation rate. This is important, since it constitutes data timing information carried by the transmitted line signal.



(*a*) Type A modulation



(*b*) Type B modulation

FIG. 1—Energy spectra for repetitive dibits

In any isochronous digital transmission system, for minimum inter-symbol interference, the overall system filtering must produce a roll-off of the energy spectrum having odd symmetry about the Nyquist frequency. The Nyquist frequency, in hertz, is numerically equal to half the modulation rate in bauds; in this instance, 600 Hz above and below the carrier frequency. Optimum performance is achieved when half the required filtering is provided at the transmitter and the remaining half at the receiver. However, in the Datel Modem No. 12, practically all the spectrum shaping is carried out in the receiver; filtering at the transmitter merely attenuates the higher-order lobes of the spectrum. The reason for this is that, if signal shaping were to be applied at the transmitter, the consequent attenuation of the outer edges of the spectrum would make timing recovery difficult, if not impossible, on dibits 00 and 10 with type B modulation. The degree of performance sacrificed through not optimizing the filtering is insignificant in practice, but enables the modem to achieve code transparency more readily. At the receiver, after timing extraction, post-demodulator filters apply full raised-cosine shaping to the signal.

Demodulation of the differentially-coded signal can be achieved by comparing the phase of the received symbol with that of the symbol immediately preceding it. This is known as *differential detection*. Since these symbols can be distorted in an opposite sense, an error is more likely than if a stable reference is used for the comparison. Use of a stable reference is known as *coherent detection*, and gives a significant improvement in performance with only a small cost penalty. The Datel Modem No. 12B uses coherent detection, the reference being a locally-generated signal, phase-locked to the received carrier signal.

Backward Channel

CCITT Recommendation V26 *bis* specifies an anisochronous backward channel, operating at rates up to 75 bit/s and using frequency modulation. When specifying the Datel Modem No. 12B, it was decided that the development should aim at a backward channel operating at 150 bit/s. Characteristic frequencies of 390 Hz for binary 1 and 450 Hz for binary 0, conforming to the international recommendation, were retained; however, the performance requirements were set lower than those that might have been expected at 75 bit/s.

The wide disparity between forward-channel and backward-channel signal levels, which can occur when operating on PSTN connexions, places stringent requirements on channel-separation filters. This is aggravated to some extent both by the wider bandwidth necessary on the backward channel to attain the 150 bit/s performance, and by the adoption of type B modulation on the forward channel, necessitating recovery of lower-frequency components in that band for timing purposes. The Datel Modem No. 12B achieves the required separation and provides adequate performance on both channels over a wide variety of line characteristics.

DESCRIPTION OF MODEM

General

The modem is in 2 separate units of roughly equal size, designed to blend with present-day office equipment. Separating

FIG. 2—Table-mounted modem unit with wall-mounted line unit

the modem into 2 parts keeps the size of the table-mounted item to a minimum. The table unit contains the modulation and demodulation functions for both channels, and the control arrangements. The bulky components, such as the mains power unit and line transformers, are housed in a separate unit intended to be mounted on a wall; however, this is also designed to be table mounted in situations where wall mounting is difficult. Fig. 2 shows the equipment in a simulated typical installation. In large installations, the equipment can be rack mounted on 62-type equipment racks.

Conventional component technology is used throughout. Digital medium-scale integrated circuits are in low-power transistor-transistor logic (TTL) for minimum heat dissipation. Analogue circuits use, in the main, the operational-amplifier type of integrated circuit. All filters and equalizers are realized by resistance-capacitance active networks.

Mechanical Design

The modem unit consists of 5 cards conforming to 62-type equipment practice. Four of these contain the transmitters and receivers for each of the 2 channels, and the fifth is the control module. The cards are plugged into a chassis unit for table mounting, or into a specially wired shelf for rack mounting. The Model 2 version is formed by omitting the backward-channel transmitter and receiver cards, resulting in a reduction in height of the table-mounted unit.

The wall-mounted unit houses a further 62-type card—the line module—which performs the line-switching functions under the control of the modem unit. This line module can be one of three types, which cater for a PSTN line, a private circuit (2-wire or 4-wire), or both. The same line module is used when the equipment is rack-mounted. The wall-mounted line unit also contains an AC mains-operated power supply, which provides unregulated power for both the modem unit and line module. Voltage regulation is carried out on the chassis of the table-mounted unit, and on the line-module card.

In the past, Datel installations have involved a wall-mounted item (Case No. 200) which has been used to provide various facilities including line termination and test access. On some installations, several of these units have been necessary to provide the required facilities. The line unit has been designed to provide all facilities required by a Datel Modem No. 12B installation, thus eliminating the need for the Case No. 200. Line connexions, and all connexions to other items of equipment, such as telephone instruments, are made to the line unit. A single 22-way cable interconnects the modem and line units, using a plug and socket at the modem unit end and screw terminals in the line unit. Connexion to the customer's DTE is by a standard ISO 25-pin socket on the modem unit.

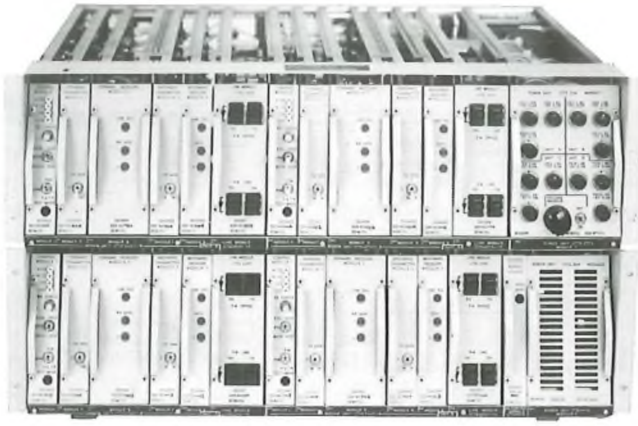


FIG. 3—Four modems and associated line equipment in rack-mounted form

When the equipment is rack-mounted, up to 4 modems, complete with associated line modules, can be accommodated on a specially wired shelf unit occupying the space of 2 standard 62-type equipment shelves. The shelf also houses a mains-operated power unit and voltage regulator which supplies all 4 modems, and a control module which provides facilities for the 4 modems to share a single PSTN line for stand-by purposes. Fig. 3 shows the complete 2-shelf arrangements.

Forward-Channel Transmitter

A simplified block diagram of the 2400 bit/s forward-channel transmitter is shown in Fig. 4. When internal timing is used, a 432 kHz signal, derived from a high-frequency crystal oscillator, is further divided to obtain the timing and other signals required by the transmitter. When the option of external timing is selected, the signal received via the data-terminal interchange circuit (113)[6] is used for bit and dibit timing.

When the modem is required to transmit data, an ON condition is applied to the request-to-send (RTS) interchange circuit by the terminal equipment. After a preset delay, the modem applies an ON condition to the ready-for-sending (RFS) interchange circuit. Four options are available for this delay to cater for a range of operating conditions; the options are 12 ms, 35 ms, 80 ms and 235 ms. The RFS ON condition is synchronized to the start of a data element to avoid possible failure to transmit the first element presented to the modem. When the ON condition is received from the RTS interchange circuit, a divide-by-eight counter, previously inhibited, is allowed to divide a 72 kHz signal derived from the crystal oscillator. The 9 kHz signal resulting from this division is applied to the phase selector circuit in 8 different phases separated by intervals of $\pi/4$ rad. During the RFS delay period, the modem transmits to line phase changes corresponding to dibit 11. This is the synchronizing signal, and the receiver of the distant modem must condition itself, by means of this signal, to interpret correctly the data that will follow. When the RFS ON condition occurs, a gate in the transmission path is opened; this allows the data received from the terminal equipment, via the transmitted data interchange circuit, to pass to the coding and phase-selection circuits.

The data stream is first divided into dibits, and each dibit is presented sequentially to the phase-address generator. From knowledge of the phase of the previous signal transmitted and the new dibit presented, the phase-address generator

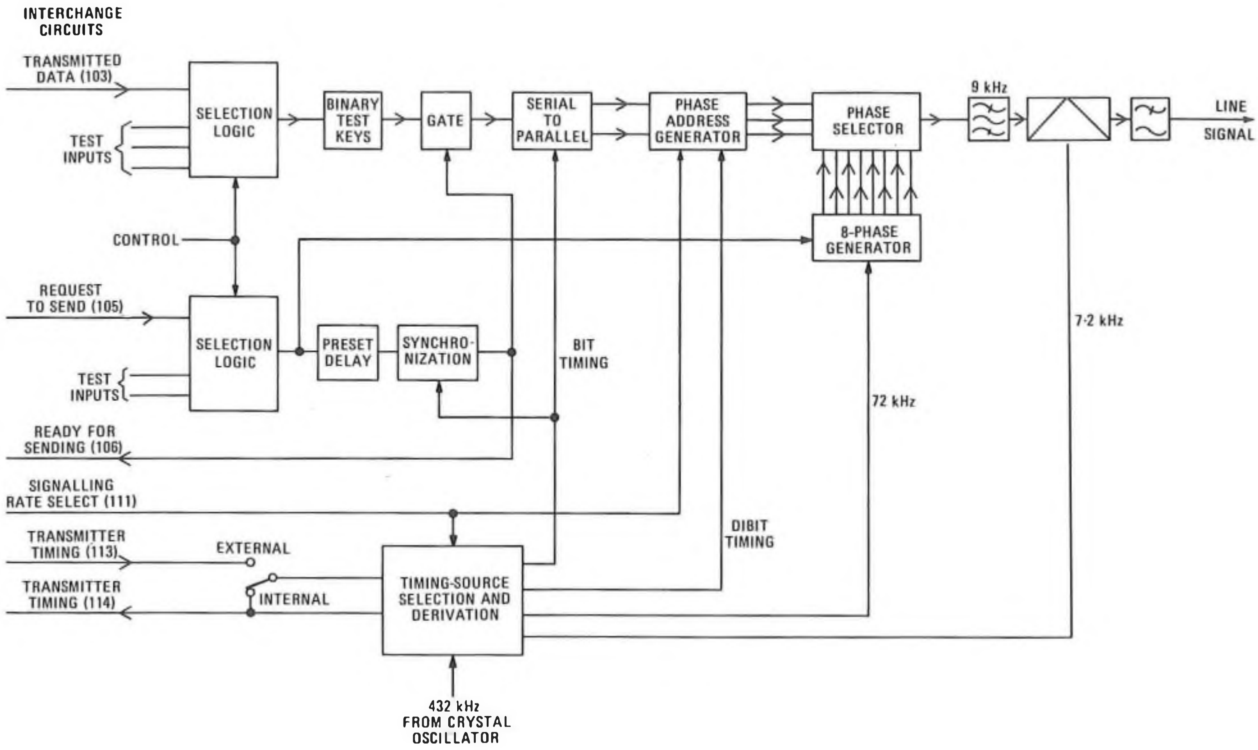


FIG. 4—Simplified block diagram of 2400 bit/s forward-channel transmitter

computes a 3-digit binary number which, when presented to the phase-selector circuit, indicates the new signal phase required to represent the dibit. The phase-selector circuit recognizes the binary number from the phase-address generator as the address of one of the 8 phases available, and allows that phase to pass to a modulator for frequency translation.

Deriving the modulated signal at a relatively high intermediate frequency in this manner simplifies removal of modulating-frequency components, which would otherwise impair the transmitted signal. A 9 kHz band-pass filter, which precedes the modulator, prevents high-frequency components of the modulating signal causing fold-over distortion. The modulated 9 kHz signal is mixed with a 7·2 kHz signal derived from the crystal oscillator, and the resulting difference frequency band is selected by a low-pass filter for transmission to line. The filtering in the transmitter does not significantly affect the envelope shape of the first lobe of the signal energy spectrum.

When operating at 1200 bit/s, appropriate timing signals are generated and, in addition, the modulation is changed from 4-phase to 2-phase. Control of the operating rate is by means of the signalling-rate-select interchange circuit.

Test facilities included in the modem (described later) must be able to turn on the transmitter (that is, simulate an ON condition on the RTS interchange circuit) and transmit data demodulated by the forward-channel or backward-channel receivers. This is accomplished by selection logic and control signals from the test circuits.

Forward-Channel Receiver

A simplified block diagram of the 2400 bit/s forward-channel receiver is shown in Fig. 5. The signal received from line is first filtered to attenuate out-of-band signals and noise. To preserve timing information at the edges of the frequency band, the band-pass filter used performs no shaping of the first lobe of the signal energy spectrum. When operating on a PSTN line, a group-delay/frequency and attenuation/frequency equalizer is connected in the transmission path by an electronic switch. When operating on a private circuit, the equalizer can be placed in or out of circuit by means of a strap option controlling the same switch. The equalizer has characteristics that are a compromise for the wide variations met on the PSTN. The output of the switch is connected to a circuit that detects the presence of a signal within the operating level range of the receiver (−5 dBm to −43 dBm),† and initiates action by other parts of the receiver.

The transmission path continues via an amplifying stage with automatic gain control (AGC), which gives a substantially constant signal level at its output for the full range of possible received signal levels. The constant-level signal is fed into 2 similar transmission paths each consisting of a modulator, effectively acting as a phase detector, a low-pass filter and a waveform slicer. The modulators are fed with 1800 Hz carrier signals, which are phase-locked to the received signal, but are in phase quadrature with each other. This is described in more detail in the next section. The design aim of the low-pass filters is to give an overall system signal energy spectrum shape that has odd symmetry about the Nyquist frequency; this gives minimum inter-symbol interference. The outputs from the slicers are 2-level signals, representing the absolute phase of the received signal when examined at the centre of each symbol. This examination is accomplished in the decoder, using the locally-generated dibit timing. The decoder also compares the phase of the received symbol with that of the previous symbol and, from this, derives the dibit; this is converted to serial form and passed to the terminal equipment via the received-data interchange circuit.

Carrier Recovery and Demodulation

At 2400 bit/s, using type B modulation, the received signal can adopt any one of 8 absolute phases. However, alternate symbols pass from one set of 4 quadrature phasors to a second set of 4 displaced by 45°. At the receiver, the locally-generated carrier signals are advanced in phase by 45° at

† dBm: decibels relative to 1 mW

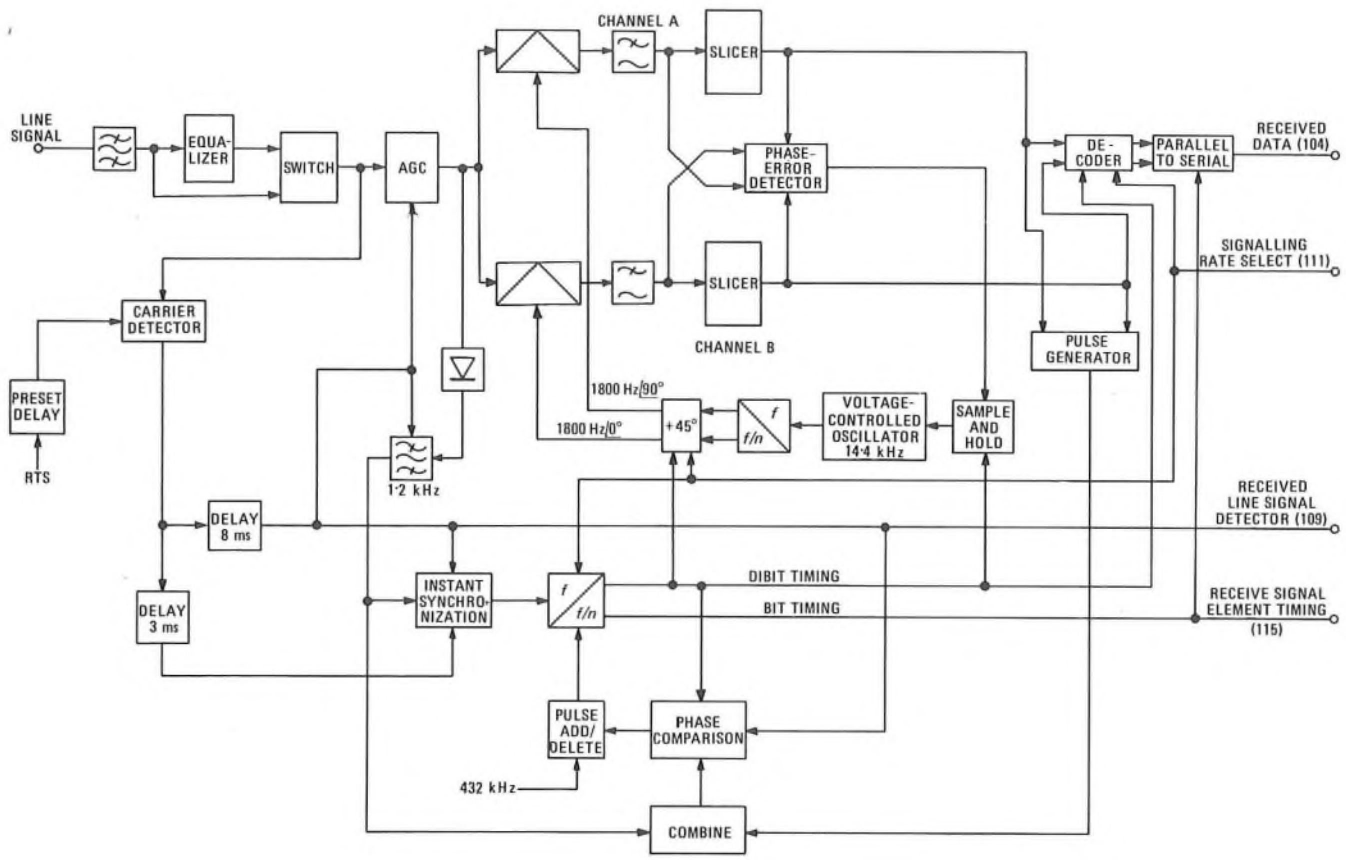


FIG. 5—Simplified block diagram of 2400 bit/s forward-channel receiver

symbol rate, thus eliminating 4 of the 8 possible phases. Fig. 6(*a*) shows the ideal phase relationship between the received signal and the local carrier signals, taking into account this phase advancement. Also shown is the demodulator output level for each of the possible signal phasors. Fig. 6(*b*) shows conditions when the local carrier signals are in advance of the correct phase. The output from the slicers on each channel is one of 2 fixed levels, even though, with incorrect carrier phase, 4 levels are possible at the slicer input. An error signal, indicating the sense and magnitude of carrier phase error, can be obtained if the demodulator output of each channel is multiplied by the slicer output of the opposite channel and the results summed in accordance with the following formula:

$$\text{error signal} = A \times B_s + B \times \bar{A}_s,$$

where A is the channel A demodulator output, B is the channel B demodulator output, $\bar{A}_s$ is the channel A slicer output inverted, and B_s is the channel B slicer output.

Applying this to Fig. 6(*b*), and substituting $+1$ or -1 for the slicer output as appropriate, gives

$$E_1 \text{ (error for signal phasor 1)} = (A_1)\times(-1) + (B_1)\times(-1).$$

$$\therefore\ E_1 = -(A_1) - (B_1).$$

Since (B_1) is negative, $E_1 = -A_1 + B_1$.

Therefore, as $A_1 > B_1$, E_1 is a negative quantity.

$$E_2 \text{ (error for signal phasor 2)} = (A_2)\times(-1) + (B_2)\times(+1).$$

$$\therefore\ E_2 = -(A_2) + (B_2).$$

Since both (A_2) and (B_2) are negative,

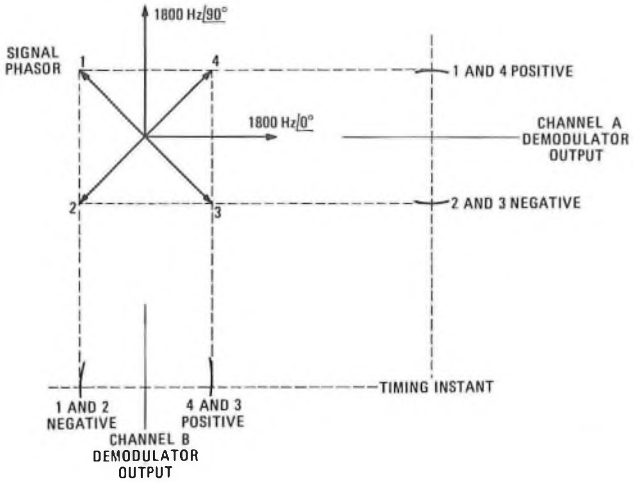
$$E_2 = A_2 - B_2$$

Therefore, as $B_2 > A_2$, E_2 is a negative quantity.

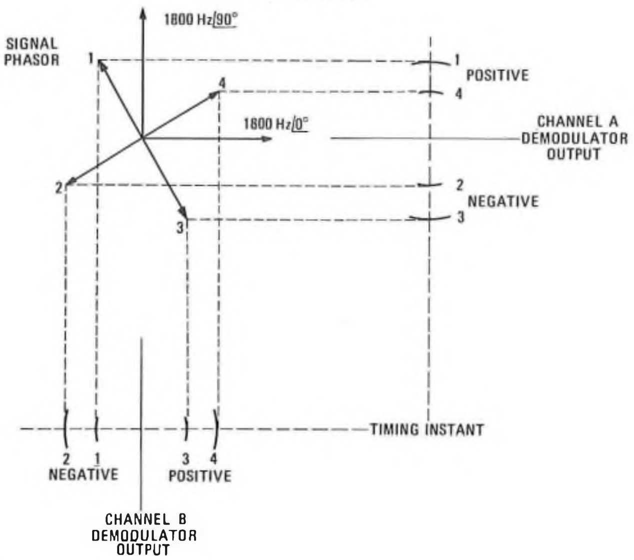
For signal phasors 3 and 4 in Fig. 6(*b*), the error signal is also negative and its magnitude is equal to the difference between the demodulator output levels on the 2 channels. With correct phase conditions (Fig. 6(*a*)), the error signal is zero and, if the phase error is the opposite direction to that shown in Fig. 6(*b*), the error signal is of opposite (positive) sign.

It is important to note that, because the phases of signal phasors are changing from symbol to symbol, the error is best determined at the timing instant; that is, the mid-point of the symbol. The phase-error detector circuit is therefore sampled by a narrow pulse generated by the dibit timing signal, and the error voltage stored on a capacitor. This voltage is used to control the frequency of an oscillator from which the local carrier signals are derived, and thus controls their phase. The loop locks in the condition where the error signal is minimum.

When operating in the 1200 bit/s mode, the modulation is 2-phase, with a 90° advance at each symbol. Thus, the received signal adopts one of 4 absolute phases, but alternate symbols are in phase quadrature. At the receiver, the phase of locally-generated carrier signals is also advanced by 90° at symbol rate. Thus, only 2 relative phases of signal are seen at the demodulator. This causes the locally-generated carrier signals to lock such that one is in phase (or anti-phase) with the received signal, and the other is in phase quadrature. When in precisely the correct phase, the output from the demodulator on channel A is zero because the carrier is in phase quadrature, and the decoder operates only on the information present on channel B. If the carrier phase is incorrect, there is an output from the channel A demodulator, and the phase-error detector circuit produces an error signal in the same manner as described for the 2400 bit/s mode of operation. By maintaining the demodulating carrier in phase with the received signal, the demodulator output is at a



(*a*) Ideal case



(*b*) Locally-generated carrier signals in advance of correct phase

FIG. 6— Phase relationships between received signals and locally-generated carrier signals

maximum (the data "eye" aperture is a maximum), and the margin against error in the face of noise is optimized.

Timing Recovery

An accurate, stable timing signal is essential for the correct operation of the carrier recovery and demodulation functions. When the transmission path has distorted the received signal, accurate timing is again essential to enable the receiver to examine the centre of each symbol, where a correct interpretation is most likely to be achieved. Furthermore, this timing signal must be obtained rapidly. On a polling network, for example, where fast turn-round is required, the short RFS delay is used and the synchronizing pattern lasts for only about 12 ms. After this, the receiver must be ready to decode correctly the customer's transmitted data.

The modem receiver generates a waveform of approximately the correct frequency by dividing the 432 kHz signal from the crystal oscillator by the appropriate factor. The waveform generated is then compared with the timing pulses derived from the received signal, and its phase adjusted such that the appropriate transition coincides with the timing pulses. Timing pulses are derived from the received signal in 2 ways: directly from the line signal (carrier-derived timing); and from the demodulated signal (data-derived timing).

Carrier-derived timing is used to obtain timing information quickly, on start-up, when the synchronizing signal is being received. However, certain dibits result in a weak timing component from this source, particularly when transmission-path impairments are present; therefore, once operation has commenced, data-derived timing assists in maintaining accuracy under all conditions.

The signal from the output of the AGC circuit is full-wave rectified and applied to a tuned circuit, which selects the 1200 Hz component imparted by the modulation. This constitutes the carrier-derived timing signal. A narrow pulse is generated at each transition of the output signal from the slicers on demodulator channels A and B. These constitute the data-derived timing pulses.

The 2 timing sources are combined and a reversible counter records, at each symbol, whether the local signal is advanced or retarded in phase, relative to the timing pulses. When the counter reaches the end of its count in either direction, a pulse is added to, or deleted from, the 432 kHz oscillator signal and the counter is reset to the centre of its range. Having made a correction, at least 8 symbols must show a constant error in either direction before a corrective step is taken in that direction. This system reduces jitter produced on the receiver timing signal by random variations of the timing pulses derived from the line signal.

A circuit in the receiver detects a line signal when first received. Approximately 3 ms after detection, the carrier-derived timing signal is allowed to reset the locally-generated timing signals, such that transitions on both occur simultaneously. This resetting continues at each symbol until approximately 8 ms after signal detection. This is called *instant synchronization* and rapidly adjusts the receiver timing signal until it is very close to the correct phase. After 8 ms, the instant-synchronization circuit is disabled and timing continues to be adjusted as previously described.

When the carrier-detector circuit goes to the OFF condition (that is, the line signal falls below the operating-level range), the output from the timing phase-comparison circuit is disabled so that no corrections are made due to line noise. Thus, if the signal reappears within a short time, the timing phase is not lost and terminal equipment is not thrown out of synchronism. During such a break, however, the timing phase drifts away from optimum due to the receive oscillator frequency differing from that of the transmitter; with the oscillator stabilities specified, this drift limits the length of break that can be tolerated to 1 s.

Before a line signal is received, the AGC circuit is arranged to have a short time constant to enable it to adjust rapidly to an incoming signal. The tuned circuit from which the carrier-derived timing is obtained is also arranged to have a relatively wide bandwidth to enable it to capture the timing component quickly. Approximately 8 ms after detection of a signal, the AGC time constant is increased to enable the modem to "ride through" short signal breaks or level changes; at the same time, the *Q*-factor of the timing circuit is increased to minimize timing jitter.

When the modem is operating over a 2-wire line, the transmitted signal appears at the input of the receiver. If allowed to, the receiver would synchronize to this and, after demodulating and decoding in the normal way, would return the transmitted data to the terminal equipment. To prevent this, a clamp is applied to the carrier-detector circuit whenever the RTS interchange circuit is in the ON condition, thus holding the carrier detector OFF. This prevents the receiver from synchronizing and also holds the received data interchange circuit in the binary 1 condition. At the end of transmission, the transmitted signal may still be circulating in the 4-wire section of the line as an echo and, if the clamp on the carrier detector were removed immediately, the receiver could synchronize to this echo. If this happened, the receiver could not then rapidly adjust to a signal received from the distant end. To avoid this, the clamp on the carrier detector is maintained

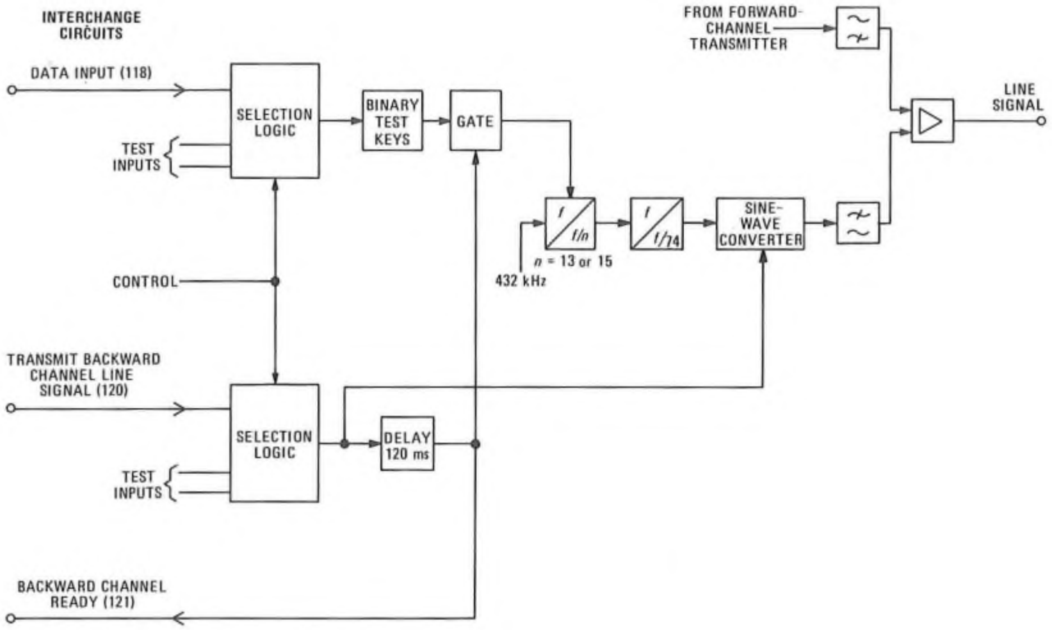


FIG. 7—Simplified block diagram of 150 bit/s backward-channel transmitter

for a preselected period after the RTS interchange circuit goes to the OFF condition. This is known as the *echo delay clamp*, and values of 9 ms, 24 ms, or 150 ms can be selected, depending on the type of circuit over which the equipment is to operate.

Backward-Channel Transmitter

A simplified block diagram of the 150 bit/s backward-channel transmitter is shown in Fig. 7. A 432 kHz signal from the crystal oscillator is divided by 13 or by 15, depending upon whether a binary 0 or a binary 1 is to be transmitted. The output signal from this programmable divider is further divided by 74 to give resulting line frequencies of 450 Hz and 390 Hz for binary 0 and binary 1 respectively.

The square-wave signals at line frequency are applied to a digital circuit which, by means of a resistive weighting network, produces an 8-step approximation of a sine wave having a frequency equivalent to that of the input signal. This gives considerable reduction of the level of harmonic frequencies in the signal, and thus reduces the degree of filtering necessary to avoid interference with the forward channel. The cost of the low-pass transmit filter is thereby reduced.

The backward-channel transmitter unit also carries a high-pass filter, through which the forward-channel signal passes before being combined with the backward-channel signal and transmitted to line. This high-pass filter attenuates components of the forward-channel signal that would otherwise interfere with backward-channel reception on 2-wire lines. The cost of all the filtering necessary for operation of the backward channel is therefore incurred only when the backward channel is provided. This is a significant saving, since the operational requirement for a backward channel amounts to less than 20% of the total modem requirements.

When the transmit-backward-channel-line-signal (TBCLS) interchange circuit is in the OFF condition, the operation of the digital sine-wave converter is inhibited and no signal is transmitted. An ON condition on the TBCLS interchange circuit enables the converter, and a binary 1 is transmitted for a period of 120 ms. The terminal equipment then receives an ON condition on the backward-channel-ready interchange circuit; simultaneously, a gate is opened which allows the input data signal to control the programmable divider and thus the line signal. Under test conditions, signals from the backward-channel or forward-channel receivers can be given control of the transmitted signal.

Backward-Channel Receiver

Fig. 8 shows a simplified block diagram of the backward-channel receiver. The forward-channel signal is separated from the backward-channel signal by a high-pass filter located on the backward-channel unit for the reasons given above. The received backward-channel signal passes to a limiter via a band-pass filter, which excludes out-of-band signals and noise. The limiter produces an output signal at logic levels, having the same zero-crossing points as the input signal; that is, having the same frequency modulation. This signal is demodulated by a digital phase-locked loop.

A 432 kHz signal is frequency-divided by a variable divider chain under control of the output of an EXCLUSIVE OR gate. The resulting frequencies are

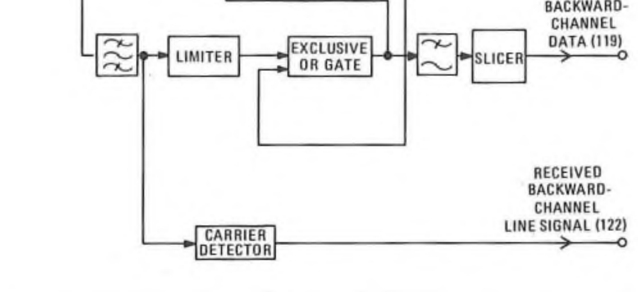
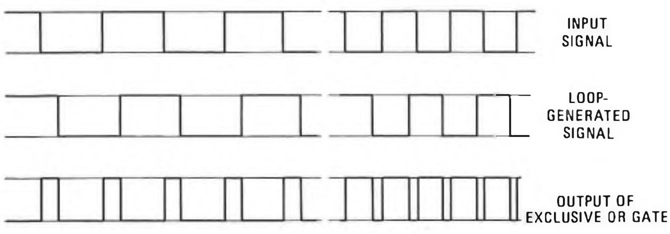


FIG. 8—Simplified block diagram of 150 bit/s backward-channel receiver



(*a*) Receiving binary 1 (390 Hz) (*b*) Receiving binary 0 (450 Hz)

FIG. 9—Significant waveforms of backward-channel demodulator

$$(432 \times 10^3) \div 768 \approx 562 \text{ Hz, and}$$
$$(432 \times 10^3) \div 1536 \approx 281 \text{ Hz.}$$

These 2 frequencies mark the extremities of the locking range of the loop, which gives adequate coverage of the input-frequency range of the backward-channel signal. When an input signal having a frequency within this locking range is applied, the average division during one cycle is automatically adjusted such that an identical frequency is generated at the output of the loop. The loop-generated signal adopts a phase relative to the input signal, which is proportional to the frequency. Fig. 9 shows the significant waveforms. The output signal from the EXCLUSIVE OR gate is positive for a period that is dependent upon the phase relationship between the input signal and the loop-generated signal. During the time that the EXCLUSIVE OR gate output is positive, the variable divider divides by 2; when it is in the zero state, a division by 4 occurs. The average level of the output from the EXCLUSIVE OR gate is proportional to the frequency of the input signal, and therefore contains a component of the modulation on that signal. The unwanted higher-frequency components are removed by a low-pass filter and the demodulated signal sliced to obtain a replica of the original data.

Line Module

The transmit and receive transmission paths from the modem unit, together with control circuits, are connected to a line module by a 22-wire flexible cable up to 5 m in length. Three versions of the line module are available, catering for either a PSTN line (Model 2), a private circuit (Model 3), or both (Model 1). A simplified block diagram of the Model 1 line module is shown in Fig. 10.

The transmit data signal, at a nominal level of −1 dBm, first passes through a buffer amplifier having a gain sufficient to offset transformer losses. The signal path is then split to the PSTN line or private circuit via separate adjustable attenuators, which allow the transmitted levels to be set independently. The command *connect to line* is given by the modem unit. This operates the appropriate relay in the line module, contacts of which disconnect the telephone circuit associated with the line and connect the data transmission path. When operating on 2-wire lines, the TRANSMIT and RECEIVE signal paths are combined without using any form of hybrid transformer. Little advantage would be gained by the use of a hybrid transformer due to the wide variation of line impedance that occurs on the PSTN (and to a lesser extent on a private circuit); the cost and bulk of the hybrid transformer are significant disadvantages. The received line signal passes through a buffer amplifier having a small gain to offset the line transformer losses.

Linearity is an important consideration in the signal path because, on a 2-wire line, any harmonics of the transmitted backward-channel signal present at a significant level will interfere with reception of the forward channel. This is aggravated by the wide disparity of signal levels possible at this point in the circuit, and also by the line DC requirements. The design ensures that harmonic distortion of signals in the backward-channel frequency band does not exceed 60 dB when the PSTN HOLD coil is passing 125 mA DC, or when the private-circuit line transformers are passing 7 mA wetting current.

For local testing, an analogue loop-back transmission path from transmitter to receiver is available, into which a nominal 14 dB attentuator is inserted. Simultaneously, a transmission loop is applied between the 4-wire RECEIVE and 4-wire TRANSMIT paths of the private circuit. This enables the distant terminal, or a BPO test centre, to carry out tests on the line. A 2 dB attenuator is inserted in this loop to avoid oscillation on the 4-wire circuit if both terminals carry out local tests simultaneously.

Control and Automatic Answering

Options are provided to enable the manner of exercising line switching control to be preselected. Under one option, the modem is connected to the leased line whenever power is applied, but can be disconnected from that line by the operation of a button on an associated telephone instrument; the modem can then be connected to the PSTN line using the

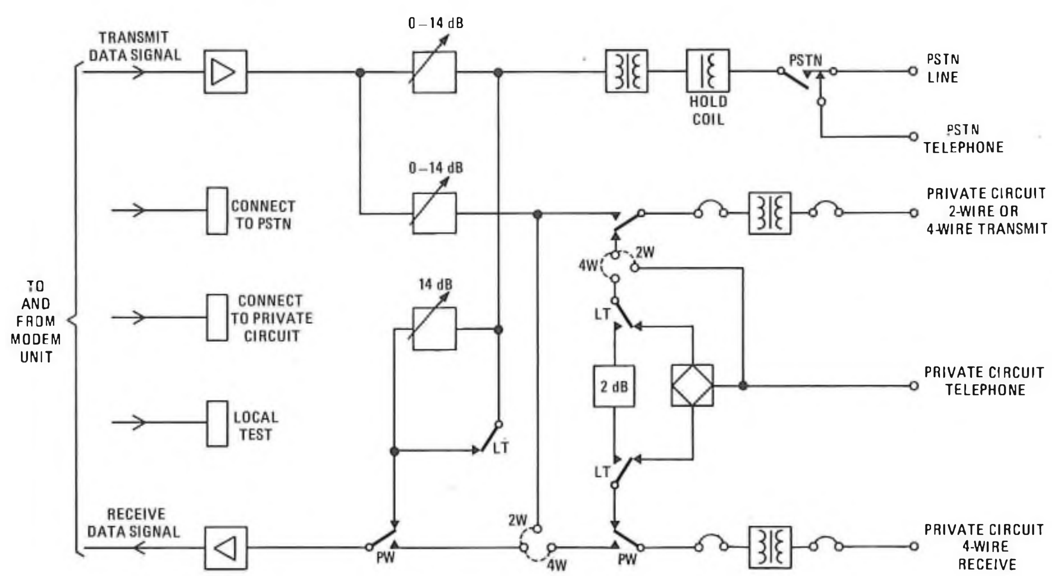


FIG. 10—Simplified block diagram of line module

data-terminal-ready method of operation. Under this method, connexion to line occurs when a DATA button on the telephone is momentarily operated, provided that the terminal equipment signifies its readiness for data transmission by appropriately conditioning the data-terminal-ready interchange circuit (No. 108/2). Under a further option, the terminal equipment can select the line by applying the appropriate condition to the select-standby interchange circuit (No. 116), and connect the modem to that line by means of the interchange circuit No. 108/1.

The modem can be used in conjunction with a Data Control Equipment No. 1 when automatic origination of calls is required, and a facility for automatically answering an incoming call on the PSTN line is also available. When the automatic-answering facility is in use, a circuit detects the presence of ringing current on the line and, provided the terminal equipment has signified its readiness to accept a call, the modem automatically connects to the line. On connexion, the modem transmits a 2100 Hz answering tone for a period of several seconds. This serves the following purposes:

(*a*) it is required when automatic-calling facilities are provided,

(*b*) on an international call, it disables any echo suppressors present on the international circuit, and

(*c*) it indicates to a caller, who inadvertently gets a wrong number, that a misconnexion has occurred.

In a large installation, where a number of modems are rack-mounted, these can be controlled from a central position at a remote location. In this situation, modems can be connected to line remotely, or conditioned to answer calls automatically, and supervisory indications are given on the control panel.

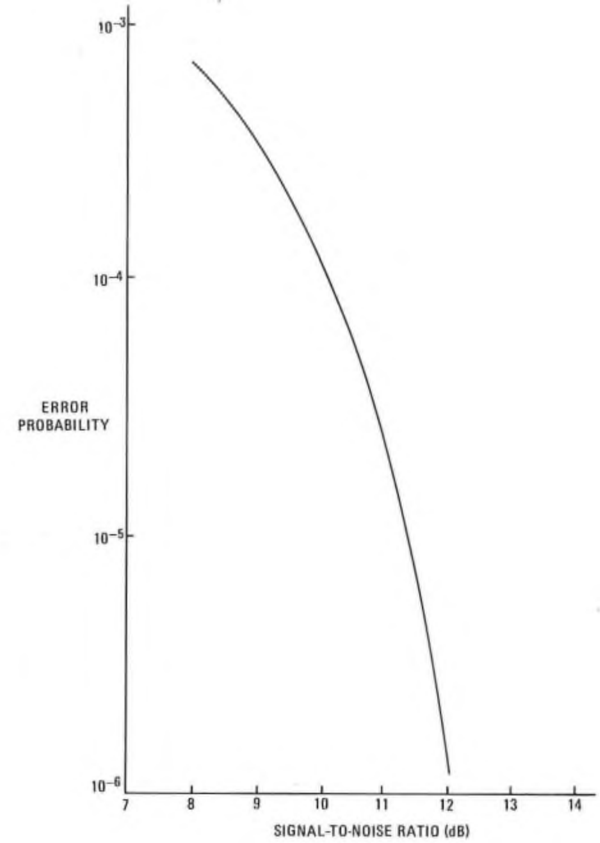


FIG. 11—Error probability performance

Test Facilities

Facilities are provided that enable the modem to be tested in local operation by the terminal equipment, or by a Datel tester connected to the terminal-equipment interface socket. Alternatively, when in the remote-test condition, the modem can be tested from a remote location via a loop applied to the terminal-equipment interface. In both of these test conditions and in normal operation, continuous binary conditions can be transmitted by means of switches on the front plates of the 62-type units; reception of these signals can then be observed on indicators on the appropriate modem receiver. The test facilities are all available for use by the customer.

To put the modem in a test condition, a switch is operated to LOCAL TEST or REMOTE TEST. In the local-test condition, signals transmitted on either the forward or backward channel are returned via the loop in the line module. In the remote-test condition, as well as operating the REMOTE TEST switch, a second switch is operated to connect the modem to either the private circuit or the PSTN line. When connected to a 4-wire private circuit, the REMOTE TEST switch connects the forward-channel received-data wire to the transmit-data wire of the same channel, and similarly loops the backward channel. Timing and certain control circuits are also interconnected to allow data received on either channel to be retransmitted on the same channel. When connected to the PSTN, or a 2-wire private circuit, interconnexions are made between the backward-channel receiver and forward-channel transmitter, and between the forward-channel receiver and the backward-channel transmitter. This enables low-rate data to be passed down the 2-wire line to the modem and back again in the opposite channel. On the Model 2 modem where a backward channel is not available, when tested remotely on a 2-wire line, the interconnexion between receiver and transmitter is passed via a binary inverter. This causes an oscillation between transmitter and receiver, which can be monitored by the remote test centre.

PERFORMANCE

The modem is expected to be capable of operation at 2400 bit/s over most connexions met on the UK PSTN, giving full code transparency with an element error rate better than 1 in 10^3. Tests using a variety of simulated line characteristics indicate that the modem will be capable of operation at 2400 bit/s and of giving an element error rate better than 1 in 10^3 on a low grade private data circuit. On higher grades of circuit, significantly better performance is expected. Fig. 11 shows the variation of error probability of a back-to-back connexion with varying levels of added 3 kHz band-limited uniform-spectrum random noise.

The distortion on the backward channel at 150 bit/s is expected to be generally better than 16% isochronous.

ACKNOWLEDGEMENT

The Datel Modem No. 12B was developed to a BPO specification by S.E. Labs. (EMI) Ltd., Feltham, Middlesex, in conjunction with Rixon Electronics Inc., Maryland, USA.

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Removal and Containment of Asbestos

The health hazard associated with asbestos dust has been well publicized, and comprehensive guidance is available for carrying out remedial action on asbestos-based materials in existing buildings. Such action consists either of removal or containment (the latter also being referred to as sealing or encapsulation). The 2 Regional Notes below, from Shrewsbury and Southampton Telephone Areas, describe examples of each type of action.

Guidance and instructions concerning asbestos are being reviewed by a Joint Working Party set up under Experimental Changes of Practice Committee 1. The review takes account of current advice from the Health and Safety Executive and other bodies. Also taken into account is experience gained in cases such as that at Shrewsbury, where removal is necessary, and others where the alternative of containment, the preferred method on grounds of both safety and cost, is practicable.

Removal of Asbestos from Shrewsbury Exchange Power Room

T. G. HENDERSON†

INTRODUCTION

Just prior to the general appreciation of the seriousness of asbestos as a potential hazard to health, the new 11 kV substation and stand-by diesel-generator room at Shrewsbury telephone exchange was sprayed with a sound-insulating coating of flock asbestos between 35–50 mm thick. This extended over the whole of the ceiling and for a distance of about 3 m down the walls. Many of the brackets supporting the forest of drop-rods were fitted on top of this layer. During the installation of the power plant, the asbestos coating was cut through and there was some damage to its surface. With the passage of time, the cut areas of asbestos began to fray, and small pieces became detached, falling to the floor.

Fibre counts were taken of the atmosphere, with both engines and extractor fans working, and proved to be well inside the laid-down safety standards. Nevertheless, the presence of this hazardous material was a matter for some concern. Two courses were open to us; namely to

(*a*) apply a sealant which would effectively reduce the possibility of any loose fibres becoming suspended in the atmosphere, or

(*b*) completely remove all the asbestos.

Although option (*a*) would have been the cheaper and quicker method of dealing with the situation, it would have meant that the problem would be present each time the surface was drilled or disturbed in any way. Furthermore, the extent to which the sprayed coating had deteriorated meant that the effectiveness of encapsulation would have been in doubt in this particular case.

Whichever method was adopted, it would be necessary to shut down the power room completely; no work could be done while the 11 kV transformers were energized. Towards the end of May 1976, it was decided that all the asbestos should be removed as soon as possible, thus eliminating all risk to staff and avoiding a possibly continuing problem.

SAFEGUARDING POWER SUPPLIES

The power room contains 2 large stand-by diesel generating sets with all their control gear and auxiliary equipment, in addition to the 11 kV transformers which are the main source of supply to the building. Arrangements had therefore to be made for alternative main and stand-by supplies to be available during the remedial work when the normal equipment would be out of service.

For replacement of the main supply, we were fortunate in still having on the premises the Midlands Electricity Board (MEB) medium-voltage (MV) transformer substation which had been our source of power before the 11 kV high-voltage feed was provided, and which was still supplying power to adjacent properties. The load for the exchange building is 207 kV A, and the MEB verified that the MV supply could take the additional load. The MEB readily agreed to make the necessary arrangements to provide us with a metered feed from the transformer.

The next problem was to obtain a suitable mobile stand-by diesel generator of adequate capacity. The Power Group at Wales and The Marches Telecommunications Board (WMTB) located a 240 kW automatic-start set which was, at that time, being overhauled and modified in the Regional Workshops at Birmingham, and which would be available by the time we needed it. The machine was provisionally reserved, and a visit was made by interested parties to view the 24 t monster and become familiar with its physical details.

While these arrangements were being made, the Area Power Planning Group, in consultation with WMTB and their maintenance colleagues, were making detailed plans for the change-over to temporary supplies for both essential and non-essential services. Also, a number of contractors had been invited to tender for the removal of the asbestos, and a suitable contractor was selected.

The change-over arrangements required a considerable amount of heavy cable to cater for 2 runs, each of about 100 m, of 3-phase live and neutral wire. The type of cable required was not readily available from British Post Office (BPO) sources, and would have cost several-thousand pounds to purchase, even if it could be obtained in time. The MEB, who had originally raised our hopes by offering to lend us some, were unable to help with lengths of the order needed. Eventually, we were very fortunate in being able to borrow a drum of 600 m long 240 mm^2 single-core cable, which was adequate for our needs, and to which we could add a neutral wire of smaller cross-section from normal BPO supplies. Our benefactor was the External Telecommunications Executive (ETE) Power Group at Criggion Radio Station.

STRIPPING

Nylon overalls and pressure respirators were ordered for BPO personnel who would be working in the room, and arrangements were made for them to be trained in safety precautions. Joint decontaminating facilities for BPO and

† Shrewsbury Telephone Area

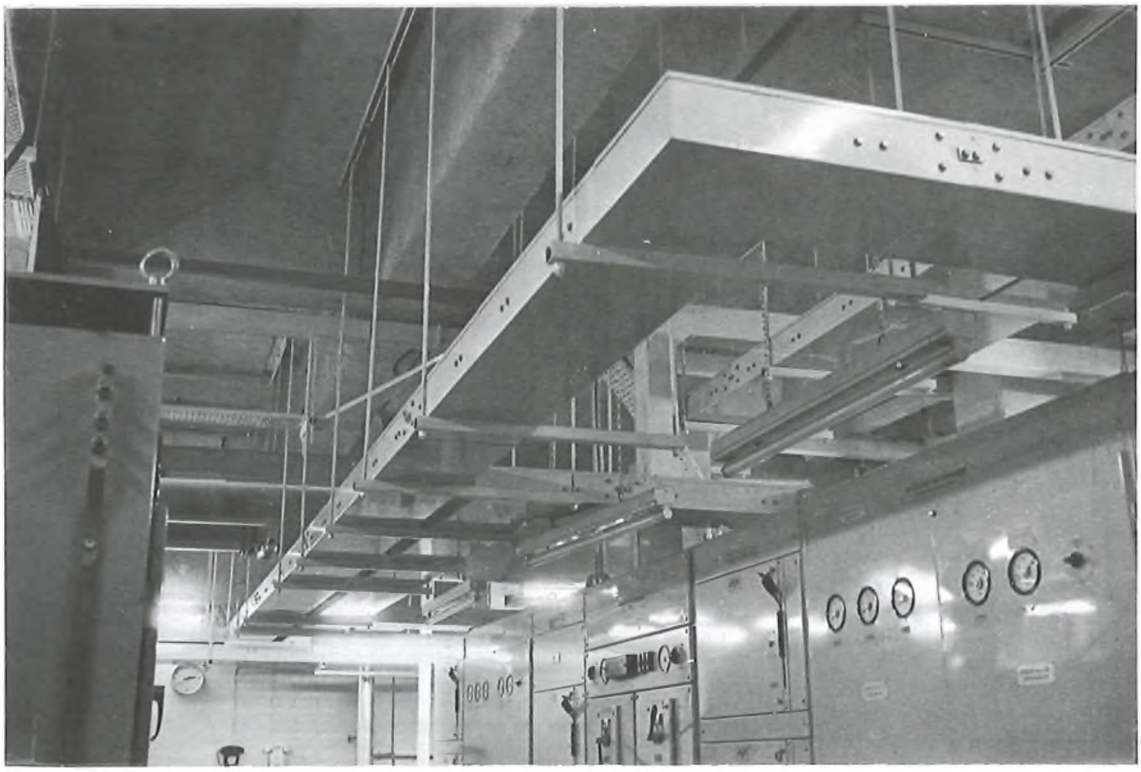

FIG. 1—Part of Shrewsbury power room, showing asbestos coating and awkward working conditions

contractor's staff were agreed, and a hot shower was provided in a locally-built cubicle. Since removal of the asbestos would entail the use of high-pressure water jets, some anxiety was felt for the safety of the equipment, particularly the high-voltage air-cooled transformers, which are particularly susceptible to damage by moisture. At one stage, cocooning of the equipment was envisaged, using a spray-on plastic cocoon of the sort used to protect laid-up naval craft. However, professional advice indicated that this would be impractical on grounds of cost, chemical incompatibility and low mechanical strength. The equipment was therefore protected by a double skin of heavy-duty polyethylene sheet, with all joints well sealed. Suitable quantities of desiccant were placed within the cubicles before the protection was fitted.

The change-over to temporary supplies took place on 22 November 1976 and, after preparatory work had been done by the Area Power Works staff (such as draining down and dismantling the oil-stillage and coolant-header tanks, and removing electrical equipment that could easily be recovered), we were able, on 1 December 1976, to hand the room over to the contractor to start stripping the asbestos.

Owing to the awkward shape and contents of the room (see Fig. 1), the operation took rather longer than was expected, and was not completed until 20 January 1977. The stripped asbestos was bagged and taken to an approved tip. The total removed amounted to 265 bags, each about the size of a flour sack, and occupied 3 skips.

The contract included the sealing of surfaces which had been asbestos coated to prevent dust arising from any fibres that might still remain, but the opportunity was also taken to redecorate the room while the equipment was out of service. One further bonus was that we were able to modify the stand-by power-feeding arrangements during the shut-down period. Originally, each stand-by engine-generator set supplied a dedicated part of the building, and any maintenance work on either set would have required the services of a mobile generator. A coupling switch was therefore fitted to enable either set to supply the whole building, each engine set having more than adequate capacity.

CONCLUSION

The work was eventually finished and, after further satisfactory fibre-count checks, recommissioning checks and a high-voltage test by the MEB, all accommodation services were restored to normal on 16 March 1977, followed by the essential services on 23 March. From the decision to remove the asbestos to actual completion of the operation took almost exactly 10 months.

During the whole operation, the Factory Inspectorate was kept informed of proceedings. The complete project was covered by a form of critical-path chart but, because there were many unpredictable factors, it was not possible to work to pre-inserted dates. However, the chart did ensure that all aspects were adequately covered, responsibilities defined and tasks carried out in the right sequence.

The fact that the whole operation, which could have been fraught with many dangers and pitfalls, was brought to a successful conclusion is due in no small degree to the excellent team-work of all concerned. In particular, thanks must be extended to our Area Planning, Works and Power Maintenance and Stores staffs, WMTB Power Group, Midland Telecommunications Regional Workshops, the District Engineer of the MEB, and the ETE Power Group at Criggion Radio Station, not forgetting the forbearance of all the occupants of the building.

It will, of course, be realized that there was more involved in the whole operation than can possibly be conveyed by these short paragraphs. However, it is hoped that the reader has been given some idea of how one Area dealt with a rather unusual and somewhat hazardous operation.

Moving a Battery to Allow Access for Sealing Asbestos

D. TODD†

An unusual problem arose recently at a customer's installation when it was found that the apparatus room containing two 50 V batteries was constructed with walls of untreated sheet asbestos. To conform to present-day standards, the asbestos sheets needed to be treated by applying a sealant. Because the contractor was unwilling to work near lead-acid cells, it was necessary (at the contractor's expense) to move the batteries from their position against the wall. The batteries consisted of one 24-cell 250 A h installation and one 24-cell 60 A h installation.

It was decided to take the unusual step of moving the batteries complete, while still connected to the load.

Taking the appropriate precautions, the cabling was uncleated from the wall, and the larger battery was jacked clear of the floor using 2 trolley jacks borrowed from the local motor-transport workshop. The weight of the battery, estimated at 2000 kg, was distributed evenly over the jacks by pieces of timber. Then, by using 4 skates positioned evenly along the length of the battery rack, the battery was moved clear of the wall to allow the sealing treatment to be carried out. Fig. 1 shows a jack and a skate approximately in position under the battery. The battery was secured in its new position by again bringing the jacks into use and removing the skates.

Vertical stability during the operation was provided by roping the battery rack to overhead iron-work, and it was possible for 2 men to move the battery without difficulty and with safety.

† Southampton Telephone Area

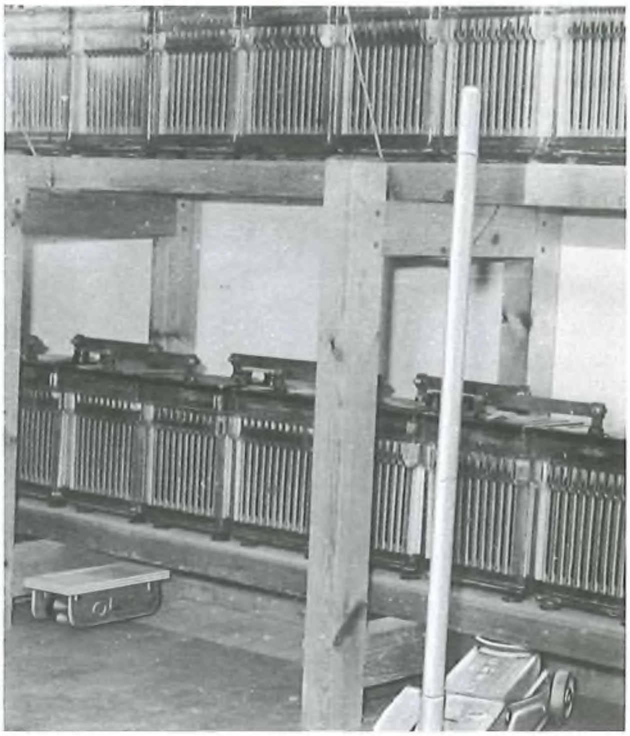

FIG. 1—Jack and skate approximately in position under battery

A similar process was used to move the smaller battery, and both batteries were restored to their original positions on completion of the wall treatment.

The whole operation proved to be considerably cheaper and quicker than providing temporary batteries, which is the more common method of avoiding interruption to service.

Lines for Lundy's Lights

H. FORD†

This Regional Note describes the work of providing an underground cable in difficult terrain on the not easily accessible island of Lundy.

INTRODUCTION

Lundy is an island about 5 km long and 1·25 km wide at its widest point, lying about 30 km west of Morte Point, near Ilfracombe on the North Devon coast (see Fig. 1).

Its precise location is Latitude 51° 10′ North, Longitude 4° 40′ West. This places the island well out into the Bristol Channel, and its length runs approximately north to south across this busy shipping lane. To safeguard ships using the Bristol Channel, 2 lighthouses exist on Lundy (Figs. 2 and 3). One is situated at the southern end above a rocky outcrop called Rat Island, and the other at the extreme northern end (North West Point). Between the two, there existed a telephone line consisting of open wire on 93 poles which, for the most part, ran along the western side of the island. About 9 poles were on the more sheltered eastern side, but the remainder were exposed to wind and weather from the Atlantic Ocean to the west. The term "more sheltered" is relative.

The line was installed in 1910 for Trinity House, who are responsible for lighthouses, and it can be imagined what a problem it has been for the British Post Office (BPO) to keep the line in good working order, bearing in mind that the service is classed as *emergency*. With 30 km of sea to cross, renewals of poles after 6-yearly tests have been difficult and expensive, aggravated by the fact that the island consists of granite, so that blasting was necessary when erecting poles. Linemen have, on occasion, had to visit the island to make

† Taunton Telephone Area

good temporary repairs made by willing lighthouse keepers, and have often been confined to the island by storms.

On 23 November 1974, a report was received that about one-third of the existing poles were in need of renewal, together with much of the overhead wire. It was also reported that Trinity House wished to have a more reliable circuit on which telemetering equipment could be used to control remotely the northern lighthouse. Furthermore, the Landmark Trust, which controls the island, expressed the view that, for aesthetic reasons, it would be pleased to see the poles removed.

SURVEY

The BPO agreed to carry out a survey and consider the engineering and organizational problems and costs of providing an underground line, including a reserve circuit. In September 1975, the survey was started, despite warnings from various sources that the island was "all granite". However, it has been recorded that Lundy had the biggest wheat field in England during the Napoleonic Wars, so that quite a large area must have been under the plough.

It became obvious that it was not possible to use the western side of the island because of the rocky nature of the terrain, but conditions on the middle of the island were more favourable, being suitable for moleploughing for a large part of the way.

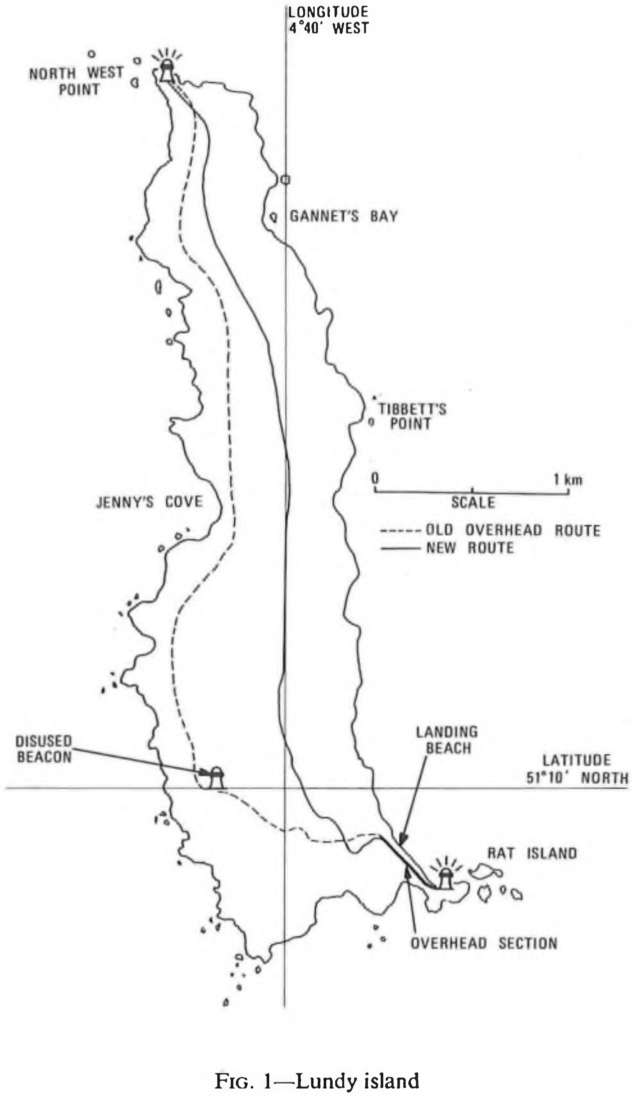

Fig. 1—Lundy island

The survey showed that 10 poles would have to remain at the more sheltered southern end of the island; the nature of the terrain there was such that to place a cable underground would involve too much expense. From fault records, local knowledge and on-site observations, it was realized that the effects of lightning could not be ignored. To minimize these effects, it would be necessary to place 4 conductors, earthed at each pole, above the 4 working conductors. Protectors would have to be fitted to the block terminals at each end of line.

Over the rest of the route, it appeared possible to bury the cable by moleplough, with some hand-trenching being necessary. At the survey stage, we expected to use blasting materials for about 150 m at the northern end of the island. It was realized that, for some distance, the cable would have to be shallow, with a minimum depth of 125 mm. To facilitate easy laying of shallow sections, an old moleplough was modified and fitted with a ploughshare.

LOGISTICS

In the meantime, Trinity House had offered to ship to the island the stores necessary for the underground line, plus the men, and also offered to let our party use accommodation on the island normally reserved for visiting Trinity House engineers.

At a meeting with Trinity House representatives, held on 20 January 1976, detailed costs, the advantages and disadvantages of the route, maintenance problems, fault reporting, the training of lighthouse keepers in testing and temporary fault clearing, installation problems and numerous other aspects were discussed and solutions proposed.

After some weeks, Trinity House accepted the BPO estimate, and a formal agreement was signed. The additional cost of placing the line underground was accepted by Trinity House in view of the many benefits, and would be offset by saving the cost of manning the northern lighthouse. Obtaining the wayleave to place the line underground presented very little difficulty.

Fig. 2—The southern lighthouse, viewed from the beach road

FIG. 3—The northern lighthouse

The external staff were mustered, the facts and problems were explained to them, and volunteers were called for. A party was chosen embodying a variety of skills including moleploughing, jointing, overhead construction and motor maintenance.

The working party sailed on 22 June 1976 from Swansea, this being the port nearest to Barnstaple available to the Trinity House vessel (THV) *Winston Churchill*. Our stores and men were all ashore on the island by that evening, much credit being due to the Trinity House sailors. Slings, especially provided for each piece of our equipment, were left attached for the duration of the voyage so that, on reaching the anchorage at Lundy, the slings had only to be hooked onto the ship's derrick and the gear lifted into the waiting Lundy tender and ferried ashore.

INSTALLATION

The moleploughing work was the first operation, and was quite successful. The blade of the plough buried itself to its full depth (about 600 mm) over much of the route, interrupted occasionally by large stones, some well over 50 kg; these stones either came out with the plough, or the plough steered itself round them. When the plough met granite, it was interesting to see the granite appear as small cubes in its track. Before the job was completed, the bolts holding the mole were worn and had to be replaced.

The moleplough fitted with a ploughshare proved its worth, especially near the northern end where the cable had to pass down a 90 m gully to the northern lighthouse, the slope being about 1 in 4. The plough was lowered into the gully and drawn upwards, so cutting a swathe in which the cable could be laid. The turf was subsequently turned back into place. Using the 2 ploughs, the job was completed sooner than expected.

It had been realized that a fair amount of hand-trenching would be necessary in rock, and we had expected to use the assistance of explosives. However, we were governed in this by the nesting of birds. A leading ornithologist expressed the hope that explosives would not be used until after 22 July. Rather than wait for this date, a compressor was brought into use and the rock was cut out. By this means, the cable was laid in steel pipe in a narrow trench to a minimum depth of 150 mm; in places, the pipe was cemented in.

The most difficult and arduous part of the work was in the overhead section. On the south-east corner of the island, the most difficult terrain over which the line passed, the poles were situated on steep slopes. Although provided with steps to ground level, these poles could be reached only after struggling up the slopes through heavy undergrowth. This work was done under the relentless sun which was characteristic of the summer of 1976 and, as the site was in the lee of the island, no cooling breeze relieved the heat. However, lying below the contours of the island, the overhead section should not suffer unduly from the effects of lightning, and the route is not too obtrusive on the landscape.

The new line came into operation on 13 July 1976. Following this, more than 80 poles from the old route were recovered.

The external work completed, the THV *Winston Churchill* was loaded for the return trip at 07.00 on 21 July, having arrived at Lundy on the previous evening to discharge supplies and stores for the lighthouses. It arrived back at Swansea at 16.45 the same day.

SERVICE ASPECTS

The insulation resistance was found to be extremely good, and the loss varied between 3·2–7·6 dB over the range 0·3–3 kHz.

To improve service facilities, the maintenance engineers at Barnstaple designed and installed a terminating panel, allowing easy access for testing and changing-over to the reserve line. A comprehensive but easily-followed programme for testing, changing-over and fault reporting was provided for use by the Trinity House keepers.

Lighthouse keepers have attended the South West Regional Engineering Training School to receive instruction on testing the line and effecting emergency repairs.

One effect of the 1976 drought was observed to be to our disadvantage. The Lundy rabbits, which are numerous, discovered that the otherwise hard and dry ground could be penetrated where we had disturbed the soil, and especially where large stones had been removed. The result was that the cable was uncovered in several places. However, after the next rains, the cable was buried again by the island's tractor.

CONCLUSIONS

The project of burying a cable on Lundy presented a challenge. To the BPO, suffering high maintenance costs on the old overhead route, there was an element of risk. The granite could have proved much more expensive to remove. The original line was a little unsatisfactory to the customer, and was certainly an eyesore to the conservationists.

The project was a fine example of cooperation between the customer and the BPO, with real endeavour on both sides to appreciate each other's problems. The end result appears to be to the advantage of both. Trinity House now has a good line at a reasonable price, and it should cost the BPO less to maintain. The line has been in service for 4 seasons, and has withstood gales from all points and several lightning storms, with no faults reported to date. Finally, the conservationists and others interested in the ecology of Lundy are also very pleased.

Tunnelling into History

R. HARPER†

It is said that the streets of London are paved with gold, and some Schedules of Reinstatement Charges appear to confirm this. Rarely, however, does subterranean London yield such historical treasures as were encountered in stage 2 of the Bishopsgate to London Bridge underground-cable link.

At the planning stage, the ductwork scheme was fairly straightforward, in as much as any job in the City of London can be described as straightforward.

At the time the Americans purchased the old London Bridge for transportation to Arizona, the British Post Office (BPO) took the opportunity to fill the box sections of the new bridge with ducts for future development. The time had come for 48 of these ducts to be extended along Gracechurch Street, past The Monument (commemorating the Great Fire of London in 1665), to Bishopsgate. Stage 2 of the scheme was a 438 m run in Gracechurch Street, virtually all of which was to be tunnelled.

Excavation work for the driving shafts excited the interest of experts in the Department of Archaeology at the Museum of London. They realized that the tunnel would pass through the site of the Roman forum (see Fig. 1), the construction of which commenced during 80–90 AD, and which was known to have been completed at the time of Hadrian's visit to Britain in the year 122 AD. The archaeologists had gleaned considerable knowledge of Roman London from excavations at various building sites in the vicinity, but had not previously had access to the forum itself. The museum staff were also elated at the prospect of tunnel archaeology which, unlike the fairly routine open-site explorations, is extremely rare, if not unique, in the UK.

With the agreement of the BPO's contractor, and after suitable indemnities and insurance cover had been arranged, the archaeologists were permitted to enter the tunnel during the miners' meal breaks, and also to sift through the excavated spoil, seeking historical clues.

The layman, expecting to see statues of Roman gods or chests full of Roman coins, would have been sadly disappointed, but the research team was in raptures over bits of white or pink concrete and fragments of grey pottery. The enthusiasm of the archaeologists was communicated to the national press and the London Broadcasting Company, and the possibility of a short television film was discussed for the BBC 2 *Chronicle* programme. This idea did not ultimately come to fruition because of the difficulties of filming in the confines of the 1·37 m high by 680 mm wide tunnel.

The forum was built in the shape of a square, with shops on 3 sides and the basilica (or Londinium Town Hall) on the fourth side. The shops were housed between the porticos of the buildings, and closely resembled the present-day shopping precinct. The basilica was approximately 150 m long and 15 m wide, and would have included a council chamber in which 2 magistrates would have occupied a raised dais at one end, from which they would have dispensed justice for minor offences and acted as arbiters in civil disputes. The BPO tunnel passed through the portico area, the basilica and the central courtyard, where fragments of material were found that indicated the presence once of a sunken decorative pool. This was regarded as a significant find by the archaeologists, who had not previously experienced this particular feature of Roman town planning.

† External Works Section, London Telecommunications Region

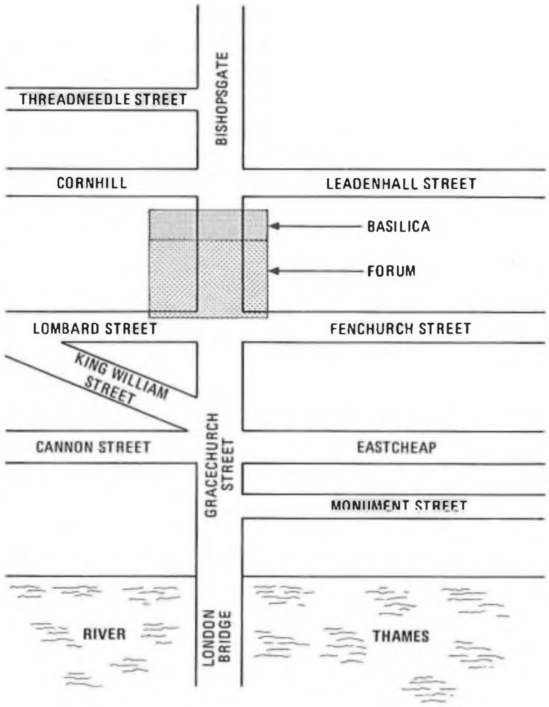

FIG. 1—Site of the Roman forum

The tunnel was driven at a depth of 6 m, which corresponded with the floor level of the basilica. The floor proved to have been soundly constructed in 500 mm white concrete, which is now showing signs of decay. It is interesting to speculate whether any BPO manholes will be found in similar condition by the archaeologists of 4000 AD.

The process of dissolution is thought to have started in about 400 AD when the Roman legions left the shores of Britain. Little is known about the ultimate fate of London's Roman settlement, but it is certain that, by the thirteenth century, the forum had disappeared from view, buried beneath several-hundred years' accumulated debris and soil deposited by the Saxons and Normans.

Relationships between the museum authorities, BPO staff and the contractor were excellent throughout the work, the cooperation of all parties resulting in a tremendous advance in historical knowledge without any delay to the work in hand. It was remarkable how the BPO and contractor Phillistines changed their discussion from, "Is this soft or hard rock?" to "Is this part of the basilica?" No greater tribute could have been paid to the infectious enthusiasm of the museum team. The archaeologists have now returned to the museum to publish a full report on their findings and to plot some of the missing lines on their site plans, this time with the alignments and dimensions measured to a high degree of accuracy.

I would like to thank Mr. Peter Marsden and his colleagues from the London Museum, P. Lowery Ltd. (the contractor), and the staff of City Telephone Area's Planning and Works Division for their help.

Institution of Post Office Electrical Engineers

RESULTS OF 1976–77 ESSAY COMPETITION

Prizes and Institution Certificates have been awarded to the following competitors in respect of the essays named.

The Council of the Institution records its appreciation to Messrs. R. H. Adams, J. Pritchett and J. Axon, who kindly undertook to adjudicate on the essays entered for the competition.

The prize-winning essays will be kept in the Institution's central library, and will be available to borrowers.

Section 1

Essays submitted by members of the Institution in all British Post Office (BPO) grades below the senior salary structure and above the grades defined in Section 2 below.

Prizes of £11

Mr. R. J. Kenworthy, Executive Engineer, Manchester Central Telephone Area: *Other Aspects of the TXE4.*

Mr. V. W. Baldwin, Executive Engineer, Telecommunications Development Department, Telecommunications Headquarters: *Call Supervision in the Large TXE Exchange Systems.*

Prizes of £6

Mr. L. W. Burkitt, Executive Engineer, North Eastern Postal Board: *The Quest for Automation in the Post Office.*

Mr. H. G. Gange, Assistant Executive Engineer, North West Telecommunications Board: *The Evolving Post Office.*

Prizes of £4

Mr. W. Findlay, Assistant Executive Engineer, Glasgow Telephone Area: *Early Days.*

Mr. E. G. Clayton, Assistant Executive Engineer, Norwich Telephone Area: *Industrial Democracy in The Netherlands.*

Mr. N. F. Hatton, Executive Engineer, South Western Telecommunications Region: *Standard Telephone Exchange Buildings.*

Mr. J. G. Wardle, Assistant Executive Engineer, Midlands Telecommunications Region: *PCM Switching Equipment.*

Section 2

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

Prize of £14

Mr. D. A. Heath, Technical Officer, Southampton Telephone Area: *The Future Transmission Network: Analogue v. Digital.*

Prizes of £7

Mr. D. MacDonald, Technical Officer, Aberdeen Telephone Area: *Highland Telegraphs, 1870–72.*

Mr. J. A. Wolden, Draughtsman, Manchester North Telephone Area: *Report on the M62 Emergency Telephone Installation.*

Mr. M. N. Fletcher, Technical Officer, Blackburn Telephone Area: *A Maintenance View of TXK1.*

Mr. K. P. Colville, Technical Officer, Scotland West Telephone Area: *The STC P1000 CT Common-Control Crossbar PABX—A Post Office Viewpoint.*

Prizes of £4

Mr. E. W. Fair, Technical Officer, Stoke-on-Trent Telephone Area: *Maintenance Aids for Trunk Tests.*

Mr. R. P. Churcher, Technician 2A, Sheffield Telephone Area: *The use of Computers in PO Telecommunications.*

Certificate of Merit

An Institution Certificate of Merit has been awarded to the following competitor.

Mr. F. Eastham, Technical Officer, Blackburn Telephone Area: *What Price a Wayleave?*

ESSAY COMPETITION, 1977–78

To further interest in the performance of engineering duties, and to encourage the expression of thought given to day-to-day departmental activities, the Council of the Institution of Post Office Electrical Engineers offers cash prizes totalling £50 and 5 certificates of merit in each of the following sections:

(*a*) the 5 most meritorious essays submitted by members of the Institution in all BPO grades below the senior salary structure and above the grades in (*b*) below, and

(*b*) the 5 most meritorious essays submitted by BPO engineering staff below the rank of Inspector.

Awards of prizes and certificates by the Institution are recorded on the staff dockets of the recipients.

An essay submitted for consideration of an award in the essay competition, and also submitted in connexion with the Associate Section IPOEE prizes, will not be eligible to receive both awards.

In judging the merits of an essay, consideration will be given to clearness of expression, correct use of words, neatness and arrangement. Although technical accuracy is essential, a high technical standard is not absolutely necessary to qualify for an award. The Council hopes that this assurance will encourage a larger number to enter. Marks will be awarded for originality of essays submitted.

Copies of previous prize-winning essays have been bound and placed in the Institution's central library. Members of the Institution can borrow these copies from the Librarian, IPOEE, 2–12 Gresham Street, London EC2V 7AG.

Competitors may choose any subject relevant to engineering activities in the BPO. A4-size paper should be used, and the essay should contain 2000–5000 words. A 25 mm margin should be left on each page. A certificate is required to be given by each competitor, at the end of the essay, in the following terms.

"*In forwarding the foregoing essay of ...... words, I certify that the work is my own unaided effort, both in regard to composition and drawing.*

Name (in block capitals) ....

Grade ....

Signature ....

Official Address ...."

The essays must reach

The Secretary,
The Institution of Post Office Electrical Engineers,
2–12 Gresham Street,
London EC2V 7AG

by 15 January 1978.

The Council reserves the right to refrain from awarding the full numbers of prizes and certificates if, in its opinion, the essays submitted do not attain a sufficiently high standard.

ELECTION OF MEMBERS OF COUNCIL, 1977–78

The results of the recent elections of Members of Council are given below, the names being shown in order of votes counted.

Membership Group 4: Mr. F. K. Marshall, Mr. J. Greenhill.

Membership Group 5: Mr. D. G. Rossiter, Mr. C. G. Williams, Mr. B. H. House, Mr. J. Storey.

Membership Group 12: Mr. C. Stanger, returned unopposed.

Membership Group 13: Mr. G. A. Gallagher, returned unopposed.

Membership Group 14: Mr. R. O. G. Clarke, returned unopposed.

Membership Group 15: Mr. K. Chinner, Mr. R. H. Quail, Mr. E. E. Jones, Mr. D. R. Norman, Mr. J. C. Clarke, Mr. D. A. Jenkins.

CONSTITUTION OF THE COUNCIL

The constitution of the Council for the year 1977–78 is therefore as follows.

Mr. J. F. P. Thomas, Chairman.

Mr. D. Wray, Vice Chairman.

Mr. C. E. Clinch, Vice Chairman.

Mr. C. F. J. Hillen, Honorary Treasurer.

Mr. E. W. Fudge, representing Group 1 (members in the Headquarters departments and the London regions holding posts in bands 1–8 of the senior salary structure).

Mr. J. W. Rance, representing Group 2 (members in the provincial regions holding posts in bands 3–8 of the senior salary structure).

Vacancy for representative of Group 3 (members in the Headquarters departments (London) holding posts in bands 9 and 10 of the senior salary structure).

Mr. F. K. Marshall, representing Group 4 (members in the London regions holding posts in bands 9 and 10 of the senior salary structure).

Mr. D. G. Rossiter, representing Group 5 (members in provincial regions and in the Headquarters departments (provinces) holding posts in bands 9 and 10 of the senior salary structure).

Vacancy for representative of Group 6 (members in the Headquarters departments (London) listed in Rule 5(a), with the exception of those in Group 14).

Mr. F. L. Brooks-Johnson, representing Group 7 (members in the London regions listed in Rule 5(a), with the exception of those in Group 14).

Mr. C. W. Read, representing Group 8 (members in the provincial regions and in the Headquarters departments (provinces) listed in Rule 5(a), with the exception of those in Group 15).

Mr. A. Haggerstone, representing Group 9 (members in the Headquarters departments (London) listed in Rule 5(b), with the exception of those in Group 14).

Mr. J. E. Rosser, representing Group 10 (members in the regions listed in Rule 5(b), with the exception of those in Groups 12 and 14).

Mr. R. C. Taylor, representing Group 11 (members in the provincial regions and in the Headquarters departments (provinces) listed in Rule 5(b), with the exception of those in Groups 13 and 15).

Mr. C. Stanger, representing Group 12 (inspectors in the London regions).

Mr. G. A. Gallagher, representing Group 13 (Inspectors in the provincial regions).

Mr. R. O. G. Clarke, representing Group 14 (Draughtsmen and above and Illustrators and above, but below the senior salary structure, in the Headquarters departments (London) and in the London regions).

Mr. K. Chinner, representing Group 15 (Draughtsmen and above and Illustrators and above, but below the senior salary structure, in the provincial regions and in the Headquarters departments (provinces)).

Mr. D. A. Barry, representing Group 16 (all affiliated members).

A. B. WHERRY

BIRMINGHAM, COVENTRY AND WEST MIDLAND CENTRE PROGRAMME, 1977–78

10 November: *Roadworks and the Post Office* by P. J. Chappell.

8 December: *Local Distribution—A Time for Change* by A. G. Hare.

9 January: *Waveguides* by W. K. Ritchie. (Joint meeting with the IEE.)

12 January: *Purpose and Methods of Financial Control* by A. Beaton.

9 February: *A Digital Switch* by G. Lawrence (GEC).

9 March: *Line for Network Planning* by J. W. Young.

6 April: *RSCs* by M. F. Arnold.

EASTERN (BLETCHLEY) CENTRE PROGRAMME, 1977–78

Except for that on 11 January, all meetings will be held in the cinema, Bletchley Park Regional Training Centre, commencing at 14.15 hours.

9 November: *Optical-Fibre Transmission* by I. A. Ravenscroft.

11 January: *The Human Factors in Telecommunications Projects* by P. James. (Joint meeting with the Colchester Centre at the Cambridge College of Arts and Technology, commencing at 14.00 hours.)

14 February: *The Will to Work* by R. J. L. Evans.

15 March: *The Main Network: Past, Present and Future* by A. W. Jones and K. E. Ward.

19 April: *Roadworks and the Post Office* by P. J. Chappell.

17 May: *Computer-Assisted Planning—The Way for the Future* by W. Edwards.

EASTERN (COLCHESTER) CENTRE PROGRAMME, 1977–78

Except for that on 11 January, all meetings will be held at the University of Essex. All meetings commence at 14.00 hours.

9 November: *Civil Aviation Authority* by E. G. Harris and A. J. Richardson.

15 November: Eastern Telecommunications Region IPOEE Quiz (details to be announced).

7 December: *Telecommunications On-Line Data (TOLD)* by L. V. Reinger.

11 January: *The Human Factors in Telecommunications Projects* by P. James. (Joint meeting with the Bletchley Centre at the Cambridge College of Arts and Technology.)

8 February: *Total Energy* by A. Mealing.

19 April: *Communications for Oil/Gas Production Platforms in the North Sea* by L. C. Nash and S. Hill.

NORTHERN IRELAND CENTRE PROGRAMME, 1977–78

16 November: *The Development of Digital Telephone Exchanges* by N. Lacey.

14 December: *Industrial Safety in the Post Office* by M. J. Lindsay.

18 January: *Telecommunications in the Republic of Ireland* by A. Mullen (Republic of Ireland Posts and Telegraphs Department).

15 February: *Optical-Fibre Transmission* by D. J. Brace.

15 March: *Inertia to Change* by H. J. C. Spencer.

12 April: *A Systems Approach* by E. A. McAleer (Queen's University, Belfast).

STONE/STOKE CENTRE PROGRAMME, 1977–78

Meetings will be held either in the lecture theatre, City Central Library, Hanley, Stoke-on-Trent, or at the Post Office Technical Training College (POTTC), Stone, and will commence at 14.15 hours.

7 November (POTTC): *Computers in Management and Society* by F. J. M. Laver (former BPO Board member).

5 December (POTTC): *The Role of Factories Division in the Post Office* by J. C. Spanton and W. L. Goldie.

9 January (Hanley): *The Impact of Electronics in the Local Network* by I. G. Morgan.

6 February (POTTC): *A Modern Approach to Engineering Training* by M. N. B. Thompson.

6 March (Hanley): *Transmission—Failure by Design* by R. G. Inns.

The Associate Section National Committee

Message from the Chairman of the National Committee

As the recently elected Chairman of the National Committee, I would like to pass on a short message to members.

Since its inauguration just over 6 years ago, the National Committee has largely overcome its teething problems, and is now consolidated as a committee comprising representatives from all regions and directorates. Its function is to serve the Associate Section as a whole by assisting individual centres as necessary, by co-ordinating effort, and by promoting competitions between centres and between regions.

Another service to affiliated centres, soon to be introduced, is the provision of insurance cover against personal accidents. All members will be covered while on Associate Section business, attending meetings and making visits (see the National Committee report below).

Travelling expenses for Associate Section members attending formal meetings of their local centres have been increased to a maximum of 90p, and may be claimed in accordance with the procedures given in Telecommunications Instruction M2 F0010, paragraphs 8 and 9, as amended by the notice on p. 423 of the *Post Office Gazette*, 18 June 1975, and further amended by the notice on p. 459 of the *Post Office Gazette*, 20 July 1977. Payment at the public transport rate for the use of private vehicles is also covered.

I wish good luck to all centres and regions.

E. W. H. Philcox
Chairman

The Associate Section National Committee Report

NATIONAL TECHNICAL QUIZ

The day before the annual conference, a meeting of regional quiz organizers took place to discuss the possibility of standardizing question papers, and it was agreed that each region would send at least 20 pairs of questions to the National Committee quiz organizer by 31 October 1977 for him to use in formulating papers for the next session of the regional quiz competition. It was also agreed that all regional quiz organizers would send in various old question papers for reproduction to help regional organizers in this year's regional sessions.

PROJECT COMPETITION

Three entries were submitted for the 1976–77 competition. At the judging, held during the May meeting of the General Purposes and Finance Committee, they were all found to be of a very high standard. The film by the Sheffield Centre, entitled *Make Someone Happy*, was about a customer applying for a telephone to be fitted, following the story through to the inaugural call, and this one turned out to be the winner. The other 2 entries were by Norwich and Colwyn Bay Centres, and both deserved the praise they received.

ANNUAL CONFERENCE

The annual conference was held at the Technical Training College, Stone, during May, and was very well attended with all regions being represented. The following officers were elected for 1977–78.

Chairman: Mr. E. W. H. Philcox (0234 61561).
Vice-Chairman: Mr. G. Rimmington (0472 43159).
Secretary: Mr. M. E. Dibden (0722 4850/5634).
Assistant Secretary: Mr. R. V. Parton (0785 45629).
Treasurer: Mr. D. B. Hickie (035 281 3190/3111).
Editor: Mr. B. Harlow (0742 732575).
Quiz Organizer: Mr. K. Marden (0204 35999).
Project Organizer/Visits Secretary: Mr. J. J. F. Anning (0626 3255).

1977–78 COMMITTEE MEETINGS

It was decided by the main committee to let only the General Purposes and Finance Committee meet during the coming financial year, to try to cut down on the travelling and high accommodation costs that are incurred for a full meeting. It is hoped that, with the publication of the News Sheet two or three times a year, centres will be kept up to date with the progress of the National Committee.

INSURANCE COVER

Negotiations for insurance cover for all affiliated centres are very near completion, and full details will shortly be circulated. Briefly, the cover is for death, loss of eyes, loss of limbs and permanent disablement. The cost of the policy will come from the present affiliation fee.

M. E. Dibden
Secretary

Associate Section Notes

ABERDEEN CENTRE

Our 1976–77 programme was concluded by visits to the British Petroleum oil pipeline control centre at Dyce and the Glenmorangie Distillery at Tain, and a talk on the coastguard service by Mr. Mickleburgh of the Aberdeen coastguard office.

Our annual general meeting and dinner was held on 20 May in the Atholl Hotel, Aberdeen. The elected office bearers for 1977–78 are as follows.

Chairman: Mr. J. A. Stephen.
Vice Chairman: Mr. R. G. Strachan.
Secretary: Mr. I. Pyper (telephone: Aberdeen 573451).
Assistant Secretary: Mr. J. H. McDonald.
Treasurer: Mr. R. Mathewson.
Librarian: Mr. B. G. Rae.

I. PYPER

CHESTER CENTRE

Silver Jubilee Exhibition

During 13–25 June 1977, Chester Centre opened to the public its Silver Jubilee Telecommunications Exhibition at Dee House, in the centre of Chester. The theme of the exhibition was the advances made in telecommunications during the first 25 years of the reign of Her Majesty Queen Elizabeth II. The stands included exhibits prepared by our members, together with borrowed items. All the organization, construction and design were carried out in the members' own time.

During the planning stages, 2 main criteria were formulated:

(*a*) that the exhibition would not just be a static display, but exhibits would consist of working equipment which the public would be encouraged to operate, and

(*b*) that exhibits would not necessarily be in chronological order, and that there would be no definite route for visitors to take; it was felt that, by doing this, visitors would feel relaxed and not be worried about seeing an exhibit out of sequence.

The exhibits covered most aspects of the engineering field, from Strowger to common-control exchanges, overhead to underground construction practice, candlestick to push-button telephones, and included Telex and Datel, and also models of early and new satellites. Some exhibits were built and designed by members to demonstrate various principles of telecommunications, and these were supplemented by a few professionally made models from Telecommunications Headquarters (namely, the Goonhilly No. 2 aerial, TELSTAR, INTELSAT IV and a crosspoint demonstration).

Exhibit illustrating local distribution and cable pressurization

The reaction of the general public was overwhelmingly favourable, with many glowing and complimentary comments written in the book provided. Several school parties attended, and the interest of pupils was stimulated when they realized that they were indeed invited to touch and operate the equipment. The favourite exhibits for such parties were the 5 + 20 cord-type and 2 + 4 cordless switchboards, which had most of the telephones on display working to them. Two teleprinters working back to back provided a great deal of interest to those who could type, and a continuous punched tape describing the centre's activities and aims was provided with a third teleprinter.

Another popular exhibit was a working pre-payment coin-collecting-box with a suitable supply of old pennies, and the amount of use made of all the earlier types of equipment clearly showed the interest and nostalgia attached to them by the general public.

The advanced techniques in systems such as pulse-code modulation, transit switching and Datel, which were explained on exhibit boards, impressed visitors, and most admitted they did not realize the extent and complexity of the work of the British Post Office.

The success of the exhibition was also due to the cooperation of our President, the General Manager of Chester Telephone Area, who provided a sympathetic attitude to the ambitions of the Centre, and made available the premises of Dee House, which were ideally sited to entice the many tourists who were in the city at that time of year.

As an additional feature, the Centre invited the Area Marketing Division to hold a sales exhibition in the same room. This added the jubilee version of the new *Compact* telephone, together with a display of office systems, to the Centre's exhibits, as well as earning revenue.

When the exhibition ended, the members felt the project had been worthwhile and that, judging by public reaction, there seemed to be a need for this type of exhibition from time to time.

D. G. RICHARDSON

DUNDEE CENTRE

In February 1977, our programme continued with an unusual look at police work through a lecture given by a finger-printing expert from Tayside CID. Examples of the various types of clue left at the scene of a crime were displayed, ranging from finger-prints on newspaper to prints from the traditional friends of the burglar—gloves. Both clues had resulted in convictions.

March saw the end of our 1976–77 session. Perhaps a fitting ending was the talk on beer and brewing given by a representative of Scottish and Newcastle Brewers. The talk was enhanced at question-time by the inclusion in the audience of a member of the Campaign for Real Ale. After sampling the company's new lager, the resulting conflict was declared a draw, neither admitting to the other's point of view.

G. K. DUNCAN

EXETER CENTRE

At our annual general meeting, held on 21 April 1977, the following members were elected as officers and committee for the 1977–78 session. Mr. J. Gregory, General Manager of Exeter Telephone Area, kindly accepted the office of President for the second successive year.

Chairman: Mr. J. J. F. Anning.
Vice Chairman: Mr. C. K. Sanders.
Secretary: Mr. J. W. Clark.
Assistant Secretary: Mr. G. E. Tout.
Treasurer: Mr. I. C. Elston.
Librarian: Mr. R. E. Allen.
Committee: Messrs. J. Brown, I. P. Lightfoot, J. Tucker, D. N. Miller, W. J. West, C. L. Reynolds, P. A. Tilley, and G. W. W. Abbott.

Our 1977 summer programme commenced with 6 evening visits to the Devon and Somerset Gliding Club at Broadhembury. The interest was so keen during the 1976–77 session that it was decided to repeat the previous programme, enabling the members who were disappointed last year to take part in the gliding this year.

During the last week in July, an all-day coach trip was arranged for a visit to the Whitefriars glassworks in the morning, followed by the Kodak photographic processing factory in the afternoon. Unfortunately, the number of members had to be limited to 20. It was a long day for our colleagues at Torquay, who had to start at 05.00 and who returned at approximately midnight. Our future programmes may incorporate similar long-distance visits, if these prove not to be too much of an ordeal.

J. W. CLARK

IPSWICH CENTRE

After completing a full programme for 1976, which the committee arranged in a determined effort to get the Centre back on an even keel, Ipswich Centre moved into 1977 with renewed enthusiasm.

The year began with a film evening in January. In February, an evening talk was given by one of our members on the tall ships' race. Also in February, an inter-departmental darts evening was held, which some 150 members and guests attended.

The programme continued with a visit in March by some 40 members to Southampton; 20 members visited the British Post Office (BPO) cable-ship depot, and the rest visited a private marine depot. In April, 128 members and friends attended the annual dinner and dance.

The annual general meeting (AGM) was also held in April, and the following officers and committee were elected for the 1977–78 session.

Chairman: Mr. B. Plant.
Vice Chairman: Mr. D. R. Ford.
Secretary: Mr. K. R. Phillips.
Assistant Secretary: Mr. G. M. Boulding.
Treasurer: Mr. F. Arnold.
Librarian: Mr. K. C. Baskett.
Committee: Messrs. C. Page, T. Woodward, C. Hammond, L. Rust, K. Baker and P. Barber.

The AGM continued with a presentation to the winner of a hobbies competition, and ended with a sausage supper.

In May, our members visited Vauxhall Motors at Luton, which proved an interesting visit. We were able to see the BPO's Bedford vans being produced.

A full programme has been organized for the rest of the year.

K. R. PHILLIPS

LONDON CENTRE

During the 1976–77 session, London has had an active year. Visits numbered about 50, and included Hawker Siddeley, Ford Motors, Brennell Engineering, Welbeck crossbar exchange, a Honeywell computer, and many others, not forgetting Guinness' brewery; I think half the Associate Section attended the last visit. Talks and films shared in the year's activity, the main lecture of the year being given in South Area by Professor Merriman. Films seem to have had a disappointing audience this year, mainly due to the cost.

Amateur radio has taken a hold within London during the last session; we now have 4 stations on the verge of being active, and one station in North West Area is already active. During the summer of 1976, North West Area represented London Centre at a Scout camp in the New Forest. North West provided a demonstration transmitting station for a fortnight for the Scouts. At the camp were Scouts from the Continent, and they used to come to the radio station in the evening in the hope of a contact with their homelands.

The annual conference this session was held at the Institution of Electrical Engineers in London; the number of members attending was well above average. There were 3 award winners this year, 2 were C. W. Brown award winners: Mr. D. T. Denchfield from Centre Area, and Mr. A. Lane from North Area. A merit award was given for the first time, to Mr. P. Corrigan of North West Area. The evening ended at the Tower Hotel for the C. W. Brown celebration.

The programme for the 1977–78 session has so far comprised a lecture at Fleet Building in September on the subject of System X. On 9 November, a talk will be given by the London Centre Chairman, Mr. R. A. Gray, on the life and times of the Associate Section; this promises to be an interesting evening. At a date yet to be arranged, a talk on air disasters will be given by Mr. N. V. Clark, the London Centre Treasurer. Mr. Clark gave a very good talk on this subject during the last session.

We are very disappointed that Prince Charles cannot, as we had hoped, grace the Associate Section with his presence later in the year; with all the pressures of the Queen's silver jubilee, the Associate Section cannot be fitted in this year. We have hopes for the future.

East Area represents London in this year's National Technical Quiz, and has the best wishes of every Area in London.

L. WOOD

MIDDLESBROUGH CENTRE

Our annual general meeting was held on 19 April 1977. The Chairman, in his report, commented on the problem of poor attendances at meetings. The Secretary reported the events of the past session, which consisted of visits to the Middlesbrough sorting office, the Phillips communication system for the Ecofisk oil fields, and the Peter Black car museum. Lectures delivered during the session were *Radio Telephones*, *TXE4*, and the regional lecture at York. The following officers were elected for the coming session.

Chairman: Mr. W. K. Brown.
Vice Chairman: Mr. W. Outhwaite.
Secretary: Mr. K. Whalley.
Assistant Secretary: Mr. R. D. Purvis.
Treasurer: Mr. P. K. Harrison.
Librarian: Mr. F. Thistlethwaite.
Committee: Messrs. I. Tyreman and D. A. Pratt.
Auditors: Messrs. L. Fysh and R. Oliver.

Suggestions for next session's programme were received, and it was decided to publish a library list in the next session's programme.

K. WHALLEY

NORWICH CENTRE

Our 1976–77 programme included a third visit to a Nottingham coal mine, together with visits to docks at Chatham and Felixstowe. There was also a visit to the British Post Office (BPO) Research Centre at Martlesham.

Evening lectures have ranged from *Modern Telephone Switching Systems* to *A History of Norwich Telephone Area*; included on the way were *The Development of Firearms* (with demonstrations) and *An Exchange Visit to Norway*.

We congratulate David Payne, our Vice Chairman, on winning the BPO prize for the Advanced Telecommunications course at Norwich City College, D. Houghton for winning the intermediate-year prize, and D. Foxhall on being awarded the Silver Medallion of the City and Guilds of London Institute for Advanced Computer Principles.

The 1977–78 programme is being compiled, and we hope to include visits to Vauxhall Motors and a local electrical switchgear manufacturer.

R. D. CAVE

Notes and Comments

CORRESPONDENCE

Microwave System Comm. Div.,
Telettra,
Vimercate (Milan),
Italy.

Dear Sirs,

First of all, we would like to compliment you and the authors on the most interesting survey of radio-relay systems in the British Post Office (BPO), published in the October 1976 and January 1977 issues of your journal (*A review of the BPO Microwave Radio-Relay Network* by Messrs. R. D. Martin-Royle, L. W. Dudley, and R. J. Fevin). We feel it provides a pleasant, thorough and useful summary background for anybody involved in microwaves.

The purpose of this letter is to request a small detail on the subject of availability.

Since availability, A, is defined as

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

(where MTBF is the mean time between failures and MTTR is the mean time to repair) and, in Part 2 of the article, data have been provided covering objectives and achievements for A as well as for applicable MTBF figures, would it be possible to have an indication of the MTTR assumed in setting the objective for A, and of the actual applicable MTTR through which the achievements of A have been attained?

We would be most grateful to the authors for any elaboration on the subject of MTTR in the BPO; this would help us in a survey we are conducting on the above subject, which is stirring a lot of interest within CCIR† circles.

Thank you.

Yours very sincerely,

P. Antoniucci

For the information of readers interested in this subject, the authors' reply to Sr. Antoniucci is reproduced below.

Telecommunications Headquarters
British Post Office.

Dear Sr. Antoniucci,

Thank you for your letter and your kind comments regarding our article.

We hope it is not too apparent that we found great difficulty in covering in sufficient detail, within the space allotted, the large number of aspects of microwave radio-relay systems which we thought would be of interest. Frankly, we admit that some subjects suffer from brevity, and perhaps reliability is one of these. However, we are pleased to take this opportunity of further explaining our procedures.

Dwelling first on the definitions, that for availability (given on page 231 of the article) strictly applies to the equipment (for example, an active unit) and is not valid when protection is taken into account. Then, service availability is more applicable but, in this case, the MTTR is of little use and one is more interested in the mean time to restore service (MTRS). It is this point which had to be omitted from the article.

The BPO's maintenance policy relies on the provision of protection channels, automatic switches and a comprehensive stock of spare exchangeable units held at convenient points. This developed from the early 1950s, when the BPO microwave network was set up to carry television; long breaks, coupled with poor MTBFs inherent in electronic-tube equipment, could not be tolerated. The prime objective is to restore service in the event of faults. A first fault is normally protected automatically, but replacement of the faulty unit is immediately initiated in order to restore the protection facilities to normal. In the event of a second simultaneous fault, again restoration of service is the main objective and, in this case, may involve manual intervention to change a panel, but it rarely involves the immediate repair of faulty units. Thus, there is less pressure on faulting and repair than there would otherwise be. You will observe that, with this procedure, the emphasis shifts from needing to know the MTTR to monitoring the MTRS.

The MTRS allows time for travelling, which may be required in some circumstances, as well as the time to effect the restoration of service. You may be interested in the achieved figures for MTRS given in the table.

Year	1970	1972	1973	1974	1975	1976
Restoration Time (min)	42·4	30·6	25·4	18·5	13·3	15·4

Unfortunately, at present, we have no data on the MTTR but, as exchangeable shelf spares are provided as a matter of policy, the turn-round of faulty units is only of particular interest if there are problems with certain units such that the fault rate is higher than can be accommodated by the repair service. A high proportion of repairs is carried out on site at the radio stations, but there is an increasing tendency to change to a fault repair service from centralized depots.

I hope this better explains our procedures. Thank you again for your interest.

Yours sincerely,

R. D. Martin-Royle
L. W. Dudley
R. J. Fevin

† International Radio Consultative Committee

Publication of Correspondence

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

Letters of sufficient interest will be published under Notes and Comments. Correspondents should note that, as it is necessary to send copy to the printer well before publication date, it will be possible to consider letters for publication in the January issue only if they are received by 7 November 1977.

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

SPECIAL ISSUES AND BACK NUMBERS

Copies of the April 1974 issue covering sector switching centres, and the October 1973 special issue on the 60 MHz transmission system, are still available.

Back numbers can be purchased, price 70p each (including postage and packaging), for all issues from April 1973 to date, with the exception of October 1975. Copies of the July and October 1970, and the April 1972, issues are also still available.

The July 1970 issue contains articles on local transmission planning, the lives of plant and depreciation, and simple metal-oxide-semiconductor logic circuits. The October 1970 issue contains articles on local telephone-cable design, call-failure detection equipment, and standard video transmission equipment. The April 1972 issue contains articles on the Goonhilly aerials, the Leighton Buzzard TXE1/TXE2/TXE6 exchange, and humans in postal engineering.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG. Cheques and postal orders, payable to "*The POEE Journal*", should be crossed "& Co." and enclosed with the order. Cash should not be sent through the post. A self-addressed label, accompanying the order, is helpful.

APPEAL: OCTOBER 1975 ISSUE

The editors would appreciate the return of spare and unwanted copies of the October 1975 issue of the *POEEJ* (Vol. 68, Part 3). Surplus copies, complete with the model-answer Supplement, should be returned to Mr. Hunwicks, Ground Floor Lobby, 2–12 Gresham Street, London EC2V 7AG.

Local-centre secretaries are asked to draw members' attention to this request.

CORRECTION

In the article *Meteorological Operational Telecommunications Network: Europe*, published in the July 1977 issue of the *POEEJ*, the mercury-wetted relay referred to on p. 124 has a break-before-make action, and not a make-before-break action as stated.

REGIONAL NOTES AND SHORT ARTICLES

The new style of presentation given to Regional Notes since the July 1977 issue has been more than matched by the quality and interest of contributions published as Regional Notes or as short articles, and the Board of Editors is happy to encourage contributions of this nature.

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 editors, printer and illustrators, and help ensure that author's 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 Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Post Office Press Notices

WORLD'S FIRST COMMERCIAL WAVEGUIDE SYSTEM

The world's first commercial waveguide system, capable of carrying half-a-million simultaneous calls, is to be installed by the British Post Office (BPO). A waveguide will link Bristol and Reading in a £7M project due to become operational by 1983.

"With this new system—in advance of anything comparable anywhere else in the world—the Post Office is again making telephone history," said Sir Edward Fennessy, formerly Deputy Chairman of the BPO and Managing Director: Telecommunications. "To have developed this waveguide to commercial exploitation from scratch is a tremendous achievement for the Post Office's Research Department and the firms—BICC and Marconi—who collaborated with us."

The millimetric waveguide system has been thoroughly described in recent issues of the *POEEJ* (Apr. 1976, July 1976 and Jan. 1977).

The decision to go ahead with the world's first commercial use of millimetric waveguide is the culmination of a decade of research by the BPO into this system. It was carried out as part of the BPO's continuing study of new telecommunication systems to meet growing demands for existing services, and to prepare for new services. The BPO will shortly be starting discussions with Marconi for the supply of the electronic equipment, BICC for the waveguide, and the British Steel Corporation for the manufacture of the steel pipe in which the waveguide is housed.

Detailed planning of the 125 km Reading–Bristol route is now under way. To increase the security of the system, 110 km of the route will go across open country.

The waveguide will be housed in a continuous steel pipe of 100 mm diameter. Construction and laying of the pipe is due to start in 1979, for completion in 1980. Installation of the waveguide will then follow immediately afterwards, to be finished by 1981.

Five repeaters will be needed, at roughly 20 km intervals along the route. Installation of this equipment is scheduled for 1982.

The proposed waveguide system will, at Reading, be provided with links to the 60 MHz cable system, over a spur of the cable from Reading to High Wycombe. At Bristol, connexions will be made from the waveguide to cable and microwave radio links to south-west England and South Wales. These connexions will include links to the new satellite communications earth station at Madley, and to the existing earth station at Goonhilly.

SOLAR-POWERED TELEPHONES

Telephone service to a warden's post in a bird sanctuary in East Anglia has been powered by solar panels for the past 2 years, and the experiment has been such a success that the British Post Office may extend the system.

The solar panels recharge the batteries which provide power for a very-high-frequency (VHF) radio link from the customer's telephone to the exchange. Even on cloudy days, it is still possible for the solar panels to collect enough energy to power the system. There are many VHF radio links in the country which could use this energy-saving method.

VHF radio is the only practical way telephone service can be provided to people living in the more sparsely-populated parts of the country. Normally, VHF links are both expensive to install and maintain. By using solar panels to recharge the batteries which power the radio link, maintenance is much easier, with inspection trips being made every 3 months instead of every 3 weeks. This is particularly important in Scotland, where maintenance trips can involve hours of travelling, often to islands without a scheduled boat service.

At the Blakeney Point bird sanctuary, near Cley-next-the-Sea, Norfolk, it has been shown that, even during the winter, the solar panels—located on top of a 9 m pole so that no shadows fall on them—can produce enough power to recharge the batteries.

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Employees of the British Post Office can obtain the *Journal* through local agents.

Binding

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Remittances for all items (except binding) should be made payable to "*The POEE Journal*" and should be crossed "& Co."

Advertisements

All correspondence relating to advertisement space reservations, copy, proofs etc., should be addressed to Betty George, Advertisement Manager, The Kemps Group, 1–5 Bath Street, London EC1V 9QA (telephone: 01-253 5314 or 01-253 3871).

Distribution and Sales

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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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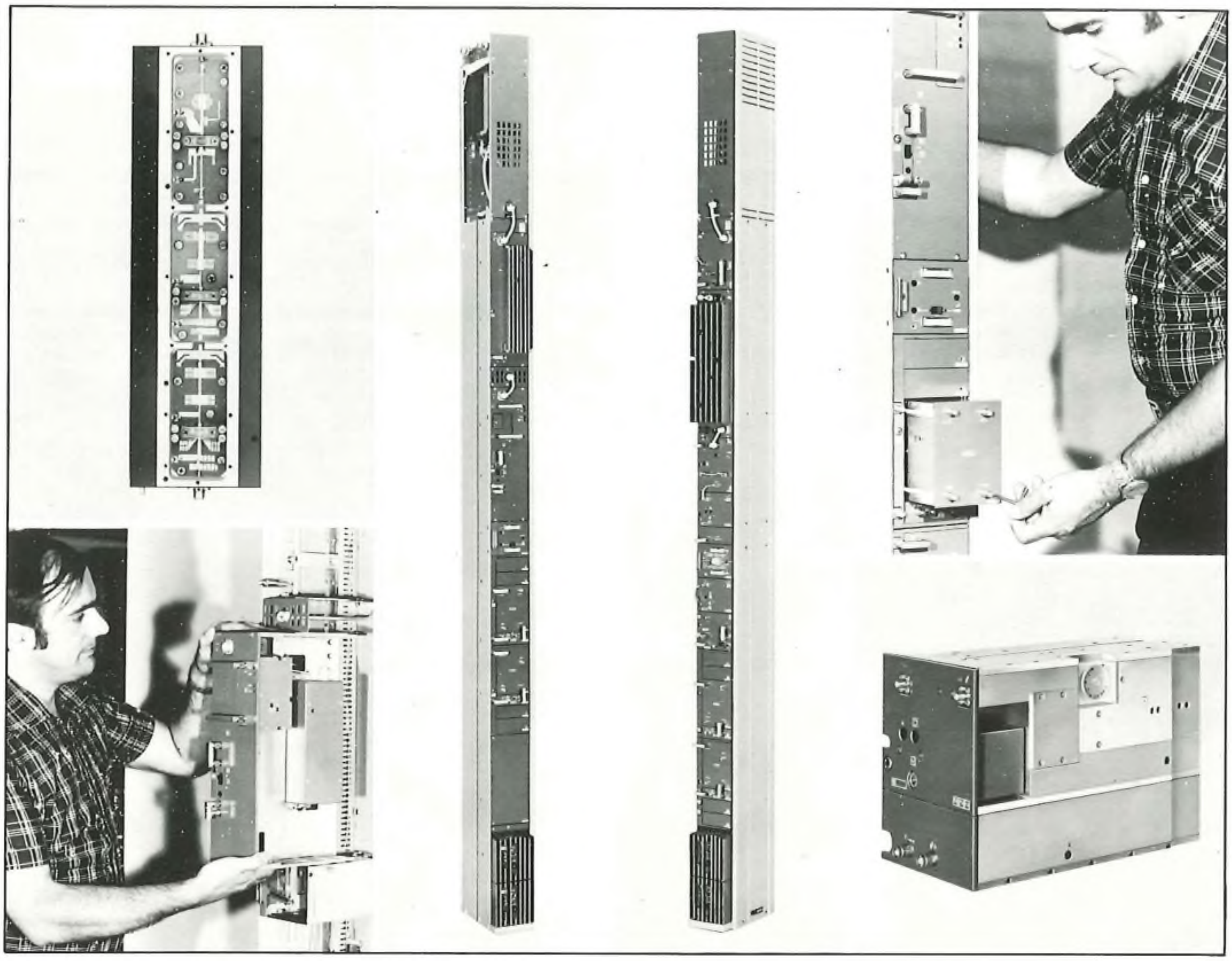

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