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Contents

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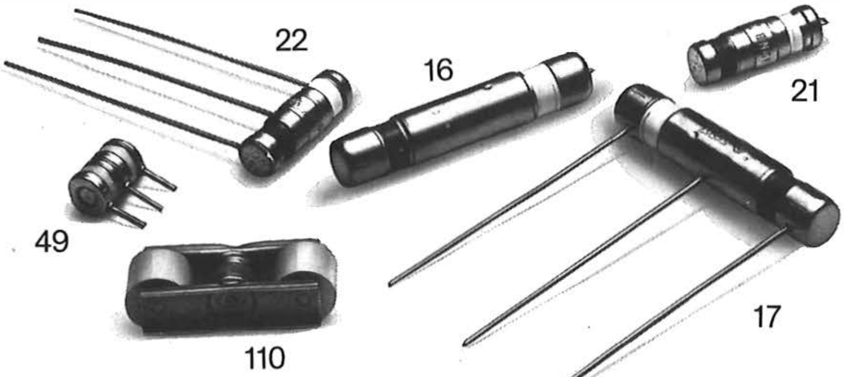

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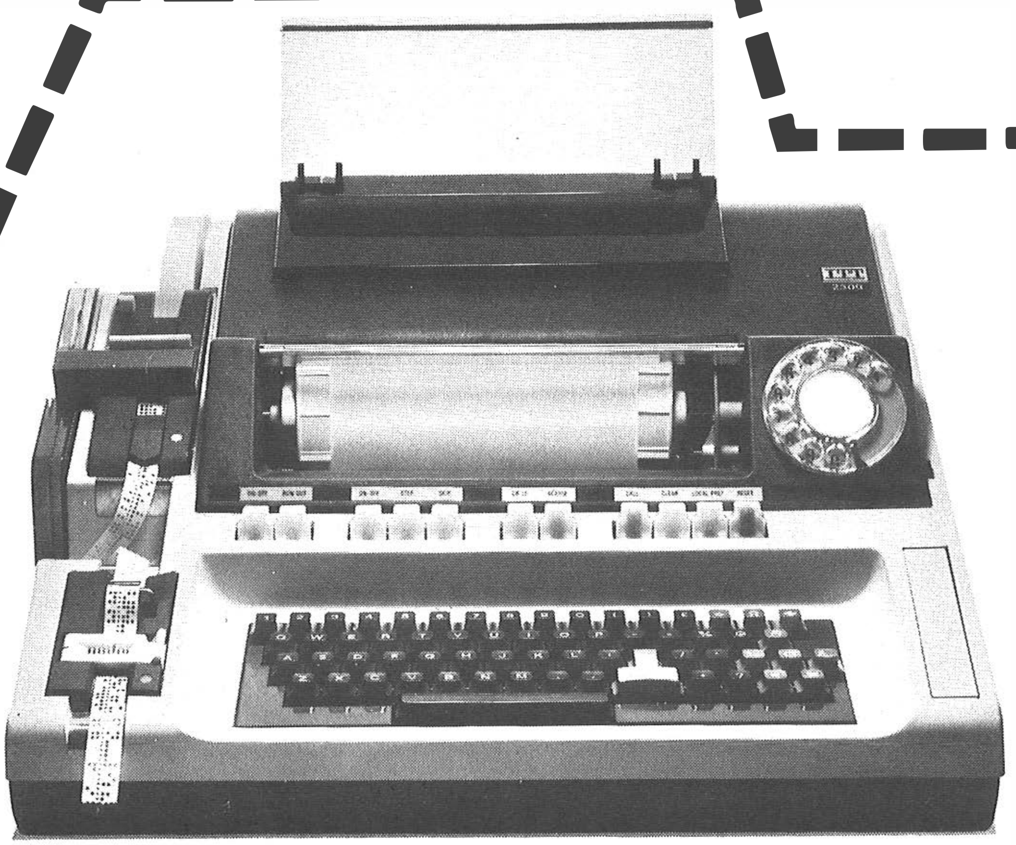

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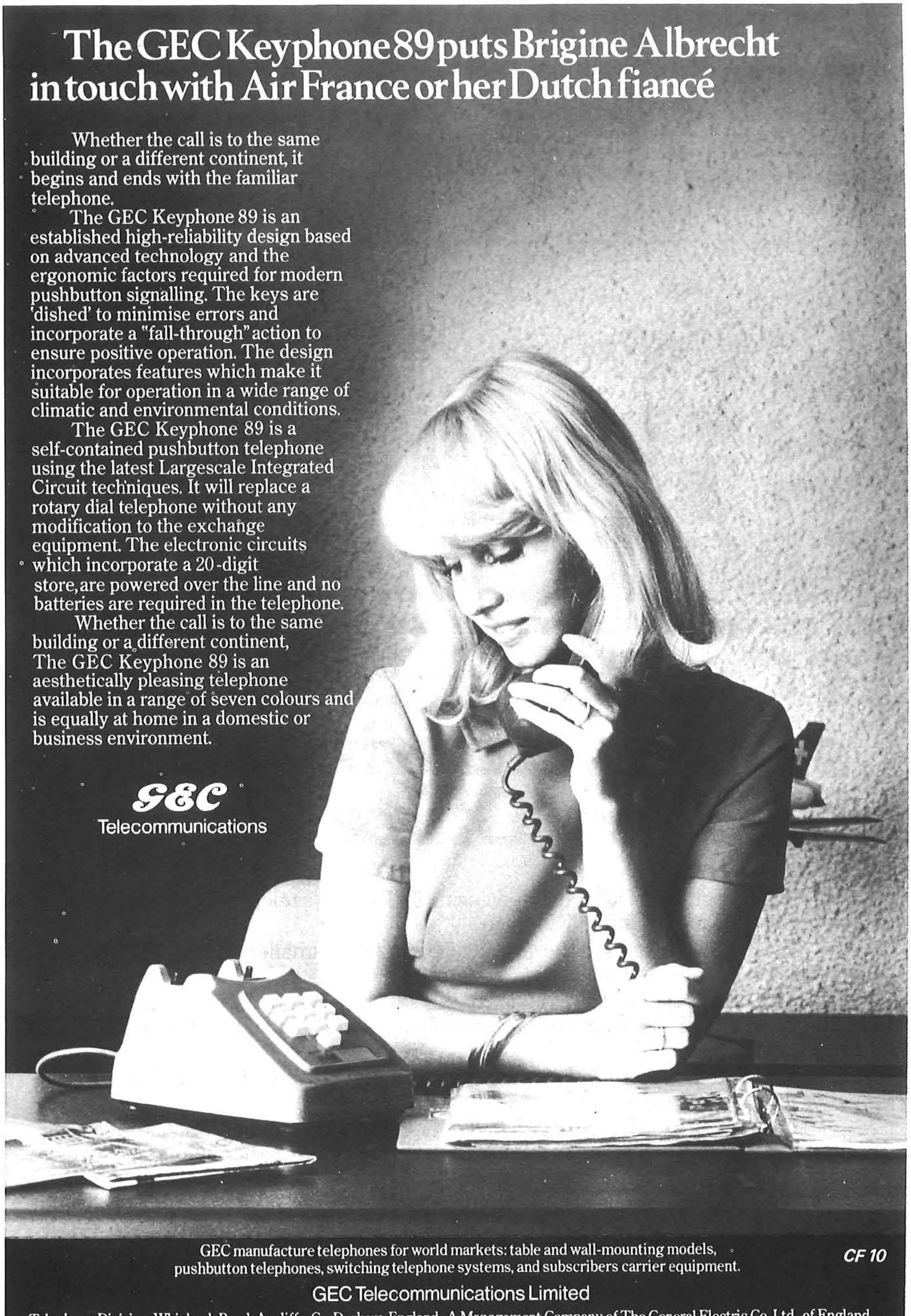
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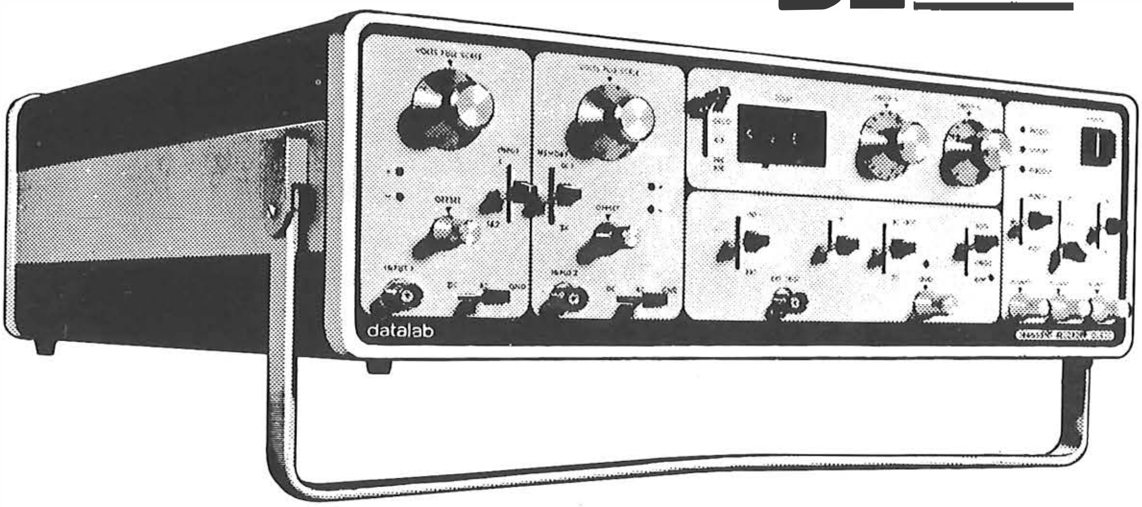
waveform storage with a DL922



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The Post Office Electrical Engineers' Journal

EDITORIAL

British-designed digital-switching telephone exchanges are to be installed in the UK telecommunications network by the end of 1981. The first exchanges to be installed will be small local exchanges; the installation of digital trunk and junction-type exchanges will follow. Collectively, the family of digital exchanges is known as *System X*.

System X is a major development for the future enhancement of telecommunications services and facilities to customers, and will provide the switching element of an integrated network of digital transmission and switching systems. The design and development aspects of the System X project were established only after many years of collaboration between the British Post Office and its main switching-equipment suppliers—GEC, STC and Plessey. System X has been designed to be competitive on world markets.

The article on page 221 of this issue of the *Journal* commences a series of articles that will describe the engineering and technical aspects of System X.

The *Supplement* to this issue is devoted entirely to the coverage of Level 1 Technician Education Council (TEC) and Scottish Technical Education Council (SCOTEC) courses. For the first time in nearly 50 years, the *Journal* breaks with its tradition of publishing model answers to City and Guilds of London Institute (CGLI) examination questions. However, in parallel with our coverage of TEC, we shall continue, from the next issue of the *Supplement*, to provide coverage of CGLI subjects (at least until the last re-sit examination of a CGLI subject has been held in the UK).

The operations of the TEC are vastly different from those of the CGLI, and we are conscious of the need for our material to accord with the TEC's methods. We shall aim to complement studies in the classroom and laboratory. In broad terms, we shall be aiming to devise and publish model questions representative of the style and standard being used in colleges all over the country, and provide model answers exactly as would be expected of students. The article on page 264 of this issue explains the philosophy of the *Journal*'s coverage of TEC and SCOTEC courses. We will accept (and indeed invite) discussion of our coverage through our correspondence columns.

Microprocessor Peripherals

D. L. GAUNT and R. T. LAMB, B.SC., M.PHIL.†

UDC 681.31—181

This article describes the operation of the major peripheral devices that are used with present-day designs of microprocessors.

INTRODUCTION

Previous articles in this *Journal*[1, 2, 3] have described the operation and use of microprocessors. Although more and more components are being placed onto a microprocessor integrated circuit (IC), resulting in today's *single-chip microprocessor*, it is still rare for a single device to prove sufficient to control a complete system. To cover this deficiency, a wide variety of peripheral ICs has been produced. It is the purpose of this article to describe the operation of the major peripheral devices used with present-day designs of microprocessors. No particular manufacturer's products will be described, the general modes of operation being common. It will be assumed that the reader is familiar with the operation of a basic microcomputer system.

BUFFERS

Buffer circuits represent the most basic of the peripheral devices. Indeed, it may be argued that they are not peripherals at all since they are necessary for the effective functioning of all but the simplest of microprocessor-based systems, enabling the central processing unit (CPU) to interface with the other elements of the system. There are two potential problems of interfacing, either or both of which may be met in a particular system; these are, inadequate driving power and incorrect signal levels. Data and address buses are most likely to be subject to these problems, but the control and timing bus may also need buffering.

Because of the high density of component packing on the CPU chip, the output transistors are physically small in size and hence limited in the power that they can dissipate. The limitation is usually shown as a maximum current that the device can provide (source) or accept (sink) for particular output levels. The problem is most acute for devices fabricated in metal-oxide-semiconductor (MOS) technology, in which the transistors have an intrinsically higher impedance. For small systems, using only small amounts of memory (either as read-only memory (ROM) or random-access memory (RAM)) and a few input or output ports, the bus loading may be within the driving capability of the CPU; but, as the amount of memory or input/output ports is increased, the CPU drive capability is exceeded on the address and data buses. The situation is worst where an MOS-fabricated CPU has to drive bipolar devices, but the use of other MOS components in the system does not necessarily improve matters because the higher input capacitances of MOS transistors create greater transient loads on the drive transistors. It must be remembered that, even though the CPU is addressing only one device at a time, the disabled inputs of all the other devices and, in the data bus, any high-impedance tri-state outputs (that is, they can be set to logic high or low when the chip is enabled, or the third, high-impedance state when disabled), all contribute to the loading of the CPU.*

When all the components of a system are fabricated by the same process, this situation will lead normally to a common set of logic levels with tolerances that are acceptable to all devices within the system. However, if technologies are mixed, the different devices in the system may have different logic level needs, which may be met by appropriate buffering. This is most likely to occur when MOS devices interwork with bipolar components such as transistor-transistor-logic (TTL). The present trend is to make MOS fully compatible with TTL, but one of the most widely-used microprocessors during the past 3 years does not have this compatibility, and many others currently available require clock signals which are not TTL-compatible, even though their logic signals are.

Both types of problem can be overcome by means of buffer amplifiers. On the address bus, a simple unidirectional buffer is all that is needed (see Fig. 1), but on the data bus, a bi-directional arrangement must be used, as shown in Fig. 2. Each line of the bus requires its own amplifier or pair of amplifiers, and all amplifiers for a particular direction of signal transfer must be enabled together. However, for the bothway or bi-directional buffer shown in Fig. 2, only one direction must be enabled at any time, otherwise the buffers will tend to oscillate. Most microprocessors generate a control signal that indicates whether it is reading in from a system or writing out to it; this facility can be used to provide, say, the *enable-in* signal while its complement (inverted signal) forms the *enable out* signal.

The buffer amplifiers may be realized in various ways. At one extreme, they may be designed using discrete components, although this is an extravagant use of space and is not to be recommended. A better approach would use some of the wide range of standard logic circuits that exist in both TTL (the 54/74 series) and MOS. These can meet both power and level requirements, although for some of the MOS circuits, pull-up resistors may be needed to obtain the requisite high levels, and there may be a need for additional logic to control the enabling signals. At the other extreme, it is possible to obtain specialized bi-directional bus-driver integrated circuits, intended for use in microprocessor systems. Although these are produced by one manufacturer as a support chip for a particular microprocessor, they can be used to buffer a wide variety of microprocessors and may prove the cheapest solution to buffering problems.

† Telecommunications Personnel Department, Telecommunications Headquarters

* Although these remarks on the subject of loading are concerned with the effect of a large system on the CPU, it will be realized that they may be applicable equally to other parts of a large system and particularly the memory chips. Hence, the need for buffering may not be confined to the CPU alone

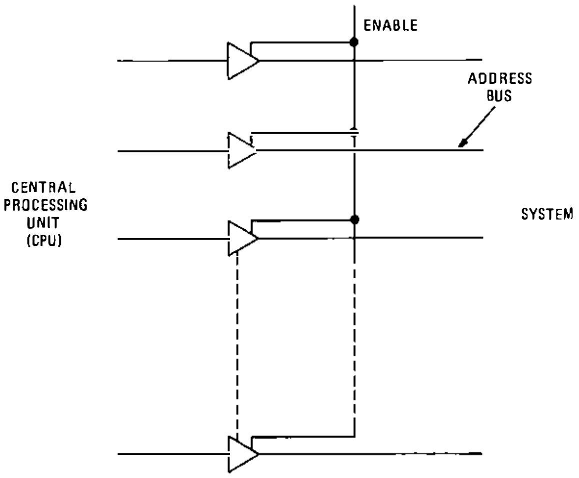

FIG. 1—Unidirectional buffering arrangement

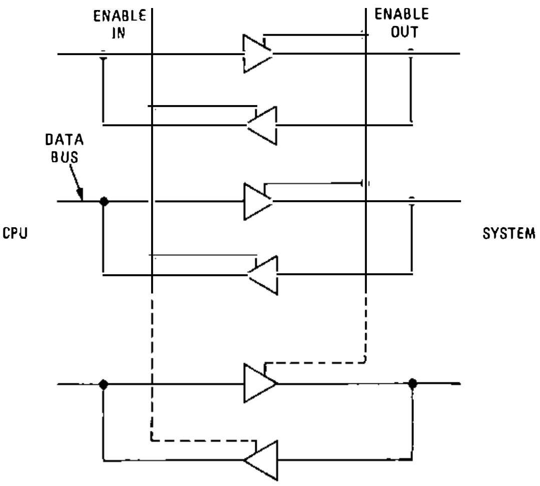

FIG. 2—Bi-directional buffering arrangement

COMMUNICATION AT A MICROPROCESSOR INTERFACE

Communication between a microprocessor and external devices is achieved via one of two circuit arrangements at the microprocessor interface: either by input/output ports, or by memory-mapped input/output ports.

Communicating via Input/Output Ports

The circuit arrangement for microprocessor access via input/output ports is shown in Fig. 3. Access to a particular input or output port is achieved by a combination of signal conditions on the address and control buses. In Fig. 3, four control lines are shown from the CPU; the information conveyed on these control lines determines which type of operation is to be performed, and Table 1 shows how this information could be decoded. For example, to pass information from the CPU to output port 6, the code 00000110 (06 hex) is placed on the low-order 8 bits of the address bus and the *port write* line is taken high. Data then passes from the CPU via the selected output port to the external data lines.

Input/output ports are easy to use and occupy no memory space. However, they are limited in their data-handling capability. In many systems, simple transference from port to accumulator is all that can be achieved, although some now allow limited logic manipulation, and a choice of destination/source register.

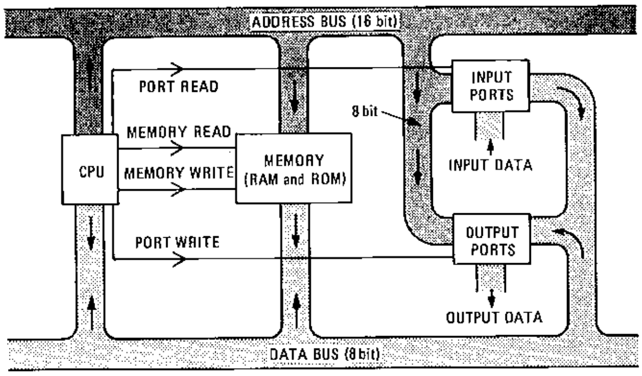

FIG. 3—Microprocessor access via input/output ports

TABLE 1

Examples of Control-Line Signals for Selected Operations

Control Lines				Operation Selected
Memory Read	Memory Write	Port Read	Port Write	
1	0	0	0	Memory Read
0	1	0	0	Memory write
0	0	1	0	Port read (input data)
0	0	0	1	Port write (output data)

Communicating via Memory-Mapped Input/Output Ports

Using the memory-mapped input/output circuit configuration, the input/output is treated as if it were part of the memory. As shown in Fig. 4, the selection between memory and input/output is made by address line A_{15} (A_{15} high selects the memory, whereas A_{15} low selects the input/output)†. Three further address lines allow 8 different input/output devices to be selected. Using an address line in this way is simple, but is wasteful of available memory space. If more

† In microprocessor terminology, the terms *high* and *low* are now in common use and refer to logic state *one* and *zero* respectively

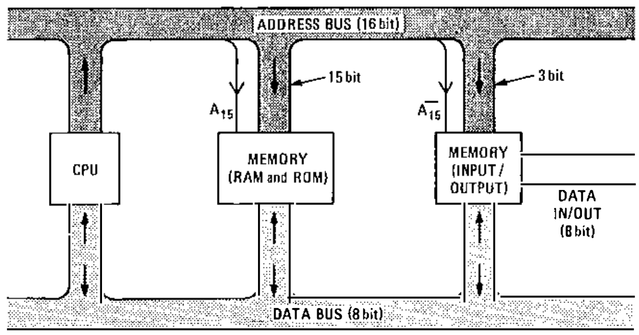

FIG. 4—Microprocessor access via memory-mapped input/output ports

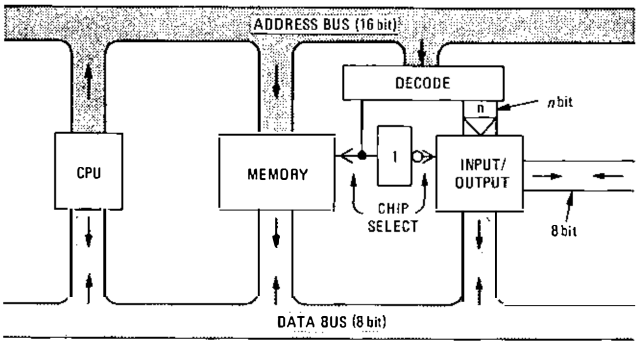

FIG. 5—Separate decoding of address lines

than 32 kword of memory is needed, separate decoding of address lines must be used; this is illustrated in Fig. 5.

Having an input/output port as a memory location allows all of the available memory reference operations in the processor's instruction set to be used on input/output.

INTERRUPT

Interrupt lines allow a microprocessor to continue working during the time that any external devices that are connected to the system do not require attention. For example, a paper-tape reader requires the services of the CPU only during the time that it wishes to transmit a character to memory.

A typical interrupt sequence is shown in Fig. 6. (For ease of description, the signalling functions are labelled *a–e* and *A–H* on Fig. 6 and these references are used in the text.) The external device requests attention by sending an *interrupt request signal* (*a*) to the interrupt control. The interrupt control checks on the priority of the interrupting device and, if this is satisfactory, passes the *interrupt request signal* (*b*) on to the CPU. This request is very likely to arrive while the CPU is partway through an instruction. Acknowledgement of the interrupt (*c*), known as *handshaking*, is then delayed until the current instruction has been executed. When the interrupt control does receive an acknowledgement, it places on the CPU data bus a bit pattern that is treated by the CPU as an instruction (*d*). As far as the CPU is concerned, it has received an instruction in the same way that it would have received one from the memory. The instruction changes the CPU's program counter so that it points to the appropriate interrupt subroutine. This process is called *vectoring* and the instruction is known as an *interrupt vector*. From this point on, events are software controlled (that is, program controlled). The sequence described below is typical of many systems, but each microprocessor has its own variant.

Having called the interrupt vector subroutine (*B*), and saved the return address on stack (*A*), a further call is made to the subroutine which deals with the interrupting device (*C*), and (*D*). The reason for this double call is that there will be more than one interrupt subroutine, each one starting a few locations further on in memory. Thus, any interrupting device that requires a subroutine of more than a few steps would overlap the next interrupt vector start address; this may not matter, for example, when there is only one interrupting device. Some microprocessors have the capability of providing a variable interrupt-vector start address, thus removing the need for a double call.

The interrupt subroutine will send/receive data from the interrupting device (*e*). The control line for send/receive data may or may not come via an interrupt control, the source will depend upon the type of interrupting device and the type of input/output used.

After the interrupt subroutine has been completed, control returns to the main programme (*E*) to (*H*).

PRIORITY INTERRUPT

In a system that has a number of devices that are capable of interrupting, some of these devices may be more important than others. In this situation, it is necessary to ensure that the most important interrupts have priority. This process, called *priority interrupt*, can be achieved using a subroutine in the program, or by using logic circuits. There are 4 main types of interrupt-priority structure.

Fixed Hierarchical Priority

In the fixed hierarchical priority structure, each interrupting device is assigned a priority level. Interruption of the CPU cannot occur until a higher priority interrupting device has been serviced. A higher priority device can always interrupt a lower one. An example is given in Fig. 7, in which priority level 1 is the highest priority.

Rotating Priority

The rotating-priority method of allocating priorities is used when all devices have equal priority. The method is analogous to a roulette wheel with a pointer. The device being "pointed

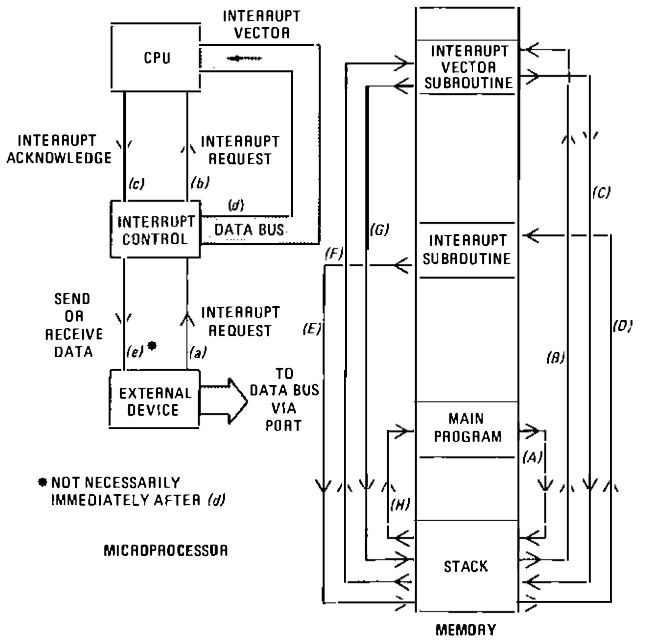

FIG. 6—A typical interrupt sequence

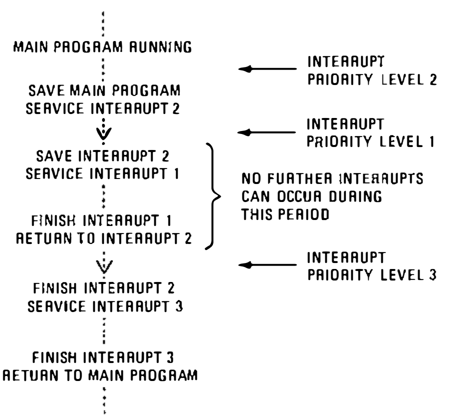

FIG. 7—Example of a fixed hierarchical priority structure

DEVICE	PRIORITY
6	6
5	5
4	4
3	3
2	2
1	1

INITIAL PRIORITY

DEVICE	PRIORITY
6	4
5	3
4	2
3	1
2	6
1	5

DEVICE 2 INTERRUPTS

DEVICE	PRIORITY
6	1
5	6
4	5
3	4
2	3
1	2

DEVICE 5 INTERRUPTS

FIG. 8—Examples of a rotating-priority sequence

at" has the lowest priority, the priority of all other devices being assigned in a ring formation. As soon as another device interrupts, it becomes lowest priority, and so on. Examples of the rotating priority sequence are given in Fig. 8; the priority level 1 is the highest priority level.

Assigned Priority

An assigned-priority structure is achieved by a combination of software and hardware. Allocation of priorities is done by software programming, while hardware logic performs the implementation. The advantage of this method is that priorities can be modified while the program is running.

Polling

The polling-priority structure is usually implemented in software. Each device is inspected, in turn, to see if it requires attention. The advantage of this approach is that it is simple to use, but it is wasteful of CPU time, since it must be run continuously.

PROGRAMMABLE INPUT/OUTPUT DEVICES

In a simple microprocessor system, the input or output ports may be realized by a simple buffer-chip, which is enabled from an address decoder whose outputs are tri-state. Thus, when the processor is to provide an output, the address bus carries the code that enables the appropriate chip, and data on the data bus is transferred to the output of the buffers and hence to the terminal device.

However, the terminal device may both accept and generate data at different times, or it may not require access to all lines on the data bus. In such cases, the programmable input/output chip may offer a better method of interfacing. Such chips are known as *programmable interface adapters* (PIAs) or *programmable peripheral interfaces* (PPIs). At present, three or four such devices are available from different manufacturers, but all offer similar facilities and have similar operation. A typical block diagram for one of these chips is shown in Fig. 9.

The chip has a number of input/output lines with associated buffers and latches or registers, grouped as two or three ports, each 8 bit wide (two ports are shown in Fig. 9). These ports are connected by a data bus to a bothway-bus buffer, to which the CPU data bus is also connected. The chip data bus is also connected to the control registers. There is a control register for each associated group of input/output lines, and internal logic allows the control registers and their associated circuitry to determine the functions of the input/output lines. External control lines connect to the CPU's control bus on one side, and to the external system on the other. Address lines are connected either to the address bus or to a decoder. Thus, the chip can be both addressed and controlled by the CPU and, at the same time, interfacing signals, such as interrupts or their acknowledgement, are provided for the external system.

Unlike the simple input/output port, however, it is not

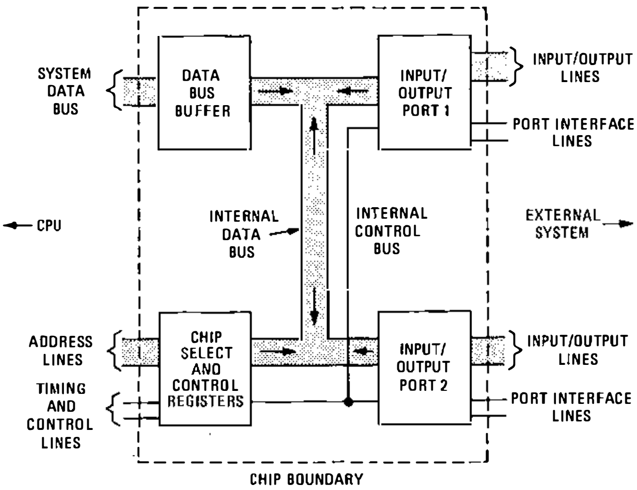

FIG. 9—Programmable input/output chip

enough for the CPU to address and enable the chip. Before it can be used, its function must be set by the appropriate program, a process known as *initialization*. This is done by inserting, either in the main program or a subroutine, a series of *memory-write* or *output* instructions (depending on the input/output structure), which transfers the appropriate words to the control registers. Each control register on the chip has a unique address, in either the memory or the input/output; to initialize this register, its address is output on the CPU address bus and the command word is placed on the CPU data bus. Then, the command word is transferred on the chip's internal data bus from the data-bus buffer to the control register.

The command word determines the function of the port associated with the control register; that is, it determines whether the port is to act as an input or an output (or, in some cases, as a bi-directional port), and it determines what interfacing signals are necessary or permitted (for example, whether interrupts are allowed). In some devices, individual lines can be programmed separately; in this case, two or three command words need to be written in to the device to complete the initialization of the port. Generally, it is not necessary to initialize all the input/output lines or ports if only some are needed for use.

Once the requisite initialization has been done, the associated port can be used to perform the pre-programmed function. Like the control registers, each port has a unique address in either the memory or the input/output, and responds accordingly when addressed by the CPU. However, at any point in the microcomputer's program, it is possible to re-address the control registers and change the programmed function of the ports by over-writing with a new command word, giving the PPI or PIA a versatility not possessed by the simple input/output port.

UNIVERSAL SYNCHRONOUS/ASYNCHRONOUS RECEIVER-TRANSMITTER

The universal synchronous/asynchronous receiver-transmitter (USART) has an extremely long name for something which performs a relatively simple function. That function is to convert a serial data stream into a parallel form or vice-versa. A typical use for a USART is to allow a Teletype to communicate with a processor. The Teletype uses an 8 bit code,† 7 bits of which are used for character information

† The 8 bit code is the USA standard code for information exchange—referred to as ASCII

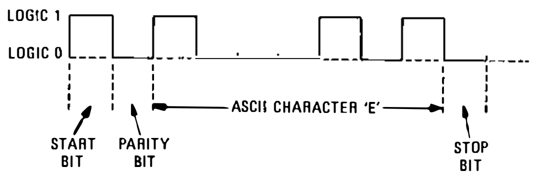

FIG. 10—Character information code

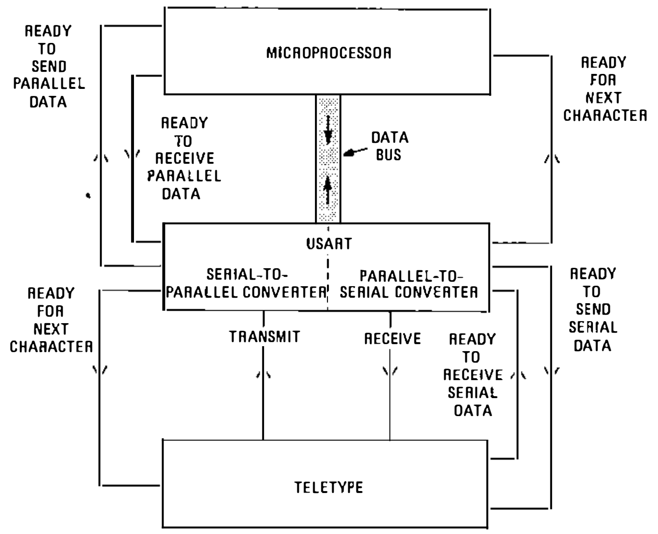

FIG. 11—Signal format at the USART interface

coding and 1 bit for parity. In addition, there are start bits at the beginning, and stop bits at the end of each character (see Fig. 10). The functions performed by a USART in the communication process between a Teletype and a microprocessor are stated below and shown in Fig. 11.

Teletype to Microprocessor

When a Teletype conveys information to a microprocessor, the USART

(*a*) stores the serial data as it arrives, ready for transmitting in parallel form,

(*b*) removes the start and stop bits, leaving only the 8 bit code,

(*c*) signals to the microprocessor when the parallel data is ready for transmission,

(*d*) places the character on to the data bus when the microprocessor responds to the *ready to send parallel data* signal, and

(*e*) if needed, sends a *ready for next character* signal to the Teletype.

Microprocessor to Teletype

When information is passed from a microprocessor to a Teletype, the USART

(*a*) receives the 8 bit parallel character from the data bus,

(*b*) signals to the Teletype that it is ready to send,

(*c*) commences sending serial data, adding start and stop bits as appropriate upon receipt of an *acknowledge* signal from the Teletype,

(*d*) indicates when transmission is complete, and

(*e*) at some time, (not necessarily at (*d*)) indicates to the microprocessor that it may send another character.

Other Types of Serial-Parallel-Serial Conversion

Although the ASCII code is a commonly used code in microprocessor systems, it is not the only one, nor is the Teletype the only serial input/output device. Therefore, some USARTs are programmable by means of code words entered into registers within the USART. These code words allow a wide range of devices and speeds to be used. For example, if the operating speed is slow, a Teletype terminal would most probably be used; for medium speed operations, a line printer would be needed; at fast speeds, a visual-display unit would be an appropriate terminal. Also, the number of character bits can vary between 5 and 8 bit, and the number of stop bits may be 1, 1½ or 2 bit.

DIRECT MEMORY ACCESS CONTROLLERS

In most currently available microprocessors, data to be output has to be held in the accumulator (that is, the register to which the result of an arithmetic or logic operation is transferred). Thus, if a block of processed data is held in the RAM and is to be output, each word in the block has first to be transferred to the accumulator and then to the output port, requiring 2 instructions, each at least 2 bytes long, per word. The converse is true for the input of blocks of data. If the device receiving or originating the blocks is slow in operation compared with the CPU, this 2-stage process is unimportant but, if the peripheral device has a speed comparable with that of the processor, the delay resulting from the method of transfer may be a problem. In that case, direct memory access (DMA) may be required, and a DMA controller chip is often the cheapest way of providing it. As the name implies, DMA provides direct connexion between the peripheral device and the microcomputer's RAM, but since the RAM is connected to the data and address buses, it follows that the CPU must relinquish control of these buses during a DMA transfer. Thus, the DMA controller must take on this function, but the problem of addressing is simplified since the data block will normally occupy a consecutive series of locations in RAM. For DMA transfer to be made, only 4 items of information are needed: the direction of transfer; the input/output port address; the starting address of the data block in the RAM; and the number of bytes within the data block. These form the basis of the programming of the DMA controller.

For several types of microprocessor, DMA is controlled by the CPU itself: for others, the control is by a separate chip. Two essentially different approaches to the problem exist. In the first, the DMA controller has a number of channels, each of which is connected continuously to a single device (such as a floppy-disc storage unit) to or from which DMA transfer may be made. A block diagram of such a chip is shown in Fig. 12. Only 2 channels are shown, but more may be provided.

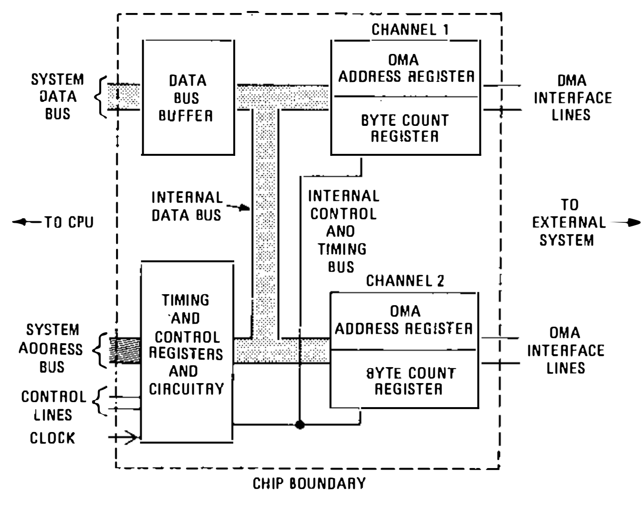

FIG. 12—A DMA controller

The channel registers and any additional control registers in the timing and control section are given addresses within the input/output or memory map. The channel registers are typically of 16 bit capacity and so are initialized in 2 consecutive *memory write* or *output* instructions. Both the DMA address register and the byte count register must be initialized for any channel. Again, it is not normally necessary for all channels to be initialized, and an additional command word in the control register is used to enable only those channels which have been initialized. The DMA address register holds the starting address in RAM of the data block, and the byte count register holds the number of bytes to be transferred. The direction of transfer, either input, output or verification (that is, comparison of data without transfer) is held either in the control register or in 2 bit of the byte count register, depending on the particular device. Finally, the input/output port information is inherent in the association of each channel with one particular external device. Since only one channel is in use at any instant, only the associated input/output port is activated, and the control signals generated by the DMA controller ensure that the correct operation is performed. It should be noted that this type of controller does not handle the data to be transferred. Thus, if a block of data is to be read from an external memory device and written into the system RAM, when the external device is ready to begin transfer, it must place a suitable signal on the DMA request line of the channel to which it is connected (it is assumed that the channel has been initialized and enabled). The control circuitry generates a signal requesting the CPU to stop processing (the *hold request* signal) and the CPU ceases operation at the appropriate moment. The CPU register contents are retained, and its bus outputs are switched to the high-impedance condition. This is known as *floating the buses*. The DMA controller now has control of the system, and loads the appropriate memory address on the address bus, as well as producing the signals which enable the input port and which cause the memory device to write the data on the data bus into the addressed location. Circuitry within the DMA controller increments the contents of the DMA address register and decrements the contents of the byte count register. When one byte has been transferred, control is returned to the CPU but, if a DMA transfer request is still present on the channel, further *hold requests* are generated and this results in the transfer of more bytes.

When the byte count register reads zero, no further transfers can be made through that channel until the registers have again been initialized. An output may be generated when this condition occurs, informing the external device that no further transfers are to be made. This is necessary when blocks of data are to be transferred, since the total storage capacity of the external device (say, a magnetic-disc unit) normally exceeds the size of the block.

The alternative approach to DMA is shown in Fig. 13. This is a single-channel device, but since it incorporates 2 address registers, A and B, it can be programmed for the whole range of transfers of data that mayoccur. Thus, register A holds the address of the source of data, and register B the address of its destination. There is, though, a major difference of operation in that the controller first carries out a *read* operation from the address defined by register A and, then, maintaining the data on the system data bus by means of the bus interface circuitry, carries out a *write* operation at the address defined by register B. This means that the data may be regarded as being transferred through this type of controller.

The rest of the operation resembles that of the type first described, with signals interfacing to the external device, and a byte count register programmed to keep track of the number of bytes that have been transferred. The DMA controller also produces the control signals needed for the *read* and *write* operations and interfaces to the CPU through *hold request* and *acknowledge* signals. One difference worthy of note is that incrementing or decrementing of the 2 address registers is not automatic, but is under the control of the program. If, for example, the transfer is to be from an input port to system memory, then the register A address needs to remain fixed, and the register B address needs to be incremented with each byte transferred.

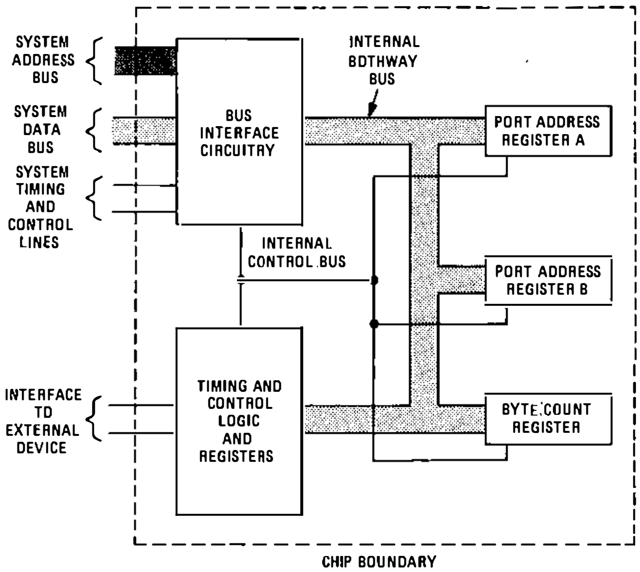

FIG. 13—A DMA controller (alternative approach to that shown in Fig. 12)

INTERVAL TIMERS

In early microprocessors, to produce trigger pulses, square waves, delays, and other timing information, it was necessary to use external circuits. In later designs, it became possible to simulate these circuits using software, but it is not always easy to get the desired accuracy, also this method uses up program space. The interval timer was developed to utilize the best of both worlds in that it has hardware timer circuits which are software programmable.

The principles of operation of an interval timer are illustrated in Fig. 14. Firstly, select lines are set to receive a control word; this word, when decoded, decides the mode of operation. Next, the data word that is used for timing is

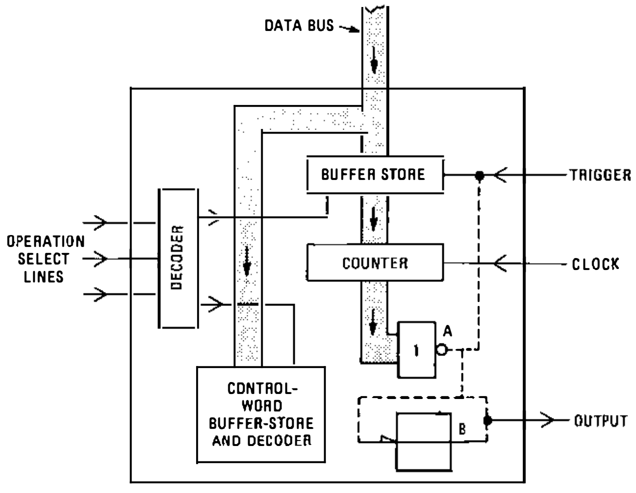

FIG. 14—Interval timer

loaded into the buffer store. When a *trigger* is activated, the data word is transferred to the counter and timing can begin.

There are many ways in which the timer may be used. Examples of interval timer applications are: monostable pulse generation, provision of divide-by-*n* functions and square-wave generation. The action of a timer in providing these functions are described below.

Monostable Pulse Generation

The sequence of operations for the interval timer to function as a monostable pulse generator is:

(*a*) the appropriate control word is loaded,

(*b*) the appropriate data word is loaded, (width of the pulse is equal to the clock period, multiplied by the number in the buffer store),

(*c*) the trigger pulse transfers data to the counter, output from A (see Fig. 14) goes high and remains high until the counter registers zero, and

(*d*) process (*c*) is repeated every time that a trigger pulse is received (that is, the monostable is re-triggerable).

Divide-by-n Function

The sequence of operations to enable the divide-by-*n* function is

(*a*) the appropriate control word is loaded,

(*b*) the appropriate data word is loaded,

(*c*) the trigger pulse transfers the data word to the counter, and

(*d*) when this count is zero, a single pulse is produced at A (see Fig. 14); this pulse re-activates the trigger line and action (*c*) above is repeated.

Square-Wave Generation

The sequence of operations for the interval timer to function as a square-wave generator is the same as that for the divide-by-*n* function except that the output pulse at A (see Fig. 14), is taken via a bistable, which produces a square wave at B. The timer circuit may first divide the input data word by 2; that is, it is shifted to the right one place. The total period of the square wave is now determined by the data word. However, an odd number will produce an asymmetric output.

SINGLE-CHIP MICROCOMPUTER PERIPHERALS

To be capable of working as a single-chip microcomputer, the chip must contain many of the functions described in previous sections, albeit in a limited form. Thus, a typical device might contain (apart from a CPU) the following:

(*a*) 1 kbyte of ROM,

(*b*) 64 bytes of RAM,

(*c*) 3 × 8 bit input/output ports (that is, 24 bothway lines),

(*d*) an interval timer, and

(*e*) an interrupt control.

Surely then, the single-chip device, by definition, needs no peripherals? This is not so. It is possible to expand both memory and input/ouput when needed. Since, however, the data and address buses do not normally appear on the output pins, multiplexing is necessary, using some of the original input/output lines. When this is done, limited expansion is possible. If expansion is necessary, the system should be carefully evaluated to see if a conventional microprocessor system would be more efficient.

BIT-SLICE MICROPROCESSOR PERIPHERALS

It is reasonable not to class the 12 or so chips that comprise the CPU element of a bit-slice microprocessor as peripherals. If this is accepted, then the requirements of the bit-slice system dictate the need for peripheral devices such as have been described.

FUTURE PERIPHERALS

There are some peripheral devices too specialized to include in this article; for example, cathode ray tube controllers. The complexity of these devices can well exceed that of the CPU itself. The trend for the more common peripherals which have been described, however, is to include more and more on the CPU chip. Interrupt control and bus driver are standard items on modern microprocessors. Another trend is towards provision of an analogue interface on a microprocessor. One such device, with an analogue/digital converter on-chip is already being marketed.

A further approach is towards what one manufacturer has called *the universal peripheral*. This is essentially a microprocessor in its own right, whose function is to be programmed as a peripheral device only. If this trend continues, the future may see chips with perhaps 6 or so microprocessors included, all of which can be programmed to undertake dedicated tasks.

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Book Review

Private Electronic Switching Systems; Conference Publication No. 163. Institution of Electrical Engineers, viii + 214 pp. 180 ills. £12.00

As the title indicates, this publication collects together all the papers read at the international conference held in London in April 1978.

Naturally, because the papers are all self contained, there is some lack of continuity, and there is little grouping of papers with similar or related themes. Further, the only index in the publication is by author, and this makes the location of papers on specific subjects difficult. Nevertheless, the publication is a collection of papers covering most of the world's new PABX systems and techniques. It is not a text book, but it does provide a good cross-section of the state of the art, with papers on customer needs and benefits; complete system descriptions; design philosophies for hardware, software, components, transmission and signalling; PABX applications; maintenance and service experience; as well as papers on less easily classifiable subjects.

The following systems are the principal ones on which papers were presented at the conference: Plessey EPB 2000; ITT Unimat range; small Viewdata exchange; TN-System 6030; PO SSMF5; BNR SL-1; Bell DIMENSION 2000; PO CDSS1; IBM 3750; GTE GTD range; Japan TD-PABX; Hitachi EX10; Fujitsu FETEX-400; TDX Systems TELEMAX; Bell Horizon; Siemens modular PABX; Finland IDGSS; Plessey PDX; Plessey K1; Philips EBX 8000.

R. C. GIBBS

System X

J. MARTIN, B.SC., C.ENG., F.I.E.E.†

UDC 621.395.34

This article introduces a series of articles to be published in this Journal that will describe the engineering and technical aspects of a family of digital-switching exchanges, known as System X. These exchanges will provide the switching element of an integrated network of digital transmission and switching systems.

INTRODUCTION

Experience in the development of the electronic switching systems in the British Post Office (BPO) and manufacturing companies of the UK has a long tradition, dating back to the early research on pulse-amplitude modulation (PAM) systems in the immediate post-war years, through to the successful electronic exchange developments (TXE2, TXE4 and TXE4A) and the digital pulse-code modulation (PCM) tandem installations at Empress in 1968 and Moorgate in 1970.

From the late 1960s to the early 1970s, a joint BPO/Industry team called the *Advisory Group on Systems Definitions* (AGSD) studied the fundamental criteria on which to base ongoing developments. The companies involved from Industry were the main switching-equipment suppliers to the BPO: GEC, PTL and STC. The work of the AGSD highlighted the need for systems that would enable the existing networks, with their limited signalling and intelligence capabilities, to be evolved into one with much greater capabilities that would be able to respond readily to the customer and service needs, both foreseen and unforeseen.

It was also apparent from this work that available device-technology offered the prospect of systems with greater reliability and economy.

As a consequence, a new family of switching and associated systems using microelectronic technology, integrated digital switching and transmission, stored-program control (SPC) and common-channel signalling was defined under the family title *System X*.

The uncertainty of future service needs and recognition of the pace of change in technology also dictated that the systems should be developed so that they had great evolutionary potential, a requirement which the definitions met by specifying a highly modular approach to system design, both in the hardware and software elements of the system.

Following a period in which the main suppliers to the BPO had been competing in design which, in turn, had resulted in a proliferation of equipment types in the BPO network, consideration was given to the way in which the development should be organized, recognizing the needs of both the BPO and its principal equipment suppliers. In 1975, it was agreed by the BPO and the companies that the development of the new systems should be carried out jointly and collaboratively by the BPO and its main switching-equipment suppliers. The aim was to ensure that the requirements of the BPO, as a large and advanced operating administration, could be allied to the requirements imposed on the system by modern manufacturing techniques, as brought forward by the manufacturing companies.

The work is co-ordinated through contracts let and funded by the BPO, which provide for the interchange of design and other information to enable each company to play its part in both the development programme and the subsequent supply of equipment.

Therefore, System X is a key development for the future of the UK Telecommunications Industry. For the BPO, it is the central feature of an overall strategy for the evolutionary development of the UK telecommunications network, which will pave the way for an expanding range of telecommunication services and facilities for customers in the future. For industry, System X is being designed to become fully competitive on world markets to give a major boost to UK exports in telecommunications.

This article provides an introduction to, and framework for, further articles on the engineering and detailed technical aspects of the system that will appear in later issues of this *Journal*.

PROGRAMME

The overall programme for System X provides for the total range of exchange applications, but the highest priority is being given to the development of digital junction tandem and trunk exchanges, to a set of local exchanges (starting with exchanges at the lower end of the traffic-carrying capacity range), and for servicing, management and accounting centres. Consideration is also being given to the programme for international exchange, manual board, and data services.

SYSTEM CONCEPTS

The ability to exploit the existing Strowger and crossbar switching and signalling systems on a network basis is constrained by a variety of limitations inherent in these systems. Thus, signalling is achieved by sending a very limited number of signals over the speech channels. Data about customer lines is not available to a central control for manipulation or onward transmission. The connexion control functions are dispersed into the switches or switch blocks and are either unable to communicate or do not have access to the sort of manipulative control power that is required for future service and facility flexibility.

System X designs overcome these limitations because the designs are based on a number of concepts, as given below.

General-Purpose Switching

General-purpose switching enables diverse types of line, or service and signalling equipment, to be interconnected, and the switching arrangement can be progressively reconfigured as service and network interworking requirements change.

Stored-Program Control

In exchanges using SPC, the facility for data processing provides a general-purpose and flexible solution to the

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problems of storing and manipulating the information and signals required to set up and control calls, and for the management of the system. Also, SPC provides flexibility in meeting unforeseen requirements in the future.

Common-Channel Signalling

The use of common-channel signalling enables control and management information to be transmitted between installations, in flexible and open-ended ways, in the form of data messages. Signalling equipment is no longer associated with individual channels.

Digital Transmission

Digital transmission provides a general-purpose economic transmission technique, suitable for all services and a wide range of transmission media; for example, cable, radio and optical fibre.

Integrated Digital Switching and Transmission

In an integrated digital switching and transmission system, speech and other signals are switched in digital form through time-shared switches. Integration minimizes the equipment required at the interface between transmission and exchange equipment, and provides a transmission performance that is virtually independent of distance and the number of exchanges through which calls are routed.

Remote Control of Exchange Functions

The remote control of exchanges enables some of the management and operational features of the network to be centralized for economy and improved service.

Concentrator Working

Concentrator working, with remote control, enables the benefits of SPC and common-channel signalling to be obtained with small, dispersed local exchange switching units.

SYSTEMS ARCHITECTURE

The adaptability that goes with these system concepts provides considerable in-service flexibility. This is further facilitated by subdividing the overall system into modular building blocks (subsystems), which can be used in more than one application and which have carefully defined features and interfaces. The principal hardware subsystems of System X are as follows.

Subscriber Switching Subsystem

The subscriber switching subsystem (SSS) concentrates traffic from a number of customers' lines onto heavily used common circuits at a local exchange. Both digital and analogue forms are being developed.

Digital Switching Subsystem

The digital switching subsystem (DSS) interconnects digital channels with high traffic loadings, at interfaces that conform with internationally-agreed standards.

Message Transmission Subsystem

The message transmission subsystem (MTS) performs common-channel signalling functions, with error correction.

Signalling Interworking Subsystem

The signalling interworking subsystem (SIS) provides facilities for interworking with existing exchanges that use a variety of channel-associated signalling systems; it also provides tones and recorded announcements.

Analogue Line Terminating Subsystem

The analogue line terminating subsystem (ALTS) converts analogue transmission signals (speech and other waveforms) into digital form and vice versa.

Network Synchronization Subsystem

The network synchronization subsystem (NSS) ensures that an exchange operates at the same average binary-digit rate as the synchronized network as a whole.

Processor Subsystem

The processor subsystem (PS) consists of a large and small processor utility with supporting microprocessors, which provides the data-processing facilities required for handling traffic and for controlling local and remote switching subsystems.

The System X software, which is stored and run on the processor subsystem, under the control of the real-time operating system, is modular in form like the hardware. It is divided into a number of software subsystems performing such functions as call processing, call accounting, overload control, maintenance control and assembly of management statistics, which include the basic traffic data needed for short and long-term planning purposes.

These software subsystems are also broken down into smaller modules, with well-defined interfaces. These features, coupled with the basic architectural features of the processors, create the ability to test, structure, and change modules without interfering with other modules, and have simplified the tasks of preparing and maintaining software on live systems.

OUTLINE SYSTEM

A block diagram showing the interconnexion of the subsystems used to form the trunk and junction tandem system is given in Fig. 1. A block diagram showing how the subsystems form the basic local exchanges is given in Fig. 2.

STANDARDS AND TECHNOLOGY

The various subsystems and applications of System X are being designed to common standards. This will enable the rationalization of design and design-processing problems and will secure the benefits of scale in development, production and operation. In determining the standards, the aim has been to generate designs that are technically advanced, cost-effective and fully competitive on world markets. The areas of standardization include

(*a*) a standard equipment construction practice, which creates an effective range of options in terms of dimensioning and maintenance access,

(*b*) an approved list of components and devices, where possible conforming with widely accepted national and international standards; new devices, particularly semiconductor devices, are added to the list as appropriate,

(*c*) circuit design rules, and standard hardware interfaces,

(*d*) software standards, including the use of a high-level programming language system, and

(*e*) power supplies, and a standard range of DC–DC converters.

SUPPORTING FACILITIES

The design is also supported by a number of modern design aids. These aids are themselves being created and improved as new technologies and opportunities emerge in parallel with the development of System X. The significance of such facilities cannot be over-estimated. Indeed, a modern design team cannot succeed in terms of speed and reliability unless

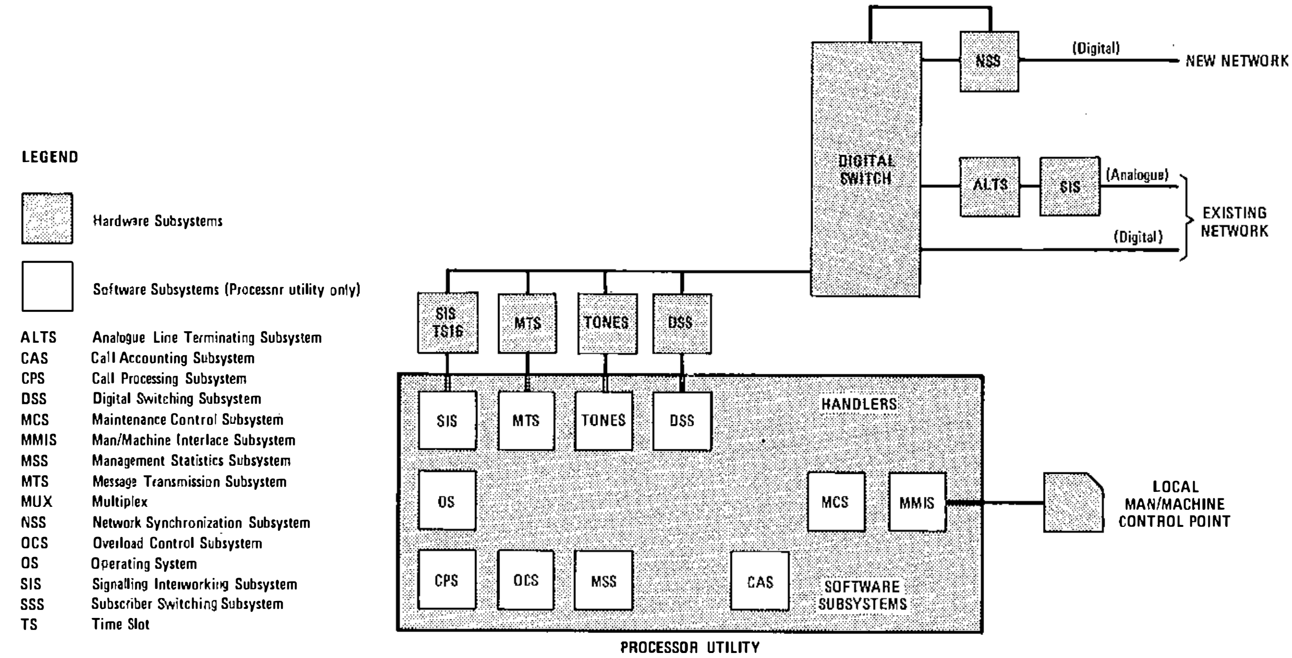

FIG. 1—Block diagram of digital main network switching centre

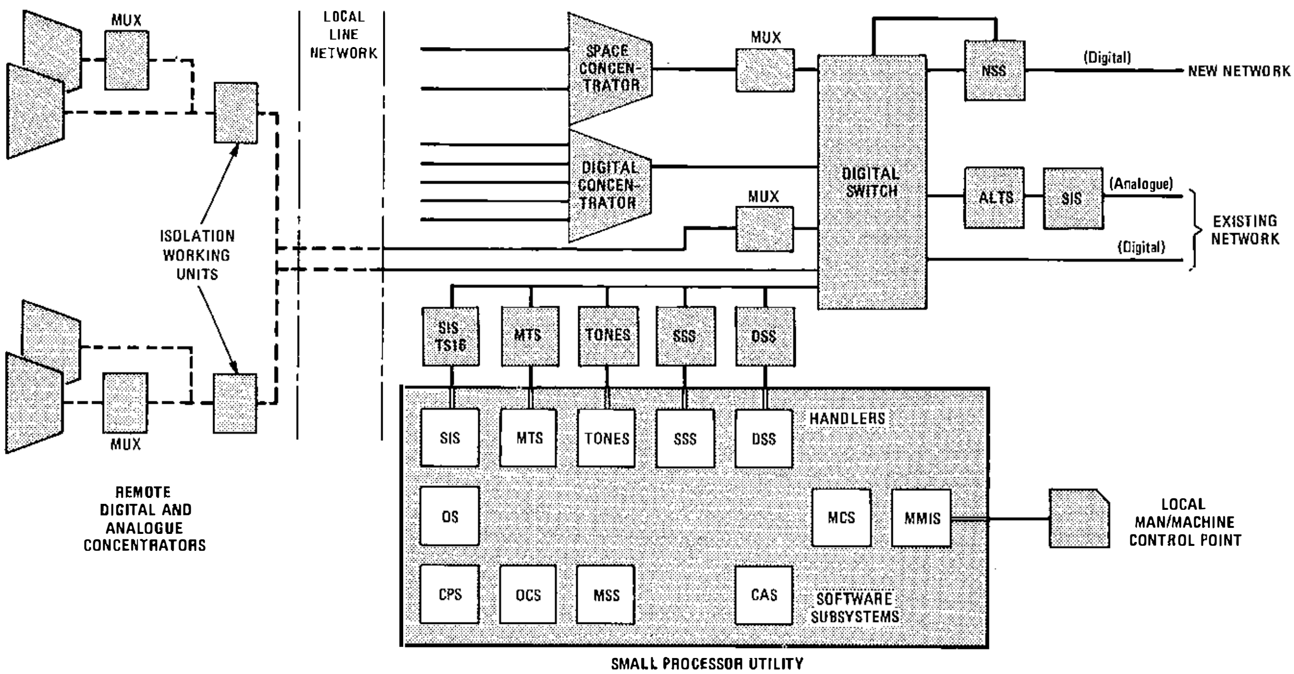

FIG. 2—Block diagram of digital local exchange

supported by aids of this sort. Progressively, data is emerging from the design facility in such a way that it can directly control production machinery, so that difficulties with accuracy and tedium in translating design information into manufacturing information are being progressively removed. These aids include the following tools.

Documentation and Data Base

The development of documentation and data-base facilities is being undertaken by design teams at various locations; a very great deal of design information must be exchanged between them and made available for planning, production and maintenance purposes. The information is not static, and both the information-exchange and documentation-updating processes must be carefully controlled. To this end, a coherent documentation scheme has been developed and a computerized data-base is being progressively implemented.

Hardware Design

Many aspects of hardware design now demand computer support. Techniques are still developing, but include: logic simulation, which checks that the design rules are met and the logic is to specification; component placement; printed-wiring board track layouts; generation of test programs for the designs; pin allocation in accordance with rules; shelf, rack and cable layout; component listings for ordering, drilling tapes for printed-wiring boards; preparation and printing of drawings onto microfilm.

Software Design

Software engineers can only complete their tasks to schedule if supported by adequate language systems on which their software can be compiled, loaded, tested and archived. Once design is complete, other linked computer-based systems are required to prepare the programs and tapes for loading into exchanges.

Many of these facilities are made generally available to the design teams via a data network and, in conjunction with the data base, these facilities are reducing the time taken to generate and test designs and move them into production. Over and above these requirements, computer programs are also required to analyse the data coming from the system for service, network management and billing purposes, create test programs for manufacturing and commissioning and so on.

USE OF SYSTEM X IN THE NETWORK

The existing telecommunication network was established for analogue telephony, with approximately a 3 kHz service capability (which is adequate for commercial speech transmission), and with rather elementary call set-up procedures. Nevertheless, the network has been successfully exploited for various derived services, including such essentially digital services as Datel and, currently, Prestel. Separate networks have, however, been provided for Telex and packet-switched data services.

With the rapidly increasing availability of digital transmission systems and the introduction of System X switching equipment, it will become progressively possible to provide 64 kbit/s switched transmission paths throughout the network from local exchange to local exchange, capable of catering for a wide and increasing range of services.

The conversion of the existing network into such an integrated digital network will spread over many years and will be constrained initially by the availability of System X equipment, while production builds up and displaces that of current, particularly electromechanical, types of exchange equipment.

It is clear that, for a long period, many of the restrictive interworking arrangements between exchanges, and with customers' apparatus, will persist, and the service benefits obtainable with System X will be distributed unevenly throughout the network. It is thus important that System X be introduced in a way that optimizes benefit to customers, and particularly business customers, and minimizes the effects of the constraining influences of the existing network.

Studies are being made of the detailed way in which System X will be used to enhance the existing network, both to satisfy interim needs and to work towards longer-term objectives, and a number of identifiable but overlapping phases in the evolution of the network are becoming apparent.

SERVICE BENEFITS

The reduced capital and running costs of System X will enable the BPO to hold down charges to customers while its enhanced and evolutionary capability, arising principally from SPC and common-channel signalling, will facilitate the provision of new and improved services as the need arises.

As System X penetrates the UK network, the basic telephone service will be progressively improved by reduction in call set-up times, improved speech transmission, less noisy connexions and a more reliable service. Similar benefits will accrue to data and other services.

More specifically, it will be possible to provide a large number of supplementary telephone services; initially a limited number of new or improved supplementary services, some of which are already available on modern PABXs, have been identified for early provision on System X public exchanges. They include such services as abbreviated dialling, call waiting, three-party service (for example, hold-for-inquiry), and transfer of calls (initially within the local call area).

The full versions of many of these supplementary services require the co-operation of two or more exchanges, not all of which may be System X (for example, transfer of calls), and some services will therefore be available only in restricted form during the early years.

PROGRESS

The design of System X has been in full swing for some time. At present, a series of models of small-to-medium sized local, junction and trunk exchanges and a network administration centre is being built at manufacturers' premises for evaluation by the BPO. These will be followed by the first production exchanges, which will prove installation, commissioning and operating procedures and their associated documentation.

Orders for System X digital trunk, junction and small local exchanges are in the course of being placed, and the BPO has recently announced that it intends to have the first exchanges in operation before the end of 1981.

CONCLUSION

The progressive enhancement of the UK telecommunications network by System X and digital transmission systems is expected to lead towards an integrated digital network. This will give a bothway digital transmission capability, initially at 64 kbit/s, between customers' terminals, with a comprehensive signalling capability between the customer and the network, and within the network.

The customer-to-customer digital capability thus provided, with the evolutionary potential of System X, should enable the UK telecommunications network to meet emerging customer needs for telephone, data and other services, including those for electronic funds transfer, electronic mail and word processing, and those provided through customers' multi-functional terminals. Thus, the basic telephone service will be progressively improved and enhanced, and new services will be provided.

The needs of the System X programme, the demands on designers working in new technologies, the creation of increasingly comprehensive development support systems and the essential close collaboration of the various design teams are all combining to provide UK telecommunications with a powerful capability to meet the needs of British customers and to compete vigorously and effectively in the world's export markets.

The technological demand, the scale of operation, and the need for a common enterprise by the BPO and the British telecommunications industry in the definition, development, manufacture, and implementation of System X, has produced a challenge to the engineering and related professions unmatched in the previous history of UK telecommunications. This challenge is being met on a personal level by every individual involved, and it is the efforts of those individuals that are placing success within our grasp.

ACKNOWLEDGEMENT

The information in this paper is based on the work of many engineers both in the BPO and UK Industry, to whom acknowledgement is due.

30-Channel Pulse-Code Modulation System

Part 3—Signalling Units

K. J. TURVEY, B.SC.(ENG.)†

UDC 621.376.56

Parts 1 and 2 of this article described the multiplex equipment and the 2·048 Mbit/s digital line system of the British Post Office (BPO) 30-channel pulse-code modulation (PCM) system[1,2]. This concluding part describes the signalling units used in conjunction with the 30-channel PCM system. The article comments on the historical background of PCM signalling units and reviews the BPO's present and future plans for such units; a technical description of the signalling units developed for the BPO 30-channel PCM system is given.

INTRODUCTION

Each manufacturer of the British Post Office (BPO) 24-channel pulse-code modulation (PCM) system developed all the constituent equipments of that system; for example, multiplex, line and signalling equipments. Because of the operational need to use the signalling units of one manufacturer in multiplexes from a different manufacturer, there were many compatibility problems that required rectification. Some of the problems were not identified until many signalling units were in service.

To eliminate compatibility problems, signalling units for the BPO 30-channel PCM system are all designed by one manufacturer. However, to preserve competitive sources of supply, arrangements have been made by the UK Telephone Engineering and Manufacturers Association for the design information to be available to their 5 members. Currently available, is an initial range of 12 units which, by providing some facilities as strappable options, replicate the facilities offered by the 17 signalling units used on the BPO 24-channel PCM system.

In the 24-channel PCM system, assistance traffic from coin-collecting boxes (CCBs) and STD traffic to group switching centres (GSCs) is routed over a PCM system via an appropriate Signalling System AC 8 (SSAC 8) relay-set and an SSAC 8 (extension type) PCM signalling unit. The SSAC 8 relay-set is, however, comparatively expensive and its size can pose accommodation problems. As the penetra-

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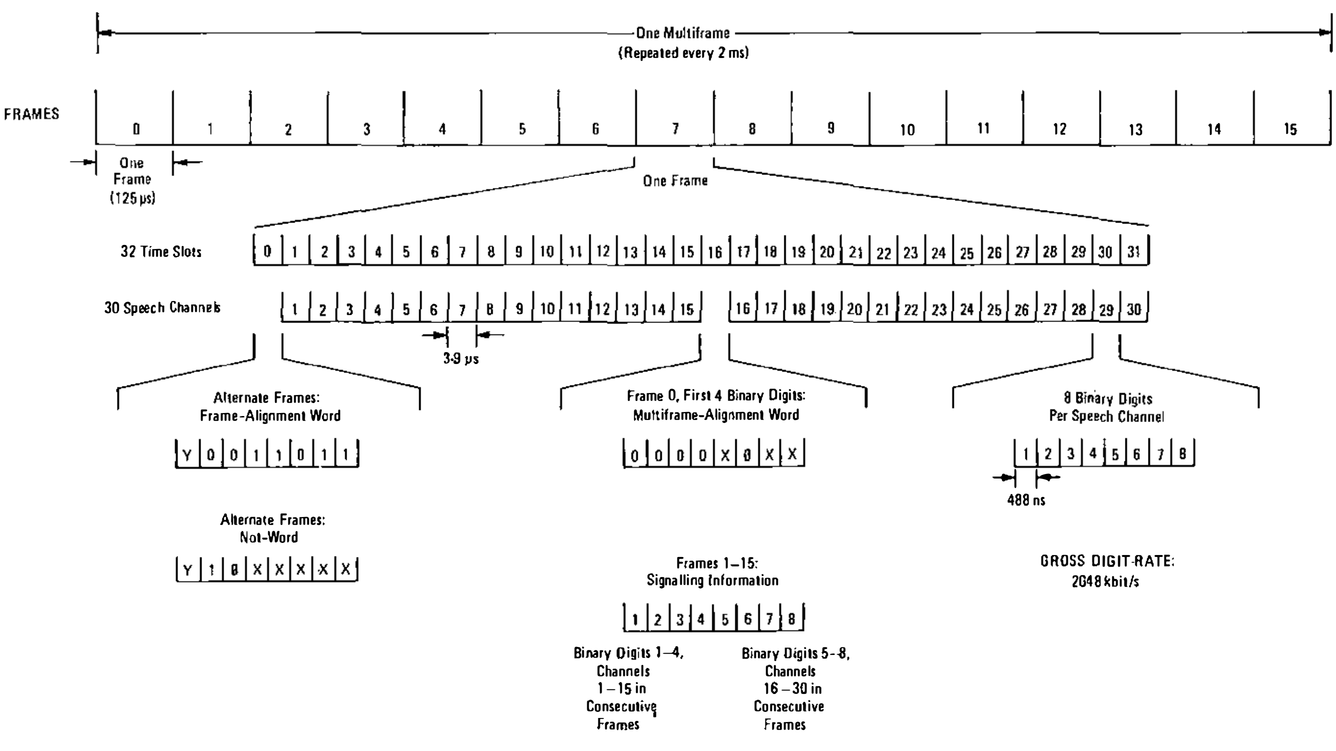


X: Digits not allocated to any particular function and set to state *one*
Y: Reserved for international use (normally set to state *one*)
Ø: Digits normally *zero* but changed to *one* when loss of frame alignment occurs and/or system fail alarm occurs (TS0 only) or when loss of multiframe alignment occurs (TS16 only)

FIG. 25—Frame format for 30-channel PCM system

tion of PCM systems into the network has increased, greater emphasis has been placed on utilizing spare channels for this type of traffic. Advantage has been taken of the adoption of the 30-channel PCM system to develop signalling units specifically to cater for such traffic. The increased signalling capability of the 30-channel PCM system considerably eases the provision of additional signals; for example, those required for coin-and-fee checking (CFC). A further 9 signalling units are being developed which will cater for

(*a*) private circuits employing single commutated (SC) DC signalling,
(*b*) circuits with metering over the junction (MOJ),
(*c*) assistance traffic from CCBs (with CFC), and
(*d*) combined level working at unit automatic exchanges (UAXs) and at electronic exchanges.

FRAME STRUCTURE OF 30-CHANNEL PCM SYSTEM

The frame structure of the 30-channel PCM system was described in Part 1 of this article[1]. However, to aid the description of the signalling aspects, the frame format is repeated in Fig. 25 of this article.

Signalling information is conveyed in time slot (TS) 16. The 8 bits contained in each TS16 are allocated to 2 channels (that is, 4 bits for each channel). To cater for the signalling requirements of all 30 channels, TS16 is submultiplexed over a period of 16 frames. The frames are numbered 0–15, and the period is known as a *multiframe*. During frame 0, a multi-frame-alignment signal (0000) is transmitted in TS16 to identify the start of the multiframe structure. In the remaining frames (1–15), 8 bits per frame are available to provide the signalling information for 2 channels. A total of 15 signals can be encoded for each channel, since binary 0000, the multiframe-alignment word, cannot be used for signalling. The functions of the 8 bits contained in TS16 of each frame are given in Table 1.

TS16 COMMON EQUIPMENT

The TS16 common equipment (CE) provides channel-select pulses, clock pulses and signalling highways between a multiplex equipment and associated PCM signalling units. The 8 bits contained in TS16 of each frame are transmitted at the 2·048 Mbit/s rate between the multiplex and the TS16 CE. The TS16 CE stores the 8 bits and conveys them to and from the PCM signalling unit at the rate of 64 kbit/s (see Fig. 26). Thus, the 8 bits contained in TS16, which had occupied 3·9 μs (one time slot), now occupy 125 μs (one frame); this change of signalling rate enables a continuous

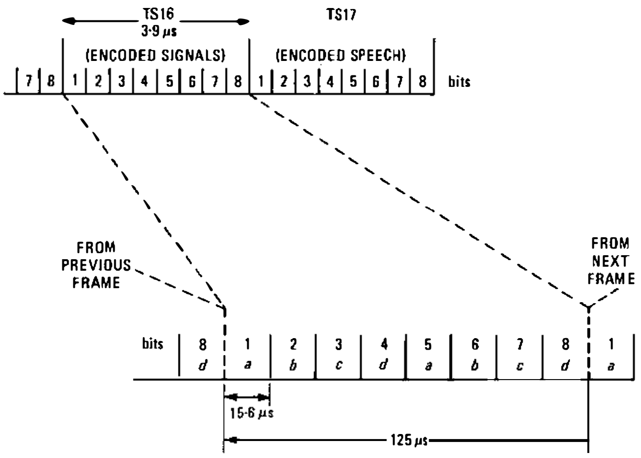


Fig. 26—Conversion of bits contained in TS16 from 2·048 Mbit/s to 64 kbit/s

TABLE 1

Functions of TS16 Binary Digits

Frame Number	Functions of TS16	
	Bits 1–4	Bits 5–8
0	Multiframe alignment word (0000)	Loss of multiframe alignment (x∅xx)
1	Signalling for channel 1	Signalling for channel 16
2	,, ,, ,, 2	,, ,, ,, 17
3	,, ,, ,, 3	,, ,, ,, 18
4	,, ,, ,, 4	,, ,, ,, 19
5	,, ,, ,, 5	,, ,, ,, 20
6	,, ,, ,, 6	,, ,, ,, 21
7	,, ,, ,, 7	,, ,, ,, 22
8	,, ,, ,, 8	,, ,, ,, 23
9	,, ,, ,, 9	,, ,, ,, 24
10	,, ,, ,, 10	,, ,, ,, 25
11	,, ,, ,, 11	,, ,, ,, 26
12	,, ,, ,, 12	,, ,, ,, 27
13	,, ,, ,, 13	,, ,, ,, 28
14	,, ,, ,, 14	,, ,, ,, 29
15	,, ,, ,, 15	,, ,, ,, 30

∅—Digit normally zero but changed to one when loss of multiframe alignment occurs
x—Digits not allocated to any particular function and set to state *one*

stream of signalling information to be provided between the TS16 CE and the PCM signalling units. Therefore, as far as the signalling units are concerned, the time taken to transmit one bit is 15·6 μs.

The 4 bits per channel used for signalling are referred to as bits *a*, *b*, *c* and *d*. Fig. 27 shows typical signals encoded (in binary) for the transmit direction of TS16 in one frame, also shown is a select pulse used to select the particular channel required and a 64 kHz clock used to extract the *a*, *b*, *c* and *d* bits in the signalling unit. Thus, for the transmit direction, 30 channel-select wires are required, plus one wire for the 64 kHz clock and one wire for the signalling highway. This is repeated for the receive direction. Table 2 shows a typical allocation of codes.

SIGNALLING UNITS

A signalling unit for a PCM system provides an interface between telephone exchange equipment and a PCM multiplex. The PCM signalling unit may simply extend a speech circuit equipped with an in-band voice-frequency (VF) signalling system, or it may additionally process and extend any associated DC signalling activity.

The majority of signalling unit types cater for loop-discon-

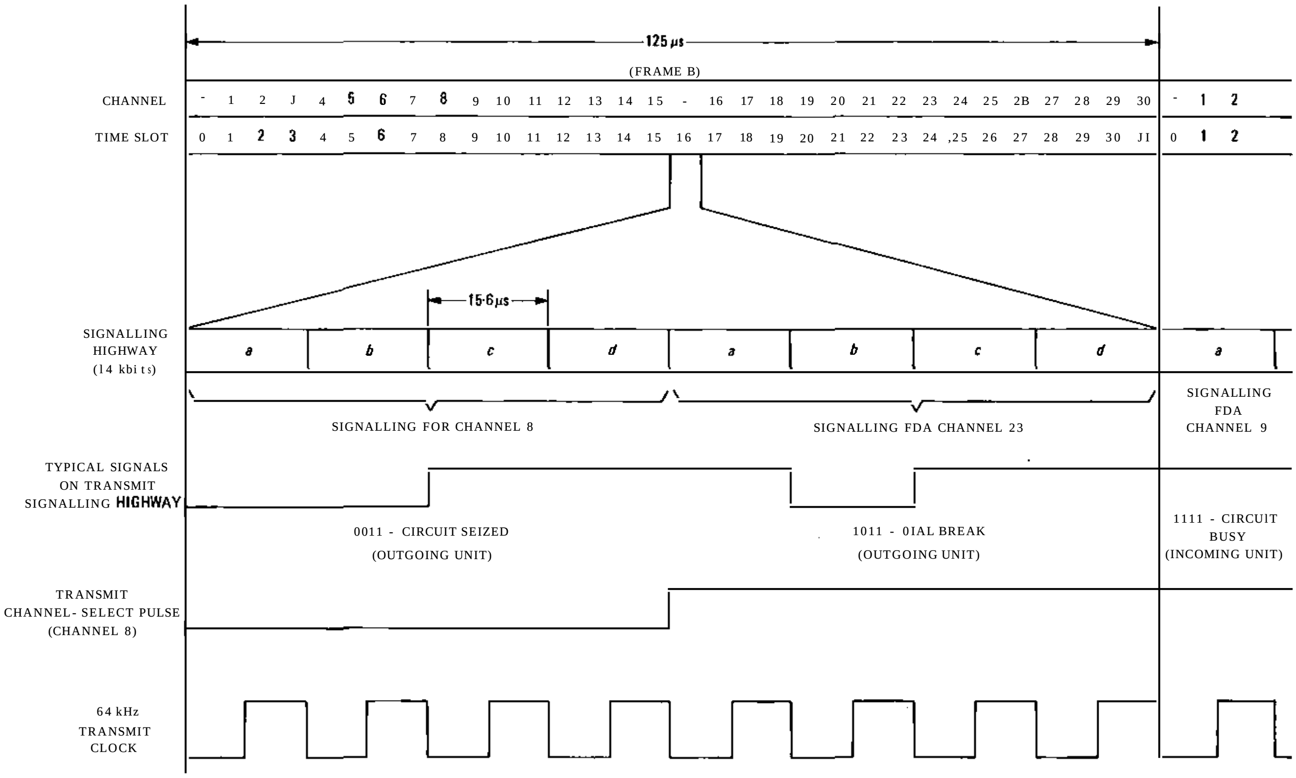


FIG. 27—Signal waveforms (frame 8)

TABLE 2

A Typical Allocation of Signalling Codes

Digits 1–4 (5–8) appearing serially in TS16				Signalling condition in forward direction	Signalling condition in backward direction
a	*b*	*c*	*d*		
1	1	1	1	Circuit idle	Circuit busy
0	0	1	1	Circuit seized	Called-subscriber answer
1	0	1	1	Dial break	—
0	1	1	1	—	Circuit free
0	0	0	1	Trunk offer	Manual hold
1	0	0	1	—	Coin fee check
1	1	0	1	Disconnexion*	Disconnexion*
0	1	0	1	Earth*	Earth*

* For use in signalling units that extend SSAC 8 type signalling by means of phantom circuits derived from transformers associated with each PCM signalling unit

nect signalling and so the operation of these signalling units is explained in some detail in this article. Other types of signalling units are available that cater for SSAC 8 signalling by extending the earth and disconnect signals over phantom connexions. Signalling units currently being developed will enable SCDC-type signalling to be extended and will enable

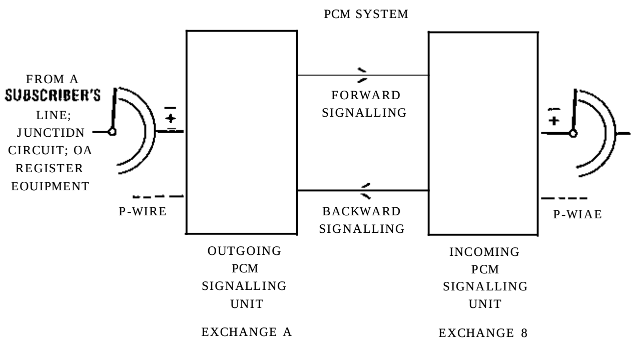


FIG. 28—Trunking diagram for the interconnexion of loop-disconnect signalling units

SSAC 8 signalling to be converted to loop-disconnect signalling.

A Typical Call-Path Routed via Loop-Disconnect Signalling Units

A simplified trunking arrangement of a call path routed via a 30-channel PCM system is shown in Fig. 28. Block diagrams of the outgoing and incoming loop-disconnect type of signalling units are shown in Fig. 29. Typical facilities offered by the outgoing and incoming units are shown but, for any particular unit type, only the appropriate facilities are provided. To reduce the number of signalling unit types required, some facilities on a unit are provided as strappable options.

When a calling-subscriber's loop is extended to the loop detector in an outgoing PCM signalling unit, the forward code is changed from the *circuit idle* state to the *circuit seized* state, and the P-wire condition is changed from the free to the busy state.

The incoming PCM signalling unit at the distant exchange

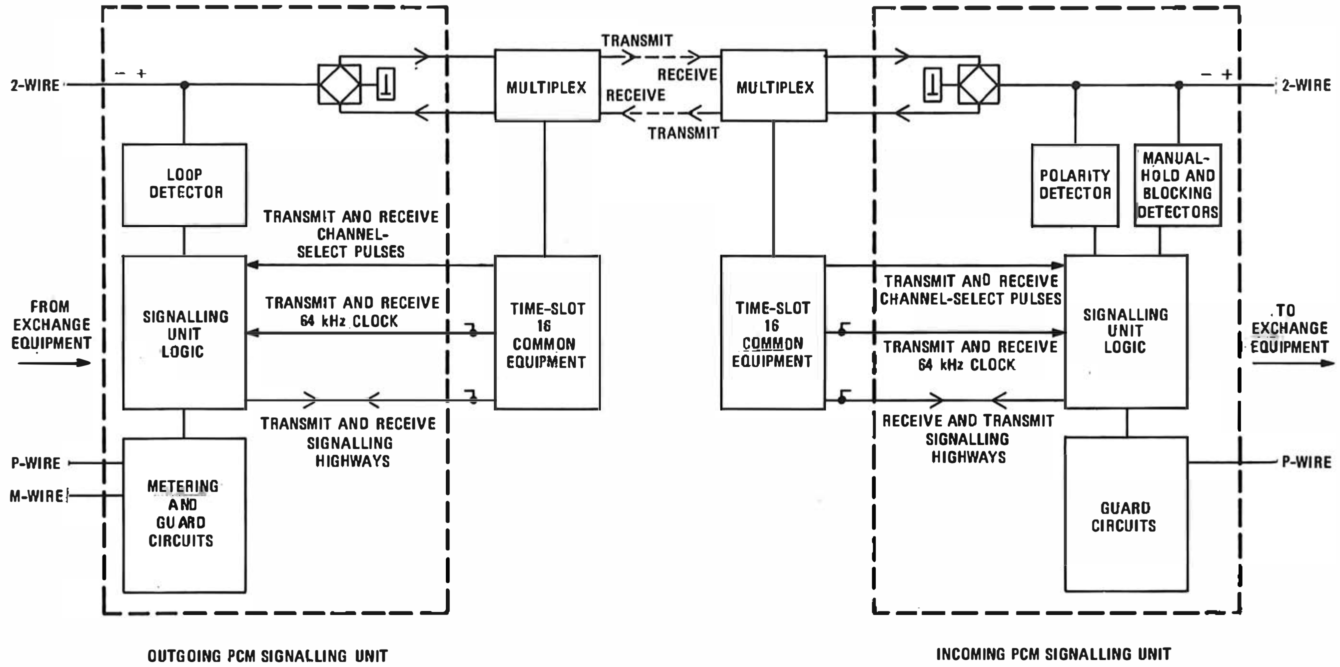


FIG. 29—Block diagram of loop-disconnect signalling units

detects the change in forward code, extends a loop condition to the 2-wire and changes the backward code from *circuit free* to *circuit busy*.

Dial break-pulses are extended over a PCM system by changing the forward code to *dial break* for the duration of each break pulse. An incoming signalling unit may simply repeat the break pulses to the 2-wire or provide a fixed-break correction. Where signalling units with break correction interface with the local network, the dial break output is fixed at 58–60 ms for all possible input speeds (7–12 pulses/s); for the main network, the output of the break pulses is fixed at 50–52 ms for all possible input speeds (9–12 pulses/s).

At the end of dialling and after a called subscriber has answered, the incoming PCM signalling unit detects the reversed polarity of the 2-wire and changes the backward code to *called-subscriber answer* (*CSA*). The outgoing PCM signalling unit reverses the polarity of the 2-wire only if the *CSA* code exceeds 40 ms. Further dial breaks are inhibited once the *CSA* code has been recognized. When required, and provided that the *CSA* code persists for at least 300 ms (100 ms in the case of MOJ), a meter pulse is initiated. The 2 separate persistence checks ensure that, the line polarity reversal is not delayed excessively if several PCM systems in tandem are encountered, and that false *CSA* codes do not cause metering (metering can be initiated either by a positive battery on the P-wire, or by a negative battery on a fourth wire—the M-wire).

On cleardown, the PCM signalling units employ sequenced release procedures in that early release is given to the preceding equipment, but the channel is not available for further traffic until a positive response is received from the distant end that all the incoming equipment has been released. When the calling subscriber clears, and after an appropriate persistence check, the forward code is changed directly to *circuit idle* and a disconnect period of 30–45 ms is applied to the P-wire to release the preceding equipment. The P-wire condition is maintained in the busy state until the backward code changes to *circuit free* (that is, until the distant end has restored to the free condition). On decoding the *circuit idle* code, the incoming signalling unit removes the loop on the 2-wire and changes the backward code from *CSA* to *circuit busy*. The incoming PCM signalling unit looks for a free condition on the P-wire after a period of at least 50 ms (to allow for the earth-disconnect period of succeeding equipment) and changes the backward code from *circuit busy* to *circuit free*. Where an incoming PCM signalling unit does not use a P-wire, a blocking detector in the 2-wire path is used to establish the free condition of the succeeding equipment.

Also provided are the normal maintenance facilities of manual busying and system busying. Other facilities (for example, trunk offering (TKO), manual hold, etc.) are included on some signalling units.

SOME CIRCUIT ELEMENTS USED IN THE 30-CHANNEL PCM SIGNALLING UNITS

As far as possible, standard circuit elements are used across the range of signalling units to facilitate computer-aided printed-wiring board design, and to ease the maintenance of the units and the stocking of spare parts. Some examples of the circuit elements used in the design of PCM signalling units are briefly described below. A typical loop-disconnect outgoing PCM signalling unit is shown in Fig. 30, and the corresponding incoming unit is shown in Fig. 31.

Loop-Detector and 2-wire-to-4-Wire Conversion Circuit Elements

The loop-detector circuit elements and the 2-wire-to-4-wire conversion unit are shown in Fig. 32. The 2-wire from an

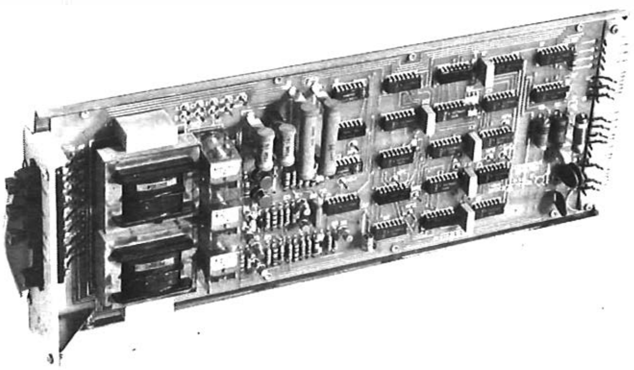


FIG. 30—Outgoing PCM signalling unit

(Photograph by courtesy of GEC Telecommunications Ltd.)

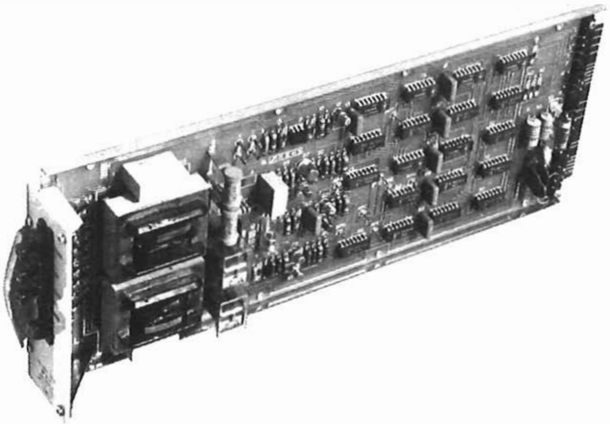


FIG. 31—Incoming PCM signalling unit

(Photograph by courtesy of GEC Telecommunications Ltd.)

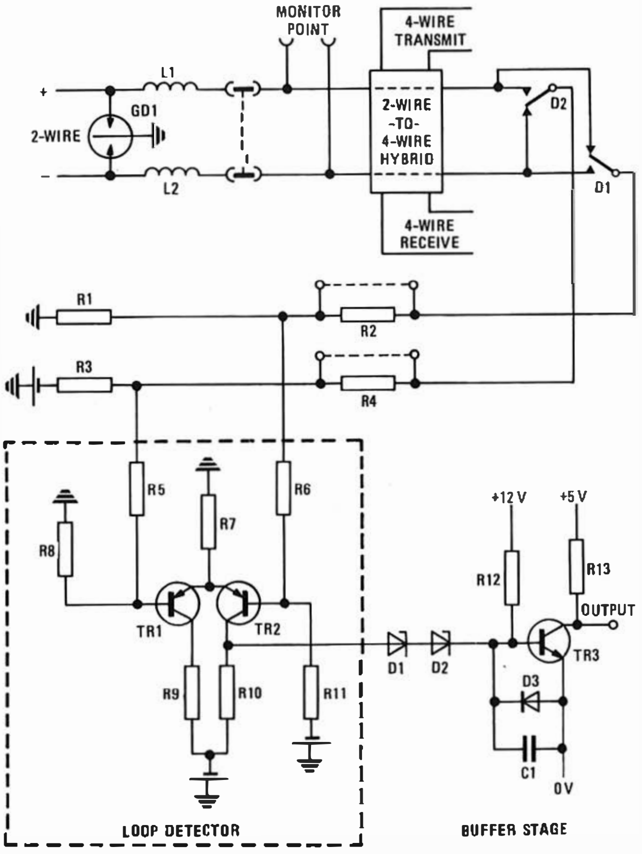


FIG. 32—Loop detector and 2-wire-to-4-wire conversion unit

exchange line is connected via high-frequency chokes L1 and L2 to a hybrid transformer, the 4-wire transmit and 4-wire receive connexions are extended to the multiplex equipment. The purpose of chokes L1 and L2, and the gas discharge tube GD1, is to filter transients that result from the operation of electromechanical relays. The line feeding current to either a subscriber's telephone instrument or to a preceding transmission bridge is provided by the exchange negative 50 V battery, which is fed via resistors R1 and R3, each 200 Ω. Relay contacts D1 and D2 reverse the line polarity when the called-subscriber-answer conditions exist. The preceding transmission bridge could be located in the same exchange as the signalling unit or at a different exchange, depending upon the routing of the preceding signalling equipment. When signalling conditions allow, resistors R2 and R4 are in circuit to reduce the power dissipation in the unit. Where this is not so, the unit must cater for a maximum line current of 120 mA; this value of line current could exist when the 2-wire is connected to a subscriber's line of minimum length.

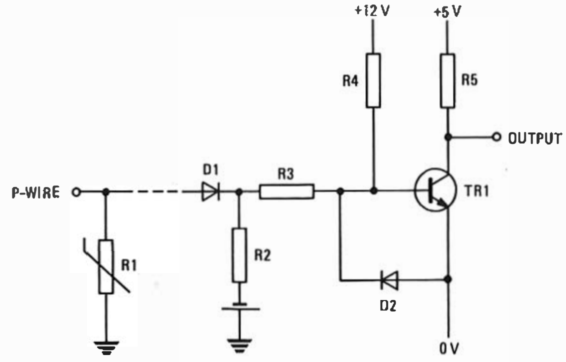


FIG. 33—Earth-detector circuit elements

Transistors TR1 and TR2 of the loop-detector circuit are connected across the 2-wire line via high-value resistors R5 and R6. In the idle condition (no loop), transistor TR1 is conducting and transistor TR2 is switched off. When a DC loop is applied to the 2-wire, TR1 is switched off and TR2 conducts. Dial break pulses on the 2-wire cause TR1 to conduct and TR2 to switch off; the switching of transistors TR1 and TR2 occurs in sympathy with the pulses received.

The output of the loop detector is converted to the appropriate logic levels by transistor TR3. The network of resistor R12, Zener diodes D1 and D2, and resistor R10 ensures that the base of TR3 is negative when no loop exists on the 2-wire. Thus, TR3 is switched off and the output state is logic 1 (+5 V). Diode D3 limits the negative potential on the base of TR3. When a loop is applied to the 2-wire, TR2 in switching on causes the base of TR3 to go positive. Thus TR3 switches on and the output state changes to logic 0 (0 V). Capacitor C1 eliminates false signals being generated due to spurious line transients of short duration.

Earth Detector Circuit Elements

The earth-detector circuit elements are shown in Fig. 33. The earth detector is used on the outgoing and incoming 30-channel PCM loop-disconnect signalling units.

A non-linear resistor, R1, is used to protect the circuit from the high transient voltages which can be present on the P-wire. Diode D1 is included to reduce the effect of the earth detector on the release lag of relays associated with the P-wire. For added protection of transistor TR1 against high transient voltages, diode D1 is an avalanche-type silicon diode; if diode D1 should break down, the current is limited by resistor R3. When the P-wire is not connected to any potentials, the junction of resistors R3 and R4 is at a negative potential, thus switching transistor TR1 off. In this state, the output of the earth-detector circuit is logic 1 (+5 V). Diode D2 protects the base-emitter junction of transistor TR1 from large negative voltages.

When the P-wire is connected to earth, the junction of resistors R2 and R3 is at earth potential (diode D1 is forward biased) and, hence, the base of transistor TR1 is at a positive potential; thus, transistor TR1 is switched on. The output state of the circuit is, therefore, logic 0 (0 V).

Reversal Detector Circuit Elements

The circuit elements of the line-reversal detector are shown in Fig. 34. In the incoming loop-disconnect signalling unit, the 2-wire line polarity is reversed when the called-subscriber answers. Due to the high transient voltages which can occur during the various stages of a call, an optically-coupled transistor (OC1), (incorporating transistor TR1 and diode D2), is used to detect this reversal. The light-emitting diode (LED) part of the device is adequately protected and a high-

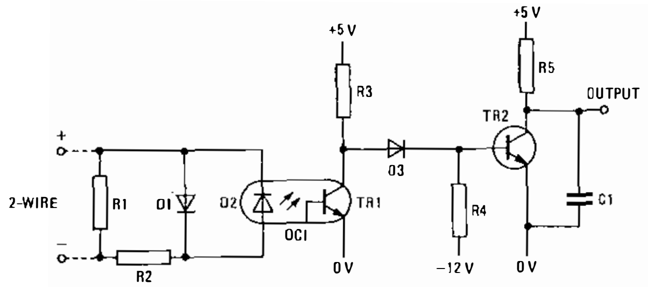


Fig. 34—Reversal-detector circuit elements

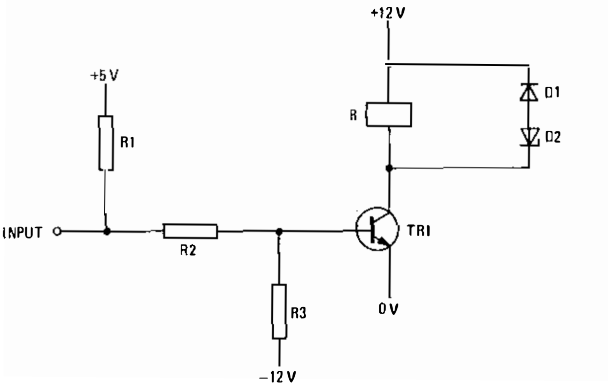
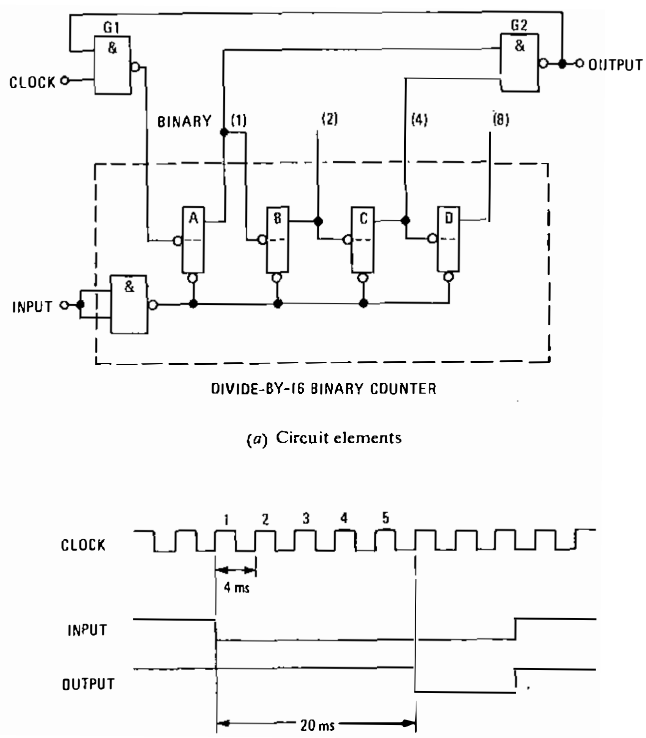


Fig. 35—Relay-driver circuit elements



(*a*) Circuit elements

(*b*) Signal waveforms

Fig. 36—Basic timing circuit

voltage immunity is afforded to succeeding components in the unit.

The polarity detector presents a resistance of about 200 Ω to the 2-wire line and caters for line currents of up to 120 mA.

With normal polarities on the 2-wire, diode D1 is forward biased and short circuits the LED (diode D2). The optically-coupled transistor, TR1, is thus switched off. The junction of resistor R3 and diode D3 is positive and, hence, transistor TR2 is switched on. The output state of the circuit is thus at logic 0 (0 V).

When the called-subscriber answers, the polarity of the line reverses and the LED diode D2 conducts. Transistor TR1 turns on, causing the junction of resistor R3 and diode D3 to be at 0 V. The base of transistor TR2 becomes negative and TR2 is switched off. The output state of the circuit is set at logic 1 (+5 V). Capacitor C1 eliminates false signals being generated due to spurious line transient voltages of short duration.

Relay-Driver Circuit Elements

Wherever possible, electronic circuit elements are used to detect and apply conditions on the 2-wire and P-wire. Where this is not practical from the point of view of cost or physical size, or where the electrical parameters are considered too hostile, electromechanical relays are used. The elements of the relay-driver circuit are shown in Fig. 35. Nearly all relay functions are achieved using BPO Type-23 relays. Conversion from logic levels to levels suitable for operating and releasing the relay is achieved by transistor TR1. Diode D1 is used to protect TR1 against the high voltages that occur on release of the relay. Zener diode D2 may be used to reduce the effect of diode D1 on the release time of the relay.

A logic 1 (+5 V) condition applied to the input causes relay R to operate, and a logic 0 (0 V) state releases relay R.

Timed Pulses and Persistence Checks

Timed operations may be made using a divide-by-16 counter which, starting at zero, stops counting when the required binary number has been reached. The basic timing circuit is shown in Fig. 36, which shows the counter connected to count to 5. If, for example, the clock period is 4 ms, (derived from the receive channel-select pulse), the timing circuit provides a timed period of 20 ms.

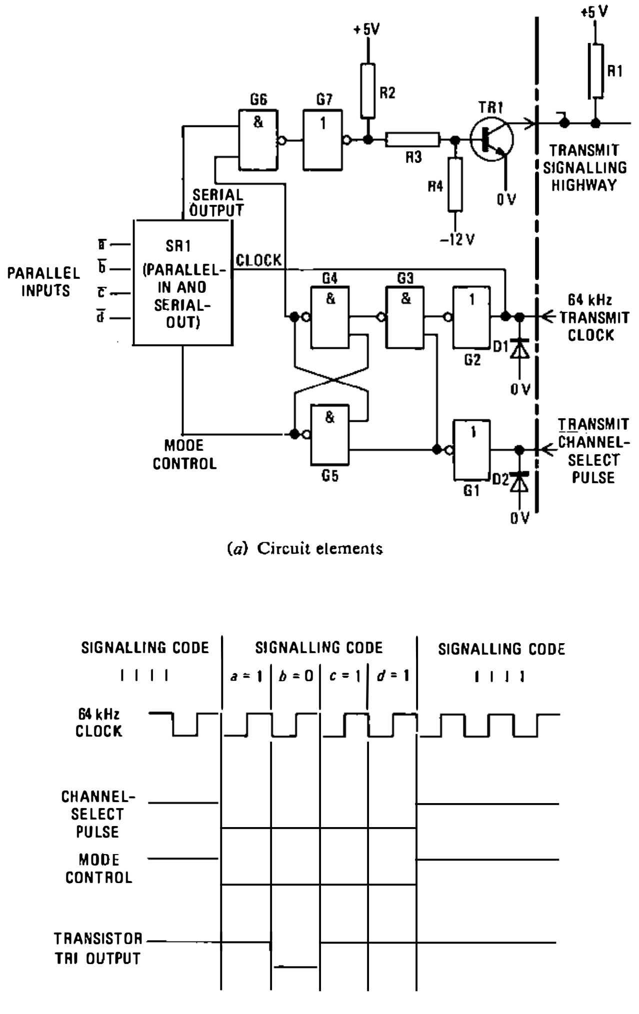
When the input of the timer is at the logic 1 (+5 V) state, bistables A–D are held reset to logic 0 (0 V). The output is set to logic 1 by NAND gate G2; clock pulses have no effect at this stage. When the input is set to a logic 0, bistables A–D count the clock pulses via NAND gate G1. After a count of 5 clock pulses (20 ms), bistables A and C are both at the logic 1 state, gate G2 causes the output to change to logic 0 which, in turn, causes gate G1 to inhibit further clock pulses. The output remains at a logic 0 until the input returns to the logic 0 state, thus resetting bistables A and C, which results in the output returning to the logic 1 state.

Signalling Encoder

A standard signal encoder (see Fig. 37) is used for all units requiring transmission of DC signals over a PCM system.

The DC signals are represented by a 4 bit code (*a*, *b*, *c* and *d*), examples of which are shown in Table 2. A 4 bit parallel-to-serial shift register, SR1, is used to introduce the appropriate 4 bit signalling code onto the common transmit signalling highway via transistor TR1. Resistor R1 is used in the multiplex to provide a "wired-or" function for all 30 signalling units and to ensure that a signalling code of logic 1111 (+5 V) is present during the appropriate transmit channel-select pulse if the signalling unit has been removed. The code 1111 represents, for example, circuit idle for an outgoing loop-disconnect unit, or circuit busy for an incoming loop-disconnect unit.

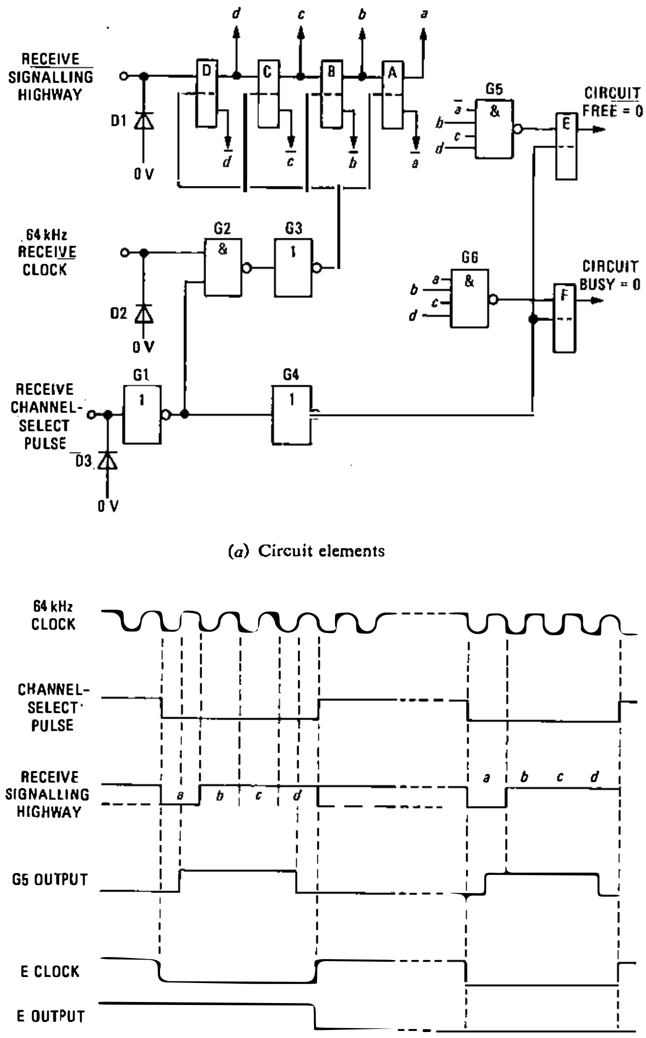
When the appropriate transmit channel-select pulse occurs (logic 0 for 4 clock periods), the mode control of SR1, in going to logic 0, staticizes the inputs *a*, *b*, *c* and *d* and reads out the parallel information in serial form by means of the 64 kHz clock. Gates G3, G4 and G5 compensate for dif-



(*a*) Circuit elements

(*b*) Signal waveforms

FIG. 37—Signal encoder



(*a*) Circuit elements

(*b*) Signal waveforms

FIG. 38—Signal decoder

ferences in the edges of the 64 kHz clock and the transmit channel-select pulse. Gate G6 ensures that information is transmitted only during the transmit channel-select period. Diodes D1 and D2 protect the integrated circuit inputs from negative transient voltages that can appear on the signalling interfaces.

Signalling Decoder

The signalling units use a standard circuit configuration (see Fig. 38) to decode signals received over a PCM system. A 4 bit serial-to-parallel converter, D-type bistable elements A, B, C and D, stores the 4 bit signal (*a*, *b*, *c* and *d*). The 4 bit signal is updated during each receive channel-select pulse. The outputs of A, B, C and D are decoded and staticized by D-type bistable elements E and F.

When the appropriate receive channel-select pulse occurs (logic 0 for 4 clock periods), NAND gate G2 allows 4 pulses of the 64 kHz clock to shift the appropriate *a*, *b*, *c* and *d* bits into the bistable elements A, B, C and D. While this occurs, inverter G4 inhibits bistable element E and F to hold their outputs steady. NAND gates G5 and G6 are used to decode the signals required (circuit free and circuit busy respectively) by connecting to the appropriate outputs or to the negated outputs of A, B, C and D.

Diodes D1, D2 and D3 protect the integrated circuit inputs from negative transients which might appear on the signalling interfaces.

COMPONENTS

For the whole range of PCM signalling units, low-power transistor-transistor-logic (LPTTL) integrated circuits (ICs) are used as the component technology. Apart from one device, the ICs selected are from those used on Signalling System AC 9 (miniaturized) equipment. All the ICs used are to BPO specification D3000.

Many reed relay failures were encountered in the 24-channel PCM signalling units. These were mainly due to their use in conditions later found to be too onerous. In the 30-channel signalling units, nearly all the relay types used are BPO Type-23, which are more reliable under these conditions.

For dial pulsing in the incoming loop-disconnect signalling units, pulse distortion aspects and the required number of operations precluded the use of a BPO Type-23 relay. A detailed investigation was undertaken to determine the most appropriate type of relay for this application. It was decided that safeguards were needed to limit in-rush currents on contact closure and, in the case of mercury-wetted reed relays, connexion of the negative wire (during pulsing) to the moving contact to reduce the effect of arcing. Extensive tests were subsequently carried out and only certain mercury-wetted reed relays and a diaphragm relay were approved for use in this particular application.

An optically-coupled transistor is used for the detection of the 2-wire polarity in the incoming loop-disconnect signalling units. (Many problems were experienced on the 24-channel PCM signalling units using relays or transistors; the problems were due to the high line-current that can flow, and from high transient voltages resulting from subsequent equipment.)

On the extended range of 30-channel PCM signalling units currently under development, the type of components and general designs used will be the same as that adopted for the initial designs. Where space is at a premium, consideration is being given to the use of thick-film resistor networks.

TITLING OF 30-CHANNEL PCM SIGNALLING UNITS

A new method of titling was evolved to aid recognition of 30-channel PCM signalling unit types. The form of the title is *Signalling Unit PCM No. XXX*. A letter-figure-letter format is used for the *XXX* designation. The first letter indicates the type of access; the figure indicates the type of signalling and the final letter differentiates between PCM signalling units having the same type of access and the same type of signalling, but which cater for different ranges of facilities.

FUTURE DEVELOPMENTS

A second generation of the BPO 30-channel PCM system is planned to utilize a new transmission equipment practice for electronics (TEP1 (E))†. The signalling units manufactured in the new equipment practice could employ various technologies; for example, complementary-symmetry/metal-oxide semiconductor (COS/MOS) integrated circuits, custom MOS, uncommitted logic arrays (ULA) or microprocessors. A major objective of such redesign is to improve export potential.

A study has been carried out by the BPO to determine the feasibility of using a microprocessor to control a signalling unit. A microprocessor-controlled outgoing loop-disconnect signalling unit is shown in Fig. 39. This signalling unit caters for a large number of facilities, thus reducing still further the number of signalling unit types that would need to be produced. Additionally, the same printed-wiring board could be used for all the outgoing 30-channel loop-disconnect signalling units currently specified.

There are other facilities (for example, signalling for out-of-area exchange lines) and other signalling systems which could be extended over a PCM system and which could be included in a second generation 30-channel PCM system equipment design.

† TEP1(E) will be described in a future article in this *Journal*

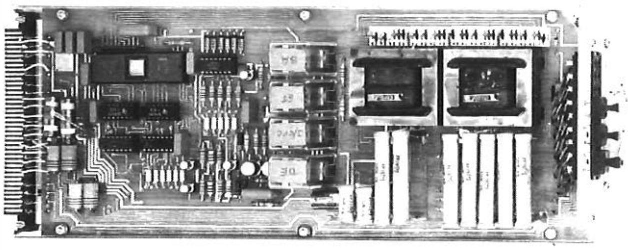


FIG. 39—Microprocessor-controlled outgoing PCM signalling unit

CONCLUSIONS

Over the last 2 years, an initial range of 30-channel PCM signalling units from 5 UK manufacturers has been extensively tested and a field trial of some unit types has been carried out under live-traffic conditions.

No serious problems were found and there were no essential differences between a unit of one manufacturer and that of other manufacturers. All 5 UK manufacturers have gained the necessary type approval from the BPO for all 12 signalling units in the initial range; that is, those signalling units that replicate the facilities available for the 24-channel PCM system. The operational and compatibility problems of the 24-channel PCM signalling units have been eliminated in the 30-channel PCM signalling units. The use of integrated circuits and more appropriate relays should lead to greatly improved reliability.

To provide additional facilities, the development of 9 PCM signalling units is well under way, with a further range planned for a second generation of 30-channel equipment.

ACKNOWLEDGEMENTS

The author wishes to thank associates in GEC telecommunications Limited for their assistance and co-operation during the development of signalling units for the 30-channel PCM system, and to those colleagues in the BPO for their assistance during the preparation of this article.

The circuit details have been reproduced by kind permission of GEC Telecommunications Limited.

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Measurement and Analysis Centres: Software Design

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UDC 621.395.31: 621.395.36: 681.3.06

Earlier articles[1, 2, 3] published in this Journal have described the operational aspects and equipment design of measurement and analysis centres (MACs), which provide facilities to measure automatically the quality of service given by the British Post Office public switched telephone network. This article, which is the last of the present series, discusses the MAC software design, which controls the sending of test calls and provides the facilities to analyse and record the results of the various MAC test programs.

INTRODUCTION

Earlier articles[1, 2, 3] in this *Journal* have described the British Post Office's (BPO's) need for measurement and analysis centres (MACs), the basic equipment employed, and its use. The most recent article[3] explained the design features of the hardware of the MAC equipment and introduced the techniques that the MAC system uses to create and monitor test calls. This article describes the software design of the MAC equipment. The software is required to respond to all input data and console commands, and is responsible for the control of all test call sending and for the analysis and generation of test call results. All the software in a MAC runs on a GEC 2050 minicomputer.

SOFTWARE STRUCTURE

The MAC application software is functionally split into 7 sub-systems, and communication between sub-systems is either by direct control or via data transfers. An additional sub-system, known as the *system-environment* sub-system, comprises a number of software routines standard to the GEC 2050 minicomputer, including device-control programs and the program to control the handling of interrupts. The relationship between the sub-systems is shown in Fig. 1. Four sub-systems are permanently housed in the minicomputer primary store (core store); these are the *system-environment*, *call-management*, *make-call* and *control-and-identify* sub-systems and it is these that are said to constitute the *real-time* software.

There is insufficient space in the main store to accommodate all of the programs. Therefore, programs that are little used are stored in a secondary store (known as *disc storage*). When one of these programs is required, it is brought into the primary store and placed in a reserved area called the *overlay area*.

The programs of the other 4 sub-systems are all overlaid into the single overlay area in the core store. These sub-systems are known as the *session-transitions*, *console-commands*, *report-generation* and *data-input* sub-systems. In total, these sub-systems comprise nearly 100 programs, operating on 6 priority levels, and they represent 10 times as much software as is resident in the core store. These sub-systems are not time critical and, therefore, the time taken to perform an overlay operation is not important.

The principle functions of each sub-system are summarized below.

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System-Environment Sub-System

The principle functions of the system-environment sub-system are

(*a*) the provision of the interrupt structure,

(*b*) the provision of the interfaces to disc, magnetic-tape cassette, keyboard printers and the transmission level check facility,

(*c*) message preparation, and

(*d*) the organization of the overlay procedures.

Data-Input Sub-System

The functions of the data-input sub-system are

(*a*) the acceptance of data from the magnetic-tape cassette or keyboard printer, and

(*b*) the preparation of operational files for the current month or the next month.

Console-Commands Sub-System

The function of the console-commands sub-system is the acceptance and processing of console commands.

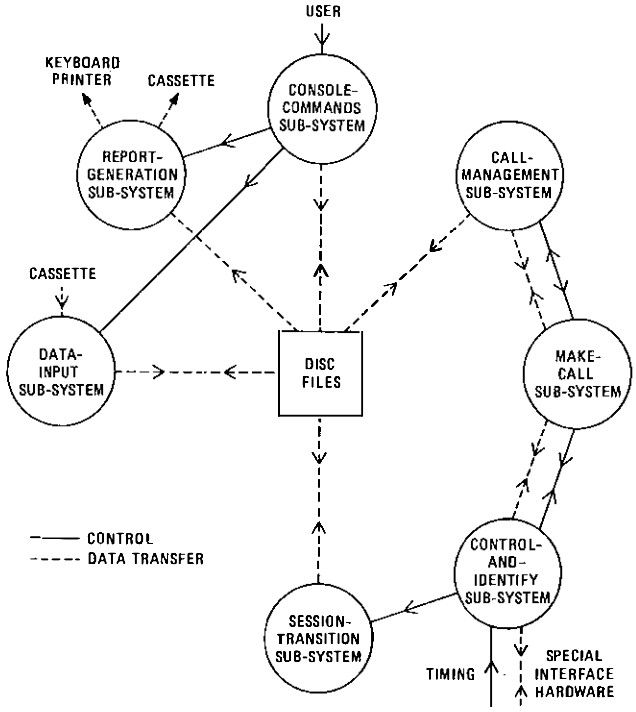


FIG. 1—MAC sub-system interfaces

Call-Management Sub-System
The functions of the call-management sub-system are

(*a*) the scheduling of calls at their correct times,
(*b*) the preparation of details of the call to be made, and
(*c*) recording the results of test calls.

Make-Call Sub-System
The function of the make-call sub-system is the initiation of calls using appropriate protocol.

Control-and-Identify Sub-System
The functions of the control-and-identify sub-system are

(*a*) the provision of an interface to the special interface hardware (SIH) for the make-call sub-system,
(*b*) maintaining system clocks,
(*c*) maintaining system time-out lists,
(*d*) time-sharing 30 senders through the makc-call sub-system, and
(*e*) the identification of supervisory tones.

Session-Transitions Sub-System
The function of the session-transitions sub-system is to perform scheduled operations at specific times of day.

Report-Generations Sub-System
The report-generation sub-system is responsible for initiating the preparation of reports on the results of sequences. Such reports are produced, on demand, daily and at the end of a measurement month.

MAC Priority Levels

There are 2 principal levels of program activity in the GEC 2050 minicomputer, these are known as the *base* level and the *interrupt* level. The central processor normally executes programs in *base* level, but control can be passed to the *interrupt-level* program to deal with a more urgent task. This transfer of control to the *interrupt-level* program can be initiated by a peripheral device, by certain hardware conditions, or by a special sequence of instructions obeyed in a *base-level* program.

Interrupt Level
The programs that run at interrupt level are themselves uninterruptible and, in consequence, must be short in length and fast in operation to deal with time-critical events. The general-interrupt-control program (GICP) responds to an interrupt, determines the interrupt type and causes appropriate action to be taken. The action could be entry to code at base level or entry to one of the other programs at interrupt level. The functions of these other programs are

(*a*) to respond to interrupts from the basic timer,
(*b*) to respond to interrupts from the SIH, and
(*c*) to respond to interrupts from the watchdog control and interrupt unit.

The watchdog control and interrupt unit enables the operation of the computer system to be monitored periodically, and an alarm signal is generated if failure is detected.

The interrupt-level programs form part of the control-and-identify sub-system.

Base Level
The remainder of the software runs at base level, which is divided into 18 separate priority levels. When base level is entered from interrupt level, the highest priority level that currently requires attention is activated. The allocation of base levels is shown in Table 1.

There arc a number of factors to be considered when selecting the appropriate priority level at which a program should operate. These are the time it takes to execute the program, the response time required, the frequency at which the program is executed, and the method of program use.

TABLE 1

MAC Priority Levels

Level		Programs and Sub-Systems
Interrupt level		GICP, time scan, line scan, watchdog control
Base level	0	Time control
	1	Disc device-control program (DCP)
	2	Magnetic-tape cassette DCP
	3	Transmission level check DCP
	4	Makc-call and line control
	5	Call management
	6	Teleprinter DCP (office)
	7	Teleprinter DCP (computer room)
	8	Dummy-messages control
	9	Claim teleprinter
	10	Session transitions
	11	Console commands
	12	Report generation
	13	Data input
	14	Messages
	15	Despooler
	16	Console-commands active level
	17	Initial active lcvel

Programming Languages

Two programming languages are used in the MAC system. The majority of the programs are written in the BPO-preferred high-level language known as *CORAL*, which is a programming language for real-time systems.

For one or more of the following reasons, the remaining programs arc implemented in the GEC 2050 assembler language:

(*a*) the program is time critical, and the use of *CORAL* would not generate code that was as efficient;
(*b*) the program is an item of the GEC 2050 minicomputer standard software, which is all produced in assembler language; or
(*c*) the program required contains a number of functions that cannot be implemented in *CORAL*.

INPUT/OUTPUT AND STORAGE OF DATA

The software of a MAC is stored in either the 48 kbyte core store of a GEC 2050 minicomputer or on a 4·8 Mbyte disc. At each MAC, there is a total of 500 kbytes of program capacity, the majority of the programs are held on the disc and are read into core store when they are needed.

Use of the Core Store

A program capacity of 40 kbytcs is permanently resident in the core store; this capacity is used for the "operating system" and the real-time software. Also in the core store is a 3 kbyte area comprising a call-activity record for each test trunk which contains data relating to the call currently being made. The remaining 5 kbyte of the core store capacity is used to hold the programs for session transitions, data input, console commands and report generation. These programs are brought into the core store from the disc as required, and they all use the same overlay area.

Use of Disc Storage

The moving-head disc is the hub of the MAC system. Most of the programs are stored on this disc, together with all the data describing the exchange units to be measured and the calls to be made. All results are recorded on the disc and, thus, the MAC system can be described as being *disc based.*

Each MAC has a fixed disc and an exchangeable disc, both operating on the same spindle. The heads of both discs are driven by the same activator mechanism. Consequently, a SEEK command on one disc positions the head of the other

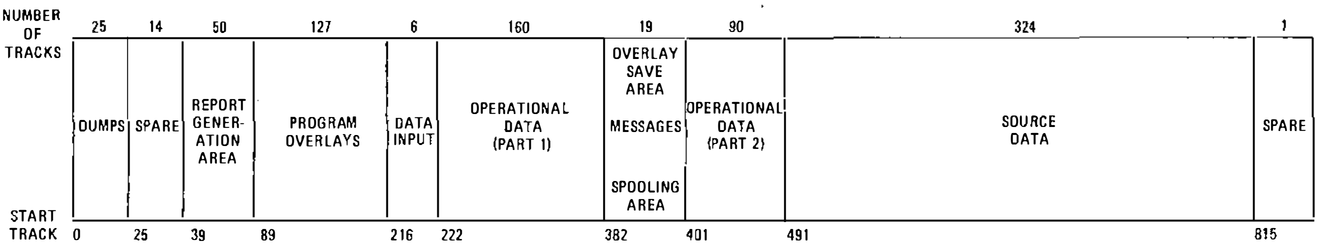


FIG. 2—Disc storage

disc over the same track. This saves considerable time when copying one disc to the other. However, concurrent operations on both discs are not possible.

During normal operation, a MAC uses the fixed disc for forming the routing details and recording the results of all test calls. The exchangeable disc is used when inputting copies of the overlaid programs. If the programs were on the fixed disc it would not be possible to start up a MAC system with an empty fixed disc. Each day, the results on the fixed disc are archived to the exchangeable disc, which is removed and replaced by a second exchangeable disc. Because the archive is retained for only a day, 2 exchangeable discs are required for this purpose; a third exchangeable disc is used during the data input process.

The organization of the data in the core and on the disc is designed to keep the number of disc accesses per call to a minimum. This is necessary because the time to execute a process is made up almost entirely of the disc accessing times and, when more than one process is being executed, delays could occur if the disc access request of one process has to wait until the disc accesses of other processes have been completed.

The average time for a disc access is optimized by the layout of the data on the disc. This is designed so that the head movement of the disc mechanisms is minimized during the recording of the results of a call and the preparation of the next call. The head of the disc remains over the track that was last read and, thus, the most frequently-used data (the operational data) is grouped together, and the less-used source and other data is positioned outside this. In the middle of the operational data are frequently-used temporary-save areas, which are used by the overlay organizer and the messages and spooling processes. This layout reduces significantly the time taken to reach the track to be read, and thus reduces the total time to read or write a file on disc. This layout is the same for all discs on all the MAC systems, even though some data items may not be used.

All disc accesses are controlled by the call-management sub-system which, in turn, calls the disc device-control program. This procedure has 3 advantages:

(*a*) the head movements of the disc are optimized by the call-management sub-system during the processing of a call and this optimization cannot be disturbed by other random user accesses to the disc;

(*b*) disc files must be locked out while they are being updated and updates of files by the call-management sub-system cannot be interrupted (this implies one controlling program that cannot be interrupted); and

(*c*) the call-management sub-system can implement error recovery.

The layout of the disc storage is shown in Fig. 2.

As discussed earlier, the MAC sub-systems are divided between those representing the real-time software of the system, and those that do not and reside on disc. A brief description of the non-real-time disc-resident sub-systems follows.

Session-Transitions Sub-System

All programs forming the session-transitions sub-system are written in *CORAL*, overlayed, and operate at the 10th base priority level. This sub-system is responsible for performing the majority of the functions occurring at specific times; for example, change of tariff period and start of a sending session.

Data-Input Sub-System

The programs in the data-input sub-system are written in *CORAL* and are overlayed; the majority of the programs operate on the 13th base-priority level. The other programs operate on the console-command level (level 11).

Typically, the MAC system requires 500 000 bytes of data to describe the interactions with the telephone network, the telephone exchange units to be measured and details of the sequences to be run. The majority of the data is input to a MAC via magnetic-tape cassettes; the tapes are prepared at Telecommunications Headquarters. Data can also be entered from a keyboard printer, but this data will not have been validated. The data from both sources is in International Organization for Standardization 7-unit code and is not readily usable by a MAC. It is a function of the data-input sub-system to translate this data into a machine binary form that is called *operational data*. The sub-system also stores the operational data and the original data (known as *source data*) on a dedicated exchangeable disc.

Report-Generation Sub-System

All programs forming the report-generation sub-system are written in *CORAL*, overlayed, and operate on the 12th base priority level.

This sub-system is responsible for printing most of the reports requested by the user, printing all the reports at the end of the measurement month, and outputting the results of the measurement sequences to a magnetic-tape cassette in a form suitable for further processing by the BPO Data Processing Executive.

Console-Commands Sub-System

All programs forming the console-commands sub-system are written in *CORAL*, overlayed, and operate on the 16th base priority level.

This sub-system is responsible for accepting all, and processing the majority of, console commands. These commands provide the user with the means of controlling the detailed operation of the MAC system.

REAL-TIME SYSTEM

As discussed earlier, the real-time software consists of 4 sub-systems, and 3 of these are described in more detail overleaf. (The fourth, the system-environment sub-system, was discussed earlier.)

Call-Management Sub-System

The call-management sub-system contains a program also known as *call management*, which is considered to be the central controller of the rest of the real-time software. This program is responsible for the scheduling of calls, for the formation of all the information necessary to make a particular call and for the recording of the results of a call. It also provides the interface to the disc files for the remainder of the MAC system. It is the largest program in the MAC system, occupying about 20 000 bytes and is written in *CORAL*. The call-management program is a very large program by most standards and it could have been split into a number of separate programs, but this would have increased its total size.

The call-management program is implemented as a number of *CORAL* segments; the allocation of functions to segments is given in Table 2.

TABLE 2

Functions of the Call-Management Program

Segment	Function
A	Control, disc, message spooling
B	Record results
C	Calculate time of next call, schedule next call
D	Form call-activity record, results printing, early morning checks

The main path through the call-management program for an individual call is shown in Fig. 3.

The form call-activity record segment of the call-management program is entered when a call is to be made. Various disc files are accessed to get the data for the call-activity record (CAR), which provides the make-call sub-system with all the information required to make a call. There is a separate CAR for each test circuit.

The record results segment updates various counts, checks the results for the call just completed and enters failures into the maintenance sequence (analysis sequence 1) when appropriate. It also causes various fault-report messages to be printed.

The calculate-time-of-next-call part of the call-management program is in the same segment as the schedule part of the program. Its purpose is to calculate the time for the next call to be performed in a measurement or analysis sequence, and to record this time in the sender time list file (STLF).

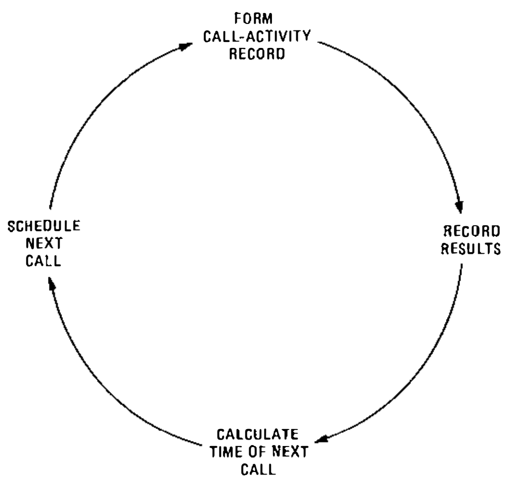


FIG. 3—Main call-path through the call-management program

The schedule part of the call-management program determines the next call to be made on the current test circuit. If there is no call to be made immediately, the program requests an event time-out on that test circuit until the next call is due.

Make-Call Sub-System

The make-call sub-system contains only a single program, which is also known as the *make-call program*, and this program occupies about 5000 bytes and runs at base-level 4.

The make-call program is written in *CORAL* and resides in the core store. The functions of this sub-system are to make calls simultaneously on up to 30 test circuits and to implement the relevant call protocol. The make-call program uses the information contained in the CAR to initiate a call; the CAR contains details that define the characteristics of a call. Some parts of the CAR are used during the call as a workspace by the make-call program. When a call is complete, the make-call sub-system places the result of the call in the CAR. When control is returned to the call-management sub-system, the results of the call are recorded on the disc, and the details of the next call are prepared. The program is "re-entrant" and is used by a program of the control-and-identify sub-system to maintain simultaneous activity on up to 30 test circuits, using a single copy of the program.

Within the control-and-identify sub-system, the multiplexing of the 30 test circuits is achieved by the line-control program. For a particular call, the line-control program is entered whenever the make-call sub-system is required to dial a digit, look for a signal tone being returned from line, or to initiate a disc transfer via the call-management sub-system. After noting, in the CAR associated with the test circuit concerned, the return point in the make-call program (the point at which the make-call program must be restarted when the required function has been performed), the line-control program initiates the program that provides the required function. Soon after the function required by the test circuit has been completed, the make-call instruction is entered at the return point for that test circuit. It may well be that the make-call instruction has been entered several times for the control of other test circuits between this particular call of line control and re-entry, but the make-call sub-system is not aware of this. However, the design of the make-call sub-system differs in one way from that necessary for processing a single test circuit. Obviously, it is not possible to rely on data in a local workspace controlled by the make-call sub-system, since this will be changed if, during a call to line control, the make-call program and its associated workspace is used to process other test circuits. Consequently, all data that must be retained is kept in the workspace of the CAR.

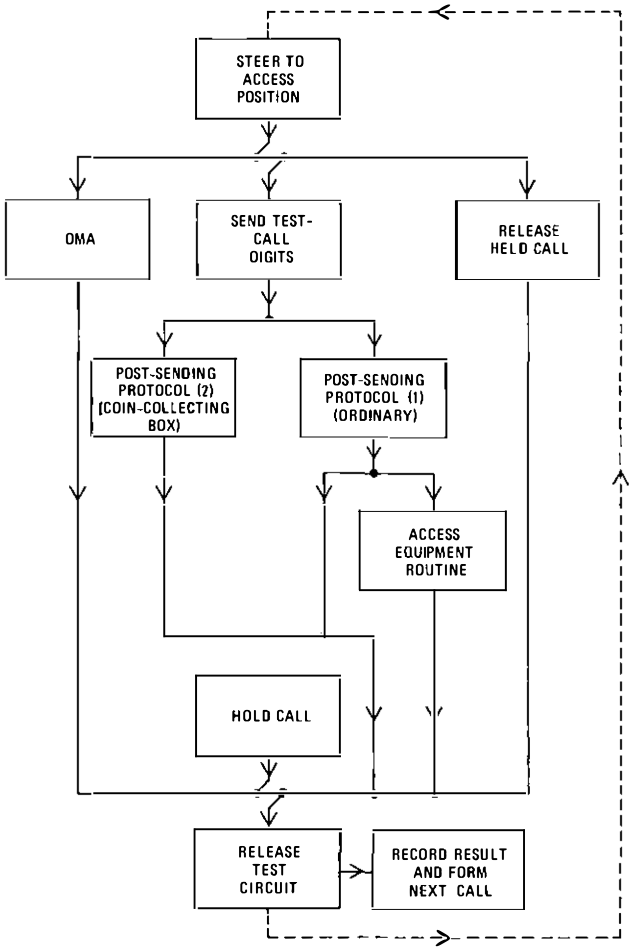
The make-call sub-system control program includes a number of procedures, each of which implements a call protocol. The structure of the make-call sub-system is shown in Fig. 4; the protocol for steering to the required access position in the access equipment at the exchange is common to all types of call. The next phase of the call may be a digits monitoring analysis (DMA), the sending of the test-call digits for a test call, or the release of a held call. Thus, it can be seen that the make-call sub-system is constructed in a modular fashion, since particular phases of a call are common to a number of different types of call, and duplication of a code is unnecessary. There are many permutations of possible paths through the make-call sub-system because test calls can be derived from combinations of routing and facility characteristics. For example,

(*a*) calls may be routed over lines used for subscribers' or coin-collecting box services,

(*b*) second meter-pulse check or second pay-tone check may be required, or

(*c*) transmission level check may be required.

Other types of calls handled by the make-call program are early morning checks and DMA calls.



DMA: Digits monitoring analysis

FIG. 4—Structure of the make-call sub-system

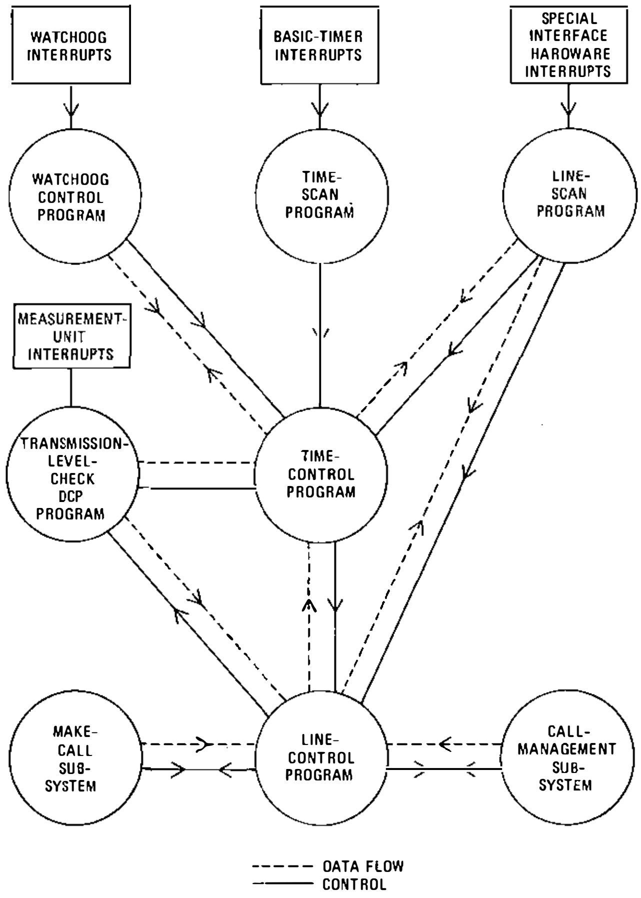


FIG. 5—Control-and-identify sub-system interfaces

Control-and-Identify Sub-System

The control-and-identify sub-system contains 9 programs, occupies about 5000 bytes and is core resident. All the programs are written in assembler language because many of the operations involving direct control of the special interface hardware (SIH) cannot readily be achieved in *CORAL*. Also, the operation of these programs is time critical and so assembler language is used for greater efficiency of the compiled code.

The 9 programs of the control-and-identify sub-system are

(*a*) time scan,
(*b*) line scan,
(*c*) watchdog control,
(*d*) time control,
(*e*) line control,
(*f*) seek match counts,
(*g*) interval,
(*h*) event, and
(*i*) transmission level check disc device-control program (DCP).

The time-scan, line-scan and the watchdog-control programs operate at interrupt level, and time-control and the transmission level check DCP programs operate at high priority base levels. The line-control program operates on the make-call priority level 4 as a procedure of the make-call sub-system. The seek match counts, interval and event programs are used as procedures of the calling programs.

A brief description of the functions of the more significant programs within the control-and-identify sub-system is given below. The interfaces within the control-and-identify sub-system are shown in Fig. 5.

The line-scan program is of particular interest because it accepts the interrupts from the SIH and processes them in accordance with the mode of operation for a test call specified by the line-control program. This processing includes the updating of the counts (via the seek-match-counts program) used by the tone identification algorithm. The method of tone identification employed by the MAC system has been described in detail in an earlier article[2].

The line-control program acts as the interface between the make-call and call-management sub-systems and provides the make-call sub-system with access to the SIH. The line-control program also acts as the test circuit multiplexer. The functional part of the line-control program is used to control a variety of functions, including counting frequency transitions on the line in a given time, looking for a specific frequency to be present on the line, dialling a digit, and identifying supervisory tones on the line. After completion of each function, the line-control program accesses the multiplexing section to check whether any other functions have been completed on other test circuits, indicated by the associated CAR-state byte being zero. This check is performed by cycling through all the CARs and, to avoid giving preferential treatment to any particular test circuit, the check is commenced at the test circuit immediately after the one just processed.

The time-scan program maintains the interval timer and schedules the time-control program. The watchdog-control program updates the time-of-day clock and activates the time-control program if the earliest event time-out in the system timeout table has expired. The time-control program is used to determine if a time-out has expired and to initiate any action necessary.

PERFORMANCE AND CAPACITY

In the preparation of the MAC system specification, much consideration was given to the method of specifying the maximum load-handling capability. The maximum load situation is dependent upon a number of parameters, which include:

(*a*) the number of test circuits in simultaneous use,
(*b*) the number of measured exchanges,
(*c*) the average duration of test calls,
(*d*) the failure rates of test calls, and
(*e*) the type of calls originated.

Certain types of calls present a heavier load than others in terms of processing time and number of disc accesses required; for example, the complexity of controlling a coin-collecting box (CCB) call is greater than that of an ordinary call. However, the MAC system was required to cater for CCB calls in the same ratio as such calls are to be found in the network (approximately 1 in 10). It would not have been meaningful to specify a maximum load handling capability in terms of an abnormal distribution of types of calls. Instead, the MAC system was specified to cope with the normal balanced load of types of calls that would be expected to occur in practice.

The performance result of a test call also affects the load on the system because failures involve more complex processing at the end of the call. Again, the MAC system was required to cope only with the normal balanced distribution of failures expected on the network, not simultaneous failures on every line. If simultaneous failures occur, the system will perform in a degraded manner.

The durations of different types of test calls vary according to a number of factors which include the type of call (for example, own-exchange, local-dialling-area or STD calls), post sending delay, and whether or not a transmission test or a second meter-pulse check is to be performed. Because the durations of test calls vary, the use of the MAC calling rate on each test circuit as a measure of performance was precluded. In the specification for the MAC system, the maximum workload handling requirement is expressed, in general terms, as 50 calls/min, but this is not a critical requirement.

The objective ways of assessing system performance are by measurement of

(*a*) the level of test circuit utilization,
(*b*) delays occurring within test calls, and
(*c*) the response time to various commands.

The bottleneck governing maximum system throughput is the contention for the use of the disc; this problem manifests itself in the form of delays in the call management function, resulting in a reduction in test circuit utilization. The peak disc accessing load occurs when a test call is being released and, under these circumstances, a contention condition can arise. The processing performed at the end of each call is the running of the call-management program; the program running time of 0·5 s is virtually dependent on the number of disc accesses since any CPU processing required can always be performed within one disc revolution. In the worst case (30 lines releasing simultaneously), 6 test circuits would be ready before the expiry of the 3 s line-release delay between test calls, and the remaining 24 would become ready at 0·5 s intervals. The worst case delay would be 12 s and the average delay would be 6 s. Therefore, it is necessary to ignore the spasmodic occurrence of long delays between test calls and, instead, concentrate on the average delay. The peak load handling ability was tested using a second GEC 2050 computer to simulate the telephone network. This test showed that the MAC system was able to support continuous sending of test calls on 30 test circuits, without delays in excess of 3 s occurring between calls.

Heavy loading on the system may not necessarily manifest itself in the form of delays between test calls. Instead, the calls themselves may be prolonged. This is so because, within a call, there are a large number of activities taking place that are under the control of the make-call sub-system, whereas the call-management sub-system is involved only once per call. Therefore, the probability that contention will arise between test circuits for the use of the line-control program (and make-call program) is much higher. The effect sought during the peak load test was a lengthening of inter-digital pause durations (and various other timings within the protocol), but it was demonstrated that this effect did not occur to any appreciable extent.

The console-commands programs are run at the overlay level and are one of the first to be affected by heavy loading. It is possible for the real-time system to be running perfectly and for the call-management and the make-call programs to be running normally, but for the console-commands programs to be completely shut-out. When the load is increasing, if the point is reached where the console commands program is shut-out, then this can serve as a useful early indication that the system is nearing maximum capacity. There are a large number of commands available, but there are only a few where the execution would be immediately noticeable. For example, it would be difficult to know accurately the time at which a test number was changed or an access position was deleted. The choice was therefore restricted to those where an output occurs on the keyboard printer immediately after execution. Again it was demonstrated during the peak-load test that this effect did not occur to any significant extent.

CONCLUSION

This article has outlined the structure of the MAC software and the considerations that have been given to its design. The software has proved to be reliable in normal operation and has attained the required performance. The modularity of the design has also meant that a number of subsequent software enhancements have been introduced easily.

ACKNOWLEDGEMENTS

The MAC software was developed by GEC Computers Ltd., in close technical co-operation with the BPO Telecommunications Development Department. The success of the development is a tribute to the expertise of GEC Computers Ltd. and the authors wish to acknowledge the valuable work of their development team.

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Optical-Fibre Transmission Systems: Properties of the Fibre Cables Installed for the 8 Mbit/s and 140 Mbit/s Feasibility Trials

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UDC 621.391.63: 666.2

This article concludes a series of articles published in this Journal which have described the 8 Mbit/s and 140 Mbit/s optical-fibre feasibility trials[1–4]. *In this final article, the transmission performance of the installed cable routes are described.*

INTRODUCTION

This is the last in a series of articles summarizing the results and experience obtained on the recent optical-fibre feasibility trials. Previous articles have described the results of the system trials [1, 2], the cabling and jointing techniques[3] employed and the cable-testing methods adopted[4]. This article discusses the transmission performances of the installed cable routes. At the same time, an attempt is made to update the reader on the general transmission properties of 'state-of-the-art' optical-fibre cables.

In total, some 40 km of graded-index fibre was installed in operational ducts running between the British Post Office (BPO) Research Centre at Martlesham and the group switching centre at Ipswich. The fibre was manufactured by Corning Glass Works (USA) and cabled in 1 km lengths by BICC using their 2-fibre PSP design[5]. The installed cables were jointed to form 2 links of 5·75 km length and one of 7·25 km length (see Fig. 1). The highest bandwidth fibres were reserved for one of the 5·75 km links and this route has since been used for system trials at 140 Mbit/s[2]. The other 2 routes have been used for 8 Mbit/s trials[1].

This article outlines the measurement programme and the principal transmission results which are presented and discussed under the main headings of loss and bandwidth. Also described, are the results of some backscatter (or pulse echo) measurements which have been carried out more recently on one of the cable routes. The article concludes with a summary and a discussion on the future trends in the transmission performances of optical-fibre cables.

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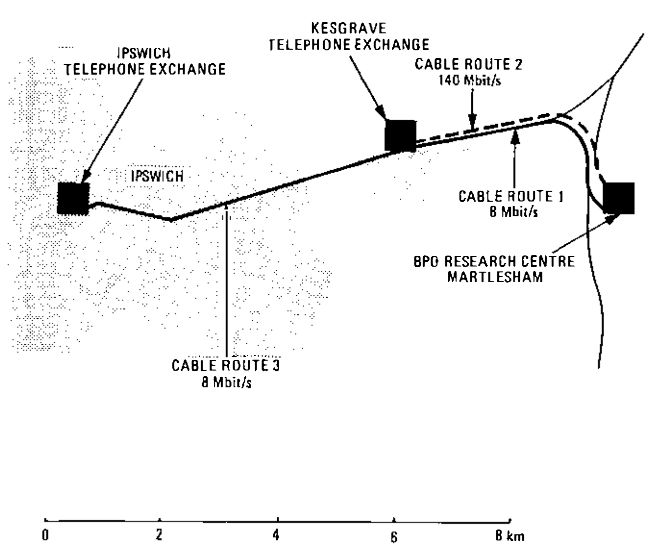


FIG. 1—Location of the cable routes

MEASUREMENT PROGRAMME

The 2 principle transmission parameters of optical-fibre cables are insertion loss (that is, the loss at zero baseband frequency) and modulation frequency response (or bandwidth); measurements of these 2 parameters were carried out on the 1 km lengths of optical fibre at all stages of the cabling and installation process. The fibres for cable routes 1 and 2 (see Fig. 1) were measured before cabling, and these results assisted in the selection of pairs of fibres to be cabled together. The criterion adopted was that fibres of similar bandwidth should be cabled together to give the maximum chance of obtaining balanced bandwidths on the 2 channels of the completed links. The transmission measurements were repeated after cabling (on drum) and after the cables had been installed in duct. Cumulative measurements of loss and bandwidth were also made as the cables were jointed together. In the case of cable route 3 (see Fig. 1), a less exhaustive programme was followed in the light of earlier results. Cumulative measurements were carried out on the installed cables, but the 1 km measurements were confined to the cabled fibres on drum only. In the case of cable routes 1 and 2, the 1 km cables were installed in order of decreasing bandwidth whereas, for cable route 3, the installation sequence was specially chosen in an attempt to maximize overall bandwidth on one channel.

In addition to the above programme, the following measurements were carried out in the laboratory:

(*a*) Refractive-index profile distributions were measured for each fibre at a wavelength of 676 nm, using a modified version of the near-field scanning technique[6]. Some of the fibres were also checked using another technique based on a method described by Stewart[7]. The profile distribution of a graded-index fibre is conveniently characterized by an equation of the form[8],

$$\left.\begin{aligned} n(r) &= n_0[1 - 2\Delta(r/a)^\alpha]^{1/2}, \text{ for } r < a \\ n(r) &= n_0[1 - 2\Delta]^{1/2}, \quad \text{ for } r > a \end{aligned}\right\} \quad \ldots\ldots (1)$$

where, r = radial co-ordinate, a = core radius, n_0 = refractive index on the axis of the fibre, and Δ = fractional difference between the axial and cladding refractive indices.

The parameter α determines the shape of the profile distribution. Optimum bandwidth properties are achieved when the transit time differences between the many modes (typically 500–1000) propagating in the fibre are minimized, and this occurs for a near parabolic distribution when α is close to 2. A fibre with α greater than the optimum value (α_{opt}) is said to be an *under-compensated* fibre (that is, tending more towards a step index distribution), whereas $\alpha < \alpha_{opt}$ leads to an *over-compensated* fibre. Equation (1) was fitted by a least-squares method to all the measured index-profiles and equivalent α values obtained for each fibre.

(*b*) The material dispersion parameter was also measured; the equation for this parameter is

$$M(\lambda) = \frac{d\tau(\lambda)}{d\lambda} = -\frac{\lambda}{c}\frac{d^2 n_0}{d\lambda^2} \quad \ldots\ldots (2)$$

where $\tau(\lambda)$ is the group delay at the source wavelength λ.

The second major limitation to fibre bandwidth is set by material dispersion, which arises due to the finite spectral linewidths of optical sources and the fact that the refractive index of the fibre material is a function of source wavelength. The material dispersion contribution to pulse broadening in an optical fibre can be assessed by multiplying $M(\lambda)$ by the linewidth of the source and the length of the fibre. The parameter was measured for the fibre type by determining the bandwidth of a fibre with very low mode (or multipath) dispersion, using a light-emitting diode (LED) source with known spectral properties.

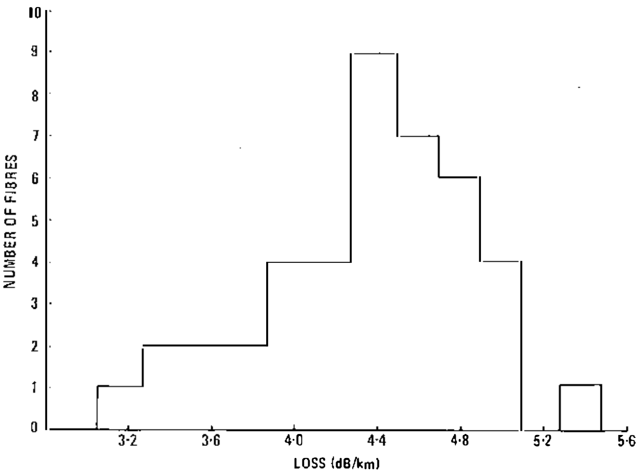
(*c*) The spectral characteristics of the sources (GaAs lasers and LEDs) used during the transmission measurements were determined using a grating spectrometer to facilitate the interpretation of material dispersion and wavelength-dependent loss effects on the cable links.

(*d*) Spectral-loss measurements were carried out on cable routes 1 and 2 after jointing, using laboratory-based equipment.

LOSS RESULTS

Measured Losses of 1 km Lengths of Fibres

A histogram of the losses of the fibres used in the trial is shown in Fig. 2. The data plotted is that measured at 820 nm on the cabled 1 km fibres prior to installation in duct. The losses of all the fibres were in the range 3·2–5·4 dB/km, with an average loss of 4·3 dB/km. This spread in loss characteristics is typical of fibre production at the present time. Loss variations within a batch are difficult to control and can arise due to



Note: The measurements were made at 820 nm on 1 km lengths

Fig. 2—Loss histogram of 42 cabled fibres

(*a*) fluctuations in impurity levels in the fibre basic materials (contaminants such as water (OH) and transition metals must be controlled typically to within the order of 1 part 10^9), and

(*b*) perturbations from the perfect waveguide structure (tiny variations in fibre core diameter and/or index difference can give rise to radiative loss through the walls of the fibre).

As fibre production techniques improve it is expected that loss histograms with narrower distributions about the mean will be achieved, but significant variations are likely to occur for some time to come and due allowance must be made for this fact when planning operational fibre-systems.

Table 1 summarizes the average losses and standard deviations measured for the fibres of the 3 cable routes at various stages in the cabling and installation programme.

TABLE 1

Losses of 1 km Lengths of Fibre

Measurement Stage	Cable Route 1 Mean loss over 12 × 1 km fibres (dB/km)	Cable Route 2 Mean loss over 12 × 1 km fibres (dB/km)	Cable Route 3 Mean loss over 16 × 1 km fibres (dB/km)
Fibre acceptance (820 nm)	4·25 (σ = 0·52)	4·39 (σ = 0·40)	—
Cable acceptance (820 nm)	4·27 (σ = 0·50)	4·31 (σ = 0·46)	4·31 (σ = 0·50)
Cable in duct (820 nm)	4·16 (σ = 0·32)	4·29 (σ = 0·34)	—

Particularly noticeable is the excellent stability of the average fibre-losses. For cable routes 1 and 2, the only routes for which exhaustive measurements were made, mean fibre-loss varied by no more than 0·1 dB/km throughout the cable manufacture and installation processes. This is thought to reflect the advantages of adopting a cable structure where the fibres are loosely contained within larger cavities[5]. Although optical fibres are not sensitive to macroscopic bends (that is, bends down to around 1 cm radius of curvature), their transmission characteristics can be significantly affected by large numbers of tiny bends (or departures from straightness) distributed along the whole length of the fibre.

This phenomenon, known as *microbending*, is perhaps the chief problem of the cable designer, who must ensure that the fibres are mechanically decoupled from their surroundings. The solution adopted by BICC (and others) seems very successful in this respect although further data, particularly on long term stability, is required before a definitive assessment can be made. The alternative approach to cable design, which employs a thick ($\approx$ 1 mm diameter) polymer coating to buffer the fibre from microbending effects, often leads to significant increases in average fibre loss ($\approx$ 0·5 dB/km) on cabling, although improvements in cabling technology may well eliminate this problem in the future.

In spite of the stability of the average fibre-losses, microbending effects were observed for a few individual fibres, and the full results for cable route 1 are shown in Table 2.

Loss increments are both positive and negative, with values ranging up to 0·9 dB/km. For the most part, these changes are due to experimental error since increments less than about 0·3 dB cannot be regarded as significant. However, the larger loss-increments are considered to reflect genuine changes in fibre performance. Significant loss-incre-

TABLE 2

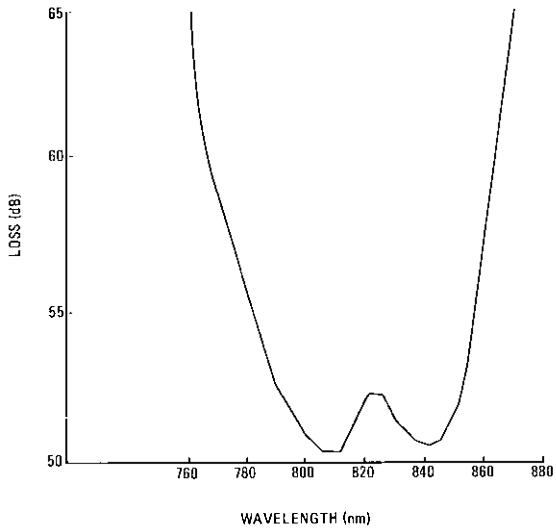
Loss Results: Cable Route 1 (820 nm)

Cable No.	Fibre No.	Loss (dB/km)		
		Cable on Reel	Cable on Drum	Cable in Duct
A	1 2	3·8 4·0	4·4 4·8	4·3 4·1
B	3 4	5·2 4·6	4·3 4·3	4·4 4·4
C	5 6	4·2 4·7	4·1 4·7	4·1 4·7
D	7 8	4·6 4·6	4·6 4·9	4·4 4·2
E	9 10	3·8 3·5	3·6 3·2	3·9 3·5
F	11 12	4·1 3·7	4·4 3·9	4·1 3·8

ments occur for only 4 fibres (Nos. 1, 2, 3, and 8). For fibres 1 and 2 (both in cable A), a loss increase has occurred on cabling, although the loss for fibre 2 has relaxed back to its original value on installation. For fibre 3, a loss reduction has been experienced on cabling, implying that significant microbending effects were present in the reeled fibre. For fibre 8, the loss reduction on installation implies that microbending effects were present in both the reeled fibre and cabled-fibre on drum. Results similar in character to the above were observed for cable route 2.

Cumulative Loss Measurements

A spectral loss curve, obtained on the installed cable route 1 with the fibres loop-jointed at one end to give a 11·5 km section length, is shown in Fig. 3. Noticeable is the small peak centred at 825 nm. The height of this peak if measured on the more usual 1 km length of fibre would amount to no more than 0·17 dB. Fig. 3 emphasizes particularly the need to choose system operating wavelengths with care for this type of fibre. The effective transmission window is confined to the range 800–850 nm and severe loss penalties result outside this range. It should be noted, however, that this is not fundamental to optical fibres. Much broader transmission windows can now be obtained with fibres containing lower levels of OH contamination. A virtually identical spectral-loss curve was obtained for cable route 2, which was jointed in similar manner.



Note: The 2 channels were jointed at one end to give a total length of 11.5 km

FIG. 3—Spectral attenuation of cable route 1

Table 3 shows the cumulative loss results for the installed cable routes 1 and 2. The predicted loss figures have been obtained by summing the losses of the individually measured sections. A comparison between the cumulative and predicted loss figures may, at first sight, seem a trivial exercise but, with optical fibres, this is not the case. The reason for this has been explained in a companion article[4]. Briefly, the problem is that the transmission characteristics of optical fibres can vary drastically, depending on the initial mode-distribution launched into them. Typically, for a 1 km length of the fibre used in this trial, loss figures can be obtained anywhere in

TABLE 3

Cumulative Losses for Cable Routes 1 and 2 (820 nm)

Route Length	Cable Route 1				Cable Route 2			
(km)	Channel 1		Channel 2		Channel 1		Channel 2	
	Cumulative Loss (dB)	Predicted Loss (dB)	Cumulative Loss (dB)	Predicted Loss (dB)	Cumulative Loss (dB)	Predicted Loss (dB)	Cumulative Loss (dB)	Predicted Loss (dB)
1	4·3	4·3	4·1	4·1	4·7	4·7	4·1	4·1
1·75	7·7	7·65	7·6	7·45	8·1	8·05	7·4	7·65
2·75	12·3	11·60	11·8	12·0	12·4	12·3	12·0	12·0
3·75	16·9	15·95	16·4	16·05	16·0	15·95	16·7	15·65
4·75	20·3	19·60	20·5	19·40	20·6	20·0	21·0	20·3
5·75	24·2	23·55	23·9	23·05	24·8	24·05	24·8	24·15
11·5*	50·0	46·45			49·7	45·05		

* Cable loop-jointed

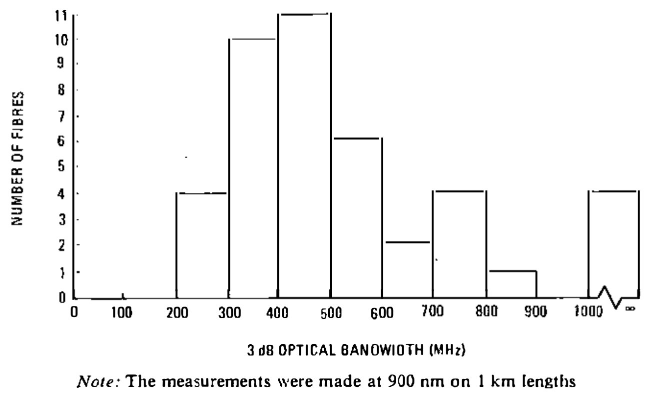
Note: All the 1 km losses used to obtain the predicted loss figures have been corrected to account for a spectral loss transient due to the LED measurement sources[9] the range 4–6 dB/km, depending on the launch conditions chosen. For long section lengths (⩾ 2 km), mode coupling and mode filtering effects arising from microbending and/or fibre production tolerances, lead to the achievement of a stable mode distribution which is independent of launching conditions. A launch distribution which approximates closely to this stable mode distribution must therefore be employed if loss results obtained on short lengths (1 km) of fibre are to be used to predict transmission performance for long jointed-section lengths (⩾ 2 km).

From Table 3, it can be seen that good agreement has been obtained with the cumulative loss figures, reflecting the fact that a stable mode launch was used in the measurements[4]. The predicted losses are somewhat lower than the measured cumulative losses because the effect of joints has not been taken into account. Unfortunately, it is not possible to accurately assess joint losses: this is due partly to measurement errors (≈ ±0·1–0·2 dB) and partly to uncertainties in the closeness of the match of the launch distribution to the stable mode distributions of the various fibres. In general, each fibre may have a slightly different stable mode distribution and the measurement distribution can only be a compromise. Moreover, the joints themselves may perturb the achievement of a stable mode distribution within a jointed sequence of fibres. However, from laboratory measurements made on sample joints, joint losses are known to be typically 0·3 dB or less, and this is broadly in line with the results of Table 3.

BANDWIDTH RESULTS

Bandwidths of 1 km Lengths of Fibre

A histogram of the bandwidths of the fibres used in the trial is shown in Fig. 4. The data plotted is that measured on the 1 km fibres prior to installation in duct. Fibre bandwidths ranged from 260–1600 MHz. This broad range in values reflects the difficulty of attaining and controlling the optimum index-profile distribution during the fibre production process. The problem can be better appreciated when it is realized that, although the optimum bandwidth for an α profile fibre is theoretically about 10 GHz for a 1 km length, a deviation of only 0·05 in α value is sufficient to degrade this figure by a factor of 20. An error of 0·05 in α corresponds to a peak refractive-index variation from the optimum of the order of only 0·0001. The actual range in α values measured for the fibres used in this trial was 1·6–3·1 and the reason for the broad spread in bandwidths becomes immediately apparent. In the future, it is expected that improvements in profile control will lead to higher average bandwidths and narrower spreads about the mean. However, the output from a fibre production process is never likely to yield fibres to a precise bandwidth specification, and due allowance for this fact must be made in the preparation of cable specifications and the planning of operational systems.



Note: The measurements were made at 900 nm on 1 km lengths

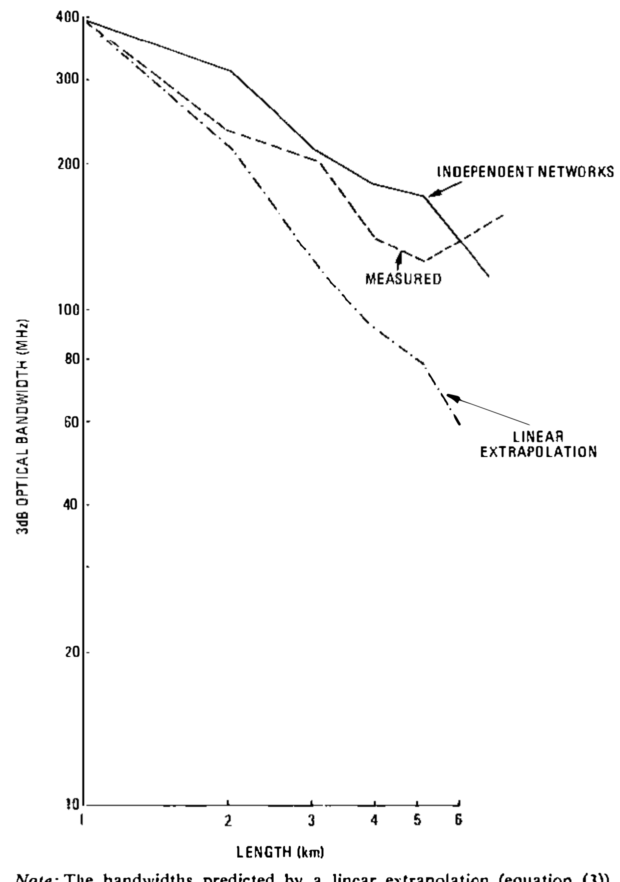
FIG. 4—Bandwidth histogram of 42 cabled fibres

The bandwidths of many of the 1 km lengths of fibre were found to be highly dependent on the initial launching conditions. This is a well known property of graded-index fibres which arises from the fact that, as launching conditions are changed, the distribution of optical power amongst the propagating modes also changes. Since, in general, each mode has a different transit time through the fibre this leads to variations in bandwidth properties. For this reason, efforts were made to standardize the launching conditions employed in the bandwidth measurements[4,9]. However, in spite of the precautions taken, results obtained at various stages in the cabling and installation processes show variations of, typically, 25%. These variations are thought to be due to residual launching effects, and improved methods for standardizing launching conditions are under development at the present time.

For longer lengths of fibre (⩾2 km), the measured bandwidths were found to be much less sensitive to launching conditions. This is due to the presence of mode coupling within the fibres which, over long lengths, leads to a breakdown in the relationship between transit time and mode number. In the limit of very long lengths, the power propagating in each of the modes becomes distributed over a range of transit times and, since this is similar for all modes, launching conditions become unimportant. Future improvements in fibre production and cabling technologies are likely to diminish the importance of mode coupling, and launching conditions may then become significant even for very long lengths of fibre.

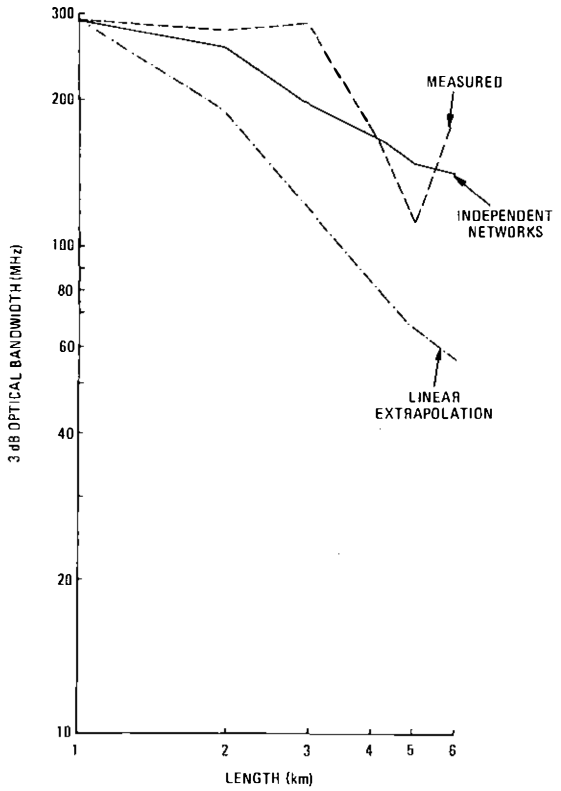
Cumulative Bandwidth Measurements

The cumulative bandwidth results of the 2 channels of cable route 1, measured as the cables were jointed, are shown in



Note: The bandwidths predicted by a linear extrapolation (equation (3)) and by the independent networks theory (equation (4)) are shown

FIG. 5—The cumulative bandwidth of cable route 1 (channel 1)



Note: The bandwidths predicted by a linear extrapolation (equation (3)) and by the independent networks theory (equation (4)) are shown

FIG. 6—The cumulative bandwidth of cable route 1 (channel 2)

Figs. 5 and 6. The fibres in this route had individual 1 km bandwidths in the range 260–610 MHz with an average bandwidth of 405 MHz. Noticeable, however, is the fact that the final bandwidths of the jointed links were still in excess of 140 MHz after 5·75 km. It was this fact that allowed preliminary system trials at 140 Mbit/s to be carried out on this route, which was initially only intended for 8 Mbit/s transmission[10]. The cumulative bandwidth results for all the installed cable routes, although favourable from a system point of view, are complicated by several interacting phenomena and cannot be characterized by simple models. This is illustrated in Figs. 5 and 6 where attempts have been made to predict the link performances from the measured bandwidths of the 1 km sections using 2 simple theories. The first of these, the linear extrapolation model[9, 11], assumes essentially that no mode-coupling occurs in the fibres and is governed by the equation

$$\sigma_{TOTAL} = \sum_{1}^{N} \sigma_N \qquad \ldots\ldots (3)$$

where σ_N is the pulse broadening (or impulse response width) due to the *n*th fibre section.

The second model, the independent networks model[9, 11], is described by the equation

$$\sigma_{TOTAL}^2 = \sum_{1}^{N} \sigma_N^2 \qquad \ldots\ldots (4)$$

and assumes that heavy mode-coupling occurs in the fibres. Better agreement is obtained with the latter model, but major anomalies are still apparent. Moreover, mode coupling, although undoubtedly a factor in determining the link performances, is not thought to be completely dominant in view of the launching effects described in the previous section.

The most marked anomaly occurs between the fifth and sixth kilometre sections in Fig. 6. This is due, at least in part, to step-like structure on the index profile of the fibre of the

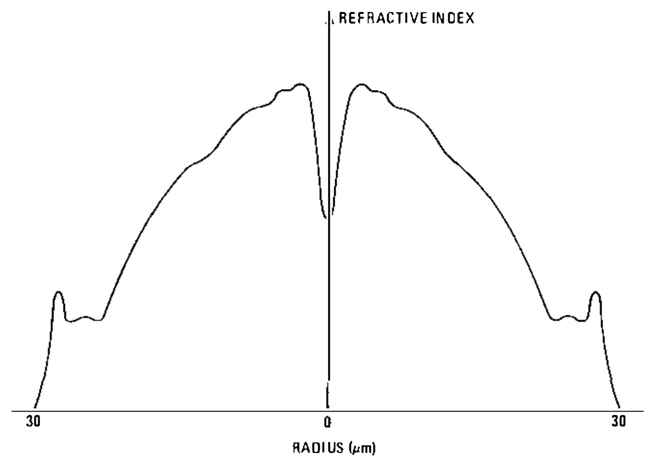


FIG. 7—The refractive-index profile of the fibre in the fifth kilometer section of cable route 1 (channel 2)

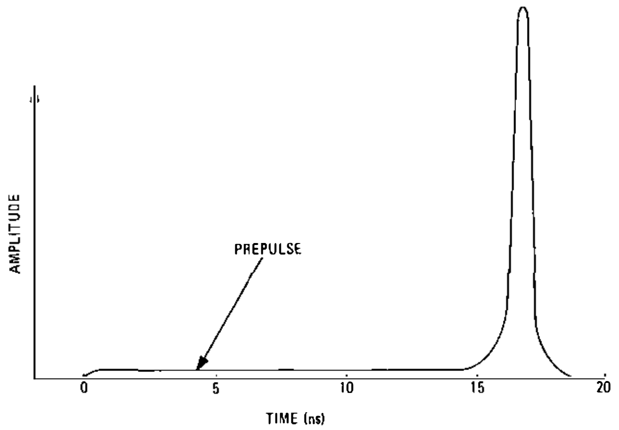


FIG. 8—The impulse response of the fibre in the fifth kilometre section of cable route 1 (channel 2)

fifth kilometre section (see Fig. 7) which leads to a long, low prepulse in front of the main fibre impulse response (see Fig. 8). The cumulative results show, however, that the prepulse has been filtered out by the sixth kilometre section, leading to a dramatic recovery in bandwidth. A similar but less marked effect is observable on channel 1 of the same cable, which also included a prepulse fibre at the fifth kilometre section. Only 2 fibres out of the entire 42 × 1 km batch exhibited this prepulse behaviour and the effect is unlikely to prove of long-term significance for optical-fibre systems. A suitable screening process, based on measurements of index profile and/or bandwidth, should enable such fibres to be removed at the fibre production stage prior to incorporation into cable.

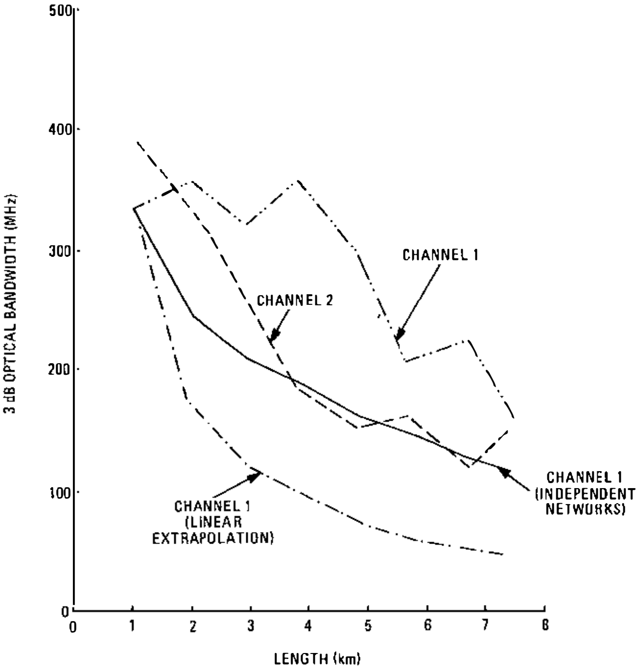
Other bandwidth anomalies are apparent in Figs. 5 and 6 for which the prepulse explanation cannot be invoked. For example, in Fig. 6, an increase in bandwidth has occurred between the second and third kilometre sections which has offset the fall between the first and second kilometre sections. This is due to partial equalization effects occurring between consecutive jointed fibres which have α values on either side of the value required for optimum bandwidth (α_{OPT}). If a fibre with $\alpha < \alpha_{OPT}$ is joined to a fibre with $\alpha > \alpha_{OPT}$, high-order modes, which are relatively fast in the first fibre, are relatively slow in the second fibre (vice versa for low-order modes) and a degree of equalization will occur provided mode-coupling effects are not dominant. It has been shown that the behaviour of a jointed pair of fibres can be quite generally described[11] by an equation of the form

$$\sigma_{TOTAL}^2 = \sigma_1^2 + \sigma_2^2 + 2r_{12}\sigma_1\sigma_2 \quad \ldots\ldots (5)$$

where σ_1 and σ_2 are the pulse broadenings (or impulse response widths) due to fibres 1 and 2 respectively, and r_{12} is a correlation coefficient between the 2 fibres. This correlation coefficient can take on values in the range:

$$-1 \leqslant r_{12} \leqslant +1 \quad \ldots\ldots (6)$$

depending on α_1 and α_2 and the amount of mode coupling present. For the cases, $r_{12} = +1$ and, $r_{12} = 0$, equation (5) reduces to the linear extrapolation and the independent network models previously described. However, when r_{12} takes on negative values (which occurs when α_1 and α_2 are on opposite sides of α_{OPT}), equalization can take place between the 2 fibres. Thus, it is possible, in principle, to joint together 2 medium-bandwidth fibres to produce a composite fibre with wide bandwidth. Following the observations made on cable route 1, an attempt was made to maximize equalization effects on one channel of cable route 3. Fibres were laid alternatively over- and under-compensated with, as far as possible, consecutive fibres having α values equally balanced about the optimum. The resultant bandwidth behaviour is illustrated in Fig. 9. The effects of material dispersion have been removed from this curve to clarify the multipath effect. On the optimized channel, the bandwidth up to 5 km is still very comparable with the bandwidths of the individual 1 km fibres used to make up the link. Unfortunately, at the sixth section it was necessary to use a fibre which was excessively over-compensated and this led to an irrecoverable fall in bandwidth. Equalization effects are, however, again apparent for the subsequent sections. On the unoptimized channel, equalization effects are also evident. These were not planned, but occurred whenever under- and over-compensated fibres were joined together. The bandwidth behaviours predicted for the optimized channel according to equations (3) and (4) are shown for comparison purposes. Particularly striking is the high bandwidth measured after the fifth section in comparison with that predicted by the independent networks model. Clearly, there is a possibility for the future that the bandwidths of installed cable routes could be optimized by alternating over- and under-compensated fibres. Using such a procedure, it might be possible to achieve high bandwidth, long-range links using relatively poor graded-index fibres. Ultimately, however, for the method to be successful, the practical gain in bandwidth would have to be sufficiently great to justify the more complex installation and maintenance procedures that would be necessary.



Note: The bandwidths for channel 1 predicted by a linear extrapolation (equation (3)) and by the independent networks theory (equation (4)) are shown. In all cases the effects of material dispersion have been removed

FIG. 9—The cumulative bandwidths of cable route 3 (Channels 1 and 2)

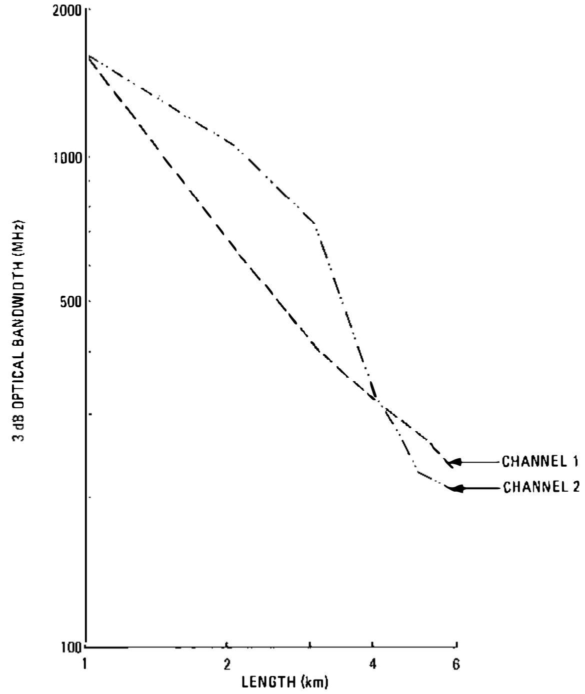


FIG. 10—The cumulative bandwidths of cable route 2

A factor that influences the usefulness of equalization in a jointed link is material dispersion. As profile control is improved in graded-index fibres it can be expected that the bandwidths of long jointed-links will become increasingly dominated by material dispersion effects. This would then lead to a simpler, inverse linear dependence of bandwidth on length. Equalization effects may, however, remain significant for lower bit-rate systems, employing lower quality graded-index fibre, and for longer wavelength systems (1–1·5 μm) where material dispersion effects are negligible.

Fig. 10 shows the cumulative bandwidth results for cable route 2. This is the wide-band link which used the highest-bandwidth fibres from the 40 km batch. The individual 1 km bandwidths ranged between 360–1600 MHz, with an average bandwidth of 890 MHz. The results for this route are most heavily influenced by material dispersion effects. Bandwidths for the shorter section lengths (1–2 km) on channel 1 are entirely material-dispersion limited. The interpretation of material dispersion effects has been complicated by the discovery of a 'chirp' effect in the measurement laser. Time-resolved spectral-measurements have shown that the centre wavelength of emission shifts to longer wavelengths within the duration of the input pulse to the fibre. Since the back end of the input pulse then has a faster transit time than the front end, pulse compression can occur, and this causes higher bandwidths to be measured than anticipated, particularly for very high bandwidth fibres. The effect is most serious for short (<1 km) lengths of fibre where output pulses can be measured which are narrower than the input pulses. Material-dispersion theory has been modified to include this phenomenon[12], and bandwidth results for very high bandwidth fibres can now be realistically interpreted. Using a measured value for $M(\lambda)$ of 85 ps.nm^{-1}.km^{-1}, it is estimated that the pulse broadening due to material dispersion alone on the two

5·75 km links is about 1·9 ns (1/e full-width). This is about three quarters of the total pulse broadening for the wide-bandwidth cable (cable route 2), and about half for the medium-bandwidth cable (cable route 1). Deconvolution of the material dispersion contribution from the measured overall bandwidths given in Table 4 leads to estimates of multipath bandwidths in the range 140–245 MHz for the 2 medium bandwidth links (cable routes 1 and 3). For the wide-bandwidth cable however, multipath bandwidth is estimated at 315 MHz for channel 1 and 420 MHz for channel 2.

BACKSCATTER MEASUREMENTS

The results of some 'backscatter' (or pulse-echo) measurements carried out on cable route 1 approximately one year after installation, using an apparatus recently developed in Research Department[4], are shown in Fig. 11.

The echo signal on the main part of the trace is due (at least in part) to Rayleigh scattering, which is the fundamental scattering mechanism in glass. For the 100 ns input pulse used in the apparatus, the received level at any point on the trace is 30 dB (optical) below the signal level propagating at that point in the fibre. Also visible are small peaks arising from refractive-index mismatches at the joints between sections. The variability of the heights of these peaks is not fully understood at present but may arise due to variations in the index-matching properties of the epoxy resin used in the jointing. The heights of these peaks should not be confused with the joint losses which are indicated by changes in level of the main trace before and after the joints. Fig. 11 clearly illustrates the usefulness of 'backscatter' testing, both for fault location and quality-control purposes. The apparatus is undergoing further development at the present time and it is hoped to produce a version suitable for routine field measurements in the near future.

SUMMARY AND FUTURE TRENDS

Some 40 km of graded-index fibre have been cabled and installed in operational ducts without breakage and with no significant degradation in transmission properties. The principal transmission properties of the installed cable routes are summarized in Table 4.

Subsequent measurements have shown that, with one exception, the transmission properties of the installed cables have remained essentially unchanged throughout the year following installation. The exception was a single 1 km section of cable which showed a 15 dB increase in loss on the fibre in one channel. Operation of the 8 Mbit/s system was not adversely affected since adequate system margin was available. The faulty cable has since been recovered and replaced by a spare section. A thorough investigation has lead

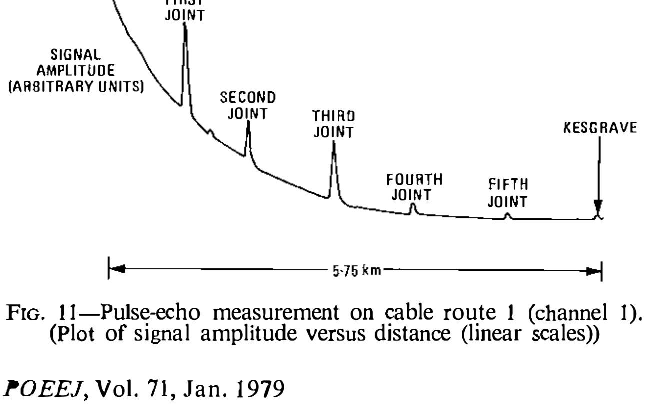


FIG. 11—Pulse-echo measurement on cable route 1 (channel 1). (Plot of signal amplitude versus distance (linear scales))

TABLE 4

Principal Transmission Results

Cable Route	Channel 1		Channel 2	
	Jointed loss 820 nm (dB)	Overall band-width (MHz)	Jointed loss 820 nm (dB)	Overall band-width (MHz)
1 (5·75 km)	24·2	140	24·0	185
2 (5·75 km)	24·8	210	24·8	230
3 (7·25 km)	31·7	145	30·4	120

Note: All bandwidths 3 db optical (900 nm, 4 nm line width)

to the conclusion that the problem was due to an isolated production fault not fundamental to the cable design.

Experience gained in the measurement programme has highlighted the need for carefully controlled launching conditions for all transmission measurements. This is particularly necessary for loss measurements where a stable-mode launch must be used if results obtained on short (1 km) lengths of fibre are to be scaled to predict losses for repeater sections of, for example, 10 km. The use of a stable-mode launch for bandwidth measurements is also desirable but, with present-day fibres does not lead to a simple extrapolation law for bandwidth.

The cumulative bandwidth results observed for the 3 installed cable routes, although favourable from a system point of view, are complicated by several effects including mode coupling, material dispersion and fibre–fibre equalization. Although theories have been developed which successfully account for these factors, precise predictions for the bandwidths of jointed links are not yet possible and it will be necessary, at least in the short term, to design optical systems using fibres which give substantial bandwidth margins for repeater sections.

In the future, improvements in fibre production and cabling technologies will lead to fibre cables with lower losses and higher bandwidths. Fibre cables are already commercially available with losses around 3 dB/km as opposed to the 4·3 dB/km (average) loss of the feasibility trial cables. The practical limit to bandwidth for graded-index fibres is as yet unknown but is likely to be determined by yield problems in the production process. Fibres with bandwidths guaranteed greater than 400 MHz km are now commercially available, but values in excess of 1 GHz km can be anticipated for the future.

Ultimately, for the wavelength range 800–900 nm, fibres will be limited by Rayleigh scattering to losses around 1·5–2 dB/km and to obtain further improvement it will be necessary to move to a longer operating wavelength. The preferred wavelength is likely to be in the 1200–1400 nm region where the material dispersion parameter of the fibres goes through a zero. The lowest reported loss for a fibre in this wavelength region is below 0·5 dB/km and clearly this offers attractive system possibilities for the future. It should be stressed, however, that these longer wavelength systems are very much in the research phase. Suitable sources and detectors are not yet widely available and the losses of most commercial fibres are much too high in the 1200–1400 nm region. First generation systems for the 1980s will operate in the 800–900 nm region where attractive system options currently exist. Commercially-available fibres have low enough losses at the present time to enable low bit-rate systems (2 and 8 Mbit/s) to operate without repeaters over most junction routes in the BPO telephone network. Repeater section lengths of 10 km or perhaps greater should be possible for 140 Mbit/s trunk systems using well-graded fibres. Longer wavelength systems, when they become available, should find most applications for submarine and trunk transmission. Ultimately, high bit-rate systems (140, 280 or 560 Mbit/s), with repeater spacings in excess of 50 km, may become possible, although it is likely that monomode fibre will be necessary to achieve the very high 1 km bandwidths required.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the work of his own staff who were responsible for carrying out the measurement programme. Thanks are also due to Dr. J. E. Midwinter for many helpful discussions and to Mr. J. H. Taylor of BICC Ltd.

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Book Review

General Mathematics for Technicians. H. G. Davis, M.SC., M.INST.P. and G. A. Hicks, B.SC. (McGraw-Hill. 294 pp. 249 ills. £3·35.

This book is a revised edition of a previous title *General Mathematics for Technical Colleges* and has clearly been written to meet the requirements of the mathematics standard unit for level one of the Technician Education Council (TEC) programme. A list of objectives is included at the beginning of each chapter, and assessment tests comprising only short-answer and multiple-choice questions are given at the end of each chapter.

The book is very clearly printed and illustrated and, being based on a previous work, is commendably free from printing errors, although, regrettably, it is not entirely free from some minor abuses of English. Remarkably, the authors have devoted well over 40% of the book to exercises and assessment tests, including answers to both; the statements of objectives occupy almost another 2½% of the book's contents. On the other hand, the number of worked examples in some chapters is relatively few. Little regard seems to have been paid to economy of space in printing the multiple-choice questions, which partly accounts for the unduly high proportion of space allotted to the exercises. This wealth of exercise material, although no doubt of great value to teachers and, to some extent, to students, has unfortunately been achieved at the expense of adequate and lucid explanation of mathematical fundamentals.

The authors have covered the great majority of the TEC syllabus, following this very closely throughout, both in the general divisions into arithmetic, algebra, etc. and, in the detailed chapter sub-divisions, into objectives. A few of the more difficult points (for example, recognizing that division by zero is not permissible, and use of the slide rule and calculator for purposes other than simple addition and multiplication) have been omitted entirely or covered very inadequately. Other sections, notably those on the binary scale, grouping of algebraic factors, solution of engineering problems with the aid of simple equations, and the comparative advantages and disadvantages of calculating aids are treated in too cursory a manner. This criticism applies in greater or lesser degree to the whole book, with the probable exceptions of the chapters dealing with geometry and the single chapter on trigonometry. These latter chapters do succeed in giving a clear and very-well illustrated introduction to these subjects.

Quite apart from the dubious value of the true-or-false and multiple-choice flavour of the book, for which they cannot be altogether blamed, the authors appear to have produced a hybrid, somewhere between a book of exercises and an explanatory list of TEC objectives. It is not clear from the preface for whom the book is intended but it seems unlikely to be of much benefit to the average telecommunications student, and it cannot really be recommended, except possibly as a prolific source of exercise material.

B. L. G. HANMAN

Extension of the British Post Office Radiopaging Service

N. W. BROWN and D. WILLETTS, B.SC., C.ENG., M.I.E.E.†

UDC 621.396.001.42: 621.395.4

This article outlines recent developments in the British Post Office Radiopaging Service, describes the system provided for London, and indicates possible future developments towards a National service.

INTRODUCTION

British Post Office (BPO) involvement in radiopaging started with the Thames Valley Radiopaging trial[1], centred on Reading, which opened for public service in February 1973. Equipment consists of an automatic paging control equipment (PCE), linked by land lines to 5 transmitter sites. The radiated signals are frequency modulated (FM) with a 2-tone code format, which is received by pocket paging receivers (pagers) of proprietary design. The basic service provides the customer with one type of alert which, if required, can be stored in the pager's memory for interrogation at an appropriate time. After being alerted, the customer normally telephones a pre-arranged number to receive a message. Early in the 1980s, when the service nears its ultimate capacity of 3540 pagers, it will need to be re-engineered to harmonize with future developments of the paging service. This article describes the extension of the BPO Radiopaging service to the London area and outlines possible future developments.

EVOLUTION OF THE SERVICE

By the mid-1970s, the development of high-code-capacity pagers and associated control equipment enabled the BPO to design a system capable of serving up to 100 000 customers in the Greater London area. A proprietary PCE, modified to meet BPO requirements, was ordered and radio coverage tests started in 1975. The system is capable of supporting several types of pager from different manufacturers.

A diagram of the system hierarchy is given in Fig. 1. Paging calls are received by the PCE and, after processing, the identity of the pager (the pager code) is sent to a zone transmitter controller (ZTC). At this nodal concentration point, the pager code is converted into a pager address, which modulates the radio emissions of the transmitters.

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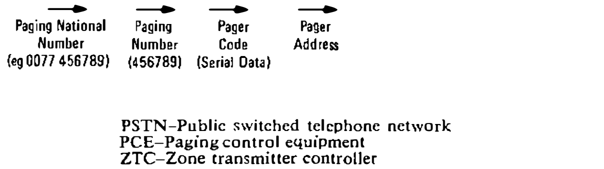


PSTN–Public switched telephone network
PCE–Paging control equipment
ZTC–Zone transmitter controller

FIG. 1—Block diagram of paging system

The transmitters were specified to have a dual modulation capability so that these could operate both FM analogue and frequency-shift-keying (FSK) digital types of pager. A contract for the development and supply of transmitters was placed early in 1974. The BPO designed and constructed the transmitter control and line interfacing equipment.

The completed system was installed during the Autumn of 1976 and opened for public service in December of that year. Facilities offered to the customer include:

(*a*) a single alert,
(*b*) an additional alert,
(*c*) a group-call facility, with a maximum size of group of 99 pagers, and
(*d*) a memory storage facility if silence needs to be preserved at the time a call is received by the pager.

Items (*a*) and (*d*) are included in the basic tariff, while items (*b*) and (*c*), which require additional public switched telephone network (PSTN) access, are charged as extras. Alerts (*a*) and (*b*) can be distinguished by different timings of an interrupted tone at the pager.

PAGERS

Pagers designed for city-wide systems need to be robust, have a high code capacity, be extremely sensitive and operate for many weeks from an easily obtainable battery. Additional marketing requirements are that the pager should be of suitable size for wearing in a breast pocket and should have a pleasing appearance.

The built-in aerial in a pager usually consists of a ferrite rod or metallic loop, giving an unavoidable directional variation in signal pick-up sensitivity. In practice, sensitivity measurements are made in free-field conditions by averaging the results from 8 incremental positions of 45° in the horizontal plane. The facilities of the Electrical Research Association have been used for this purpose, the pager under test being worn in the breast pocket to provide the pager-to-body shielding effects arising in normal use. Thereafter, the results are translated to a test jig for further laboratory tests or contract quality-assurance purposes. From an assessment of several types of pager, the BPO has specified that the sensitivity of pagers supplied for the Radiopaging service shall meet an 8-position average of 10 μV/m. This rather strict requirement is necessary to keep the power and number of radio transmitters in service to reasonable values.

Initial supplies of pagers for the London service were of a proprietary design that offered:

(*a*) 100 000 code capacity from a binary-coded-decimal signalling format,
(*b*) alternative alerts and a memory facility, and
(*c*) a 2–3 month battery life under normal conditions of use.

The colour of the case and markings were specified by the BPO Design Manager; a Freephone number has also been included to assist in the recovery of lost items.

ROUTING OF PAGING CALLS

The complete national number is dialled for all calls to Radiopaging services. Calls to paging numbers of the London PCE, dialled in the London director area, are routed through the PSTN to the outgoing trunk unit at which the PCE is accommodated. Calls from the rest of the country, including those using the transit network, are routed to one of 2 concentration points, situated to the east and west of London, and onward connected directly to the PCE by means of private circuits (see Fig. 2).

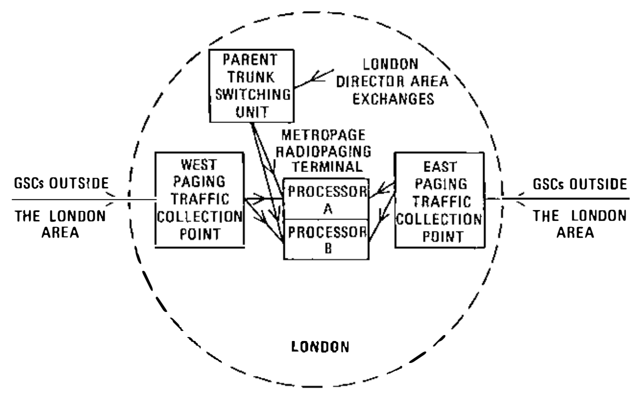


FIG. 2—Routing arrangement for London Radiopaging system

DESCRIPTION OF THE PCE

The London PCE is a Metropage 100 proprietary radiopaging terminal, manufactured in an equipment practice similar to that of the unit used in the Thames Valley service[1]. The standard Metropage 100 terminal was modified by the manufacturer to conform to the BPO requirement with respect to

(a) PSTN interconnexion,
(b) coding and identification of pagers, and
(c) outputting formats and protocols of the ZTC.

The PCE is based on 2 processors, each having 28 k word of core storage and 525 k word of disc storage. An on-line magnetic tape unit can be connected to either processor for loading data and programs, and for the daily security dump of the system data base. Each processor has its own set of PSTN input peripheral units and output units for communication with the ZTC. The processors normally operate in a load-sharing configuration, although each processor can accept the entire PCE workload if the other processor fails.

The PCE requires a 240 V AC mains supply, and also a supply from a BPO 50 V battery for PSTN line and supervisory conditions. The 240 V AC mains supply is normally derived from the 50 V battery by means of 2 DC–AC inverters, each rated at 8·5 kVA, with automatie high-speed switch-over to the exchange sub-station feed supported by a stand-by engine-set, in case of failure of an inverter.

OUTLINE OF OPERATION OF THE PCE

A block diagram of the PCE is shown in Fig. 3. The equipment has the capability to provide service for 100 000 paging numbers, but is equipped initially with a PSTN interface suitable for about 20 000 paging numbers.

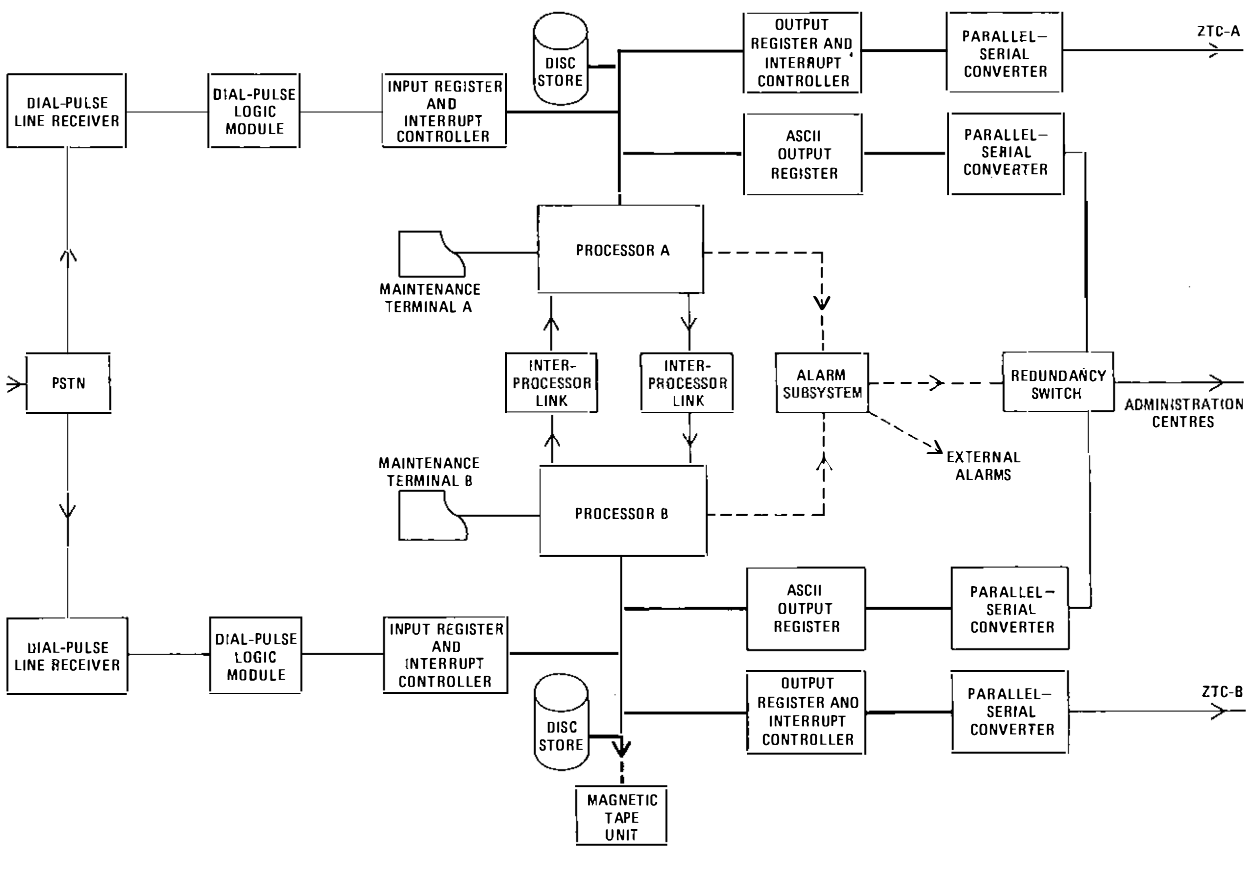


FIG. 3—Block diagram of PCE

The PSTN Interface

Each incoming circuit is provided with a dial-pulse line receiver and a dial-pulse logic module. Input registers and interrupt controllers are provided on the basis of one per 8 circuits. The detailed operation is identical to that of the Thames Valley PCE[1].

Input Call Processing

Following the dialling of a paging call, the PCE receives the final 6 digits of the national number. The processor then retrieves from the disc store the customer service file of the paging number. If the paging number is marked as valid in the service file, the identity of the pager is deposited in the output queues of the paging zones required by the customer; a recorded announcement is then connected at the PSTN interface advising that the call has been accepted. If the paging number is marked as invalid in the service file, or if there is severe congestion in the paging system, number-unobtainable tone is connected at the PSTN interface.

Information about the calls received from the PSTN is passed between the processors so that a failure of one processor or major peripheral does not lead to the loss of calls already accepted.

Output Processing

The PCE can control up to 32 paging zones, although complete flexibility of the roaming facility† is not available when many zones are controlled.

Paging calls are transmitted in batches to the paging zones, at periodic intervals. The cycle time is adjustable independently for each zone, but is typically 2 min for each processor, giving a net cycle time of 1 min. When the cycle time has elapsed, the PCE sends to the ZTC a data header, indicating the paging zone to be activated and the type of proprietary pager for which the calls are intended. The ZTC then attempts to switch on the radio transmitters in the selected paging zone. If the radio transmitters do not switch on, an appropriate message is sent by the ZTC to the PCE and an alarm generated. If a sufficient number of transmitters switch on correctly, the ZTC sends a *data-request* character to the PCE, which replies with the pager address of the first call in the output queue for the zone. The ZTC continues to request paging addresses until the PCE responds with a *clear-down* message, which indicates that all the calls in the queue for pagers of the type being processed have been sent. The ZTC switches off the radio transmitters and informs the PCE. If the PCE detects a failure or malfunction of the ZTC, or a repeated message is not accepted, a *clear-with-alarm* sequence is initiated, and the remaining calls in the output queue for that paging zone are sent by the other processor in its next cycle. As each call is sent to the ZTC, information is passed between the processors to prevent the call being transmitted by both processors.

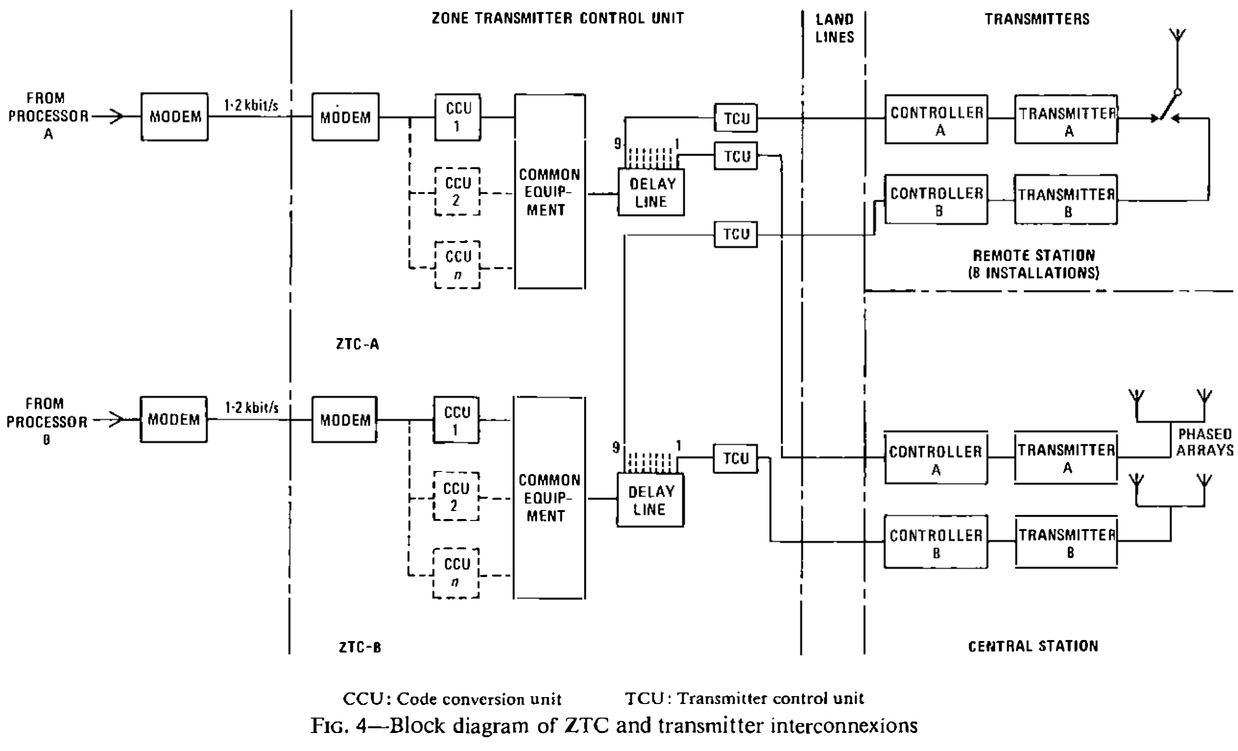
The sequence is repeated for each type of proprietory pager for which there are calls awaiting transmission in the output queue. The PCE then returns to its quiescent state until the elapse of another cycle time, or proceeds directly to the activation of the next zone if its cycle has elapsed in the meantime.

† A facility whereby a pager can receive calls in more than one paging zone

ZONE TRANSMITTER CONTROLLER

Each processor in the PCE is connected to a ZTC which, in turn, is connected by land lines to transmitters at each base station (see Fig. 4). The functions of the ZTC include: conversion of the serial data from the PCE into the various proprietary formats of the pagers; control of transmitters; and supervisory indications of the status of the line and radio part of the system. The code conversion units (CCUs) are designed to a BPO specification and supplied by the pager manufacturer; this ensures compatibility with the transmission format required by the pagers.

Batches of paging codes are received by the ZTC, preceded by a header which indicates the type of proprietary pager and the paging zone for which the paging calls are destined. The header is recognized by the CCU, which causes the ZTC to switch on the radio transmitters by sending to them a 12 bit start-stop character. This character is transmitted at 1·2 kbit/s, and contains information to set the transmitters and line equipment into the correct mode for signalling the type of pager in use (that is, tone or binary), though a recent decision



CCU: Code conversion unit TCU: Transmitter control unit

FIG. 4—Block diagram of ZTC and transmitter interconnexions

in favour of an all-binary-digital system now removes the need for the tone signalling facility.

A 3 kHz pilot tone, sent to the base station from the ZTC in the *idle* condition, is then removed, causing a *status* character to be generated by each base station and sent to the ZTC. The removal of the 3 kHz tone also signifies that the information to follow will be a batch of paging signals for radio transmission. The ZTC examines the *status* characters to determine whether or not the base stations are properly switched on; if all is correct, the ZTC requests the PCE to send the paging codes, which are received by the CCU using a handshaking communication protocol. Any codes that lack parity, or have incorrect framing, are rejected. An attempt to send these codes is then made by the other PCE processor.

For the present type of pager, the CCU converts the received data into the sequence of bits needed to modulate the radio transmitters with the appropriate code format. In this form, the data is passed via a standard BPO data modulator, giving 1·3 kHz and 2·1 kHz tones for *mark* and *space* respectively, to a 5 ms delay line, which is tapped at 25 μs intervals. Each transmitter is supervised at the ZTC by a transmitter control unit (TCU), which is connected to an appropriate tapping on the delay line and feeds the paging signal to line. All the base stations within a paging zone operate in a quasi-synchronous mode. This mode permits simultaneous emission by the transmitters, provided that the modulation is in phase; thus, the delay line compensates for modulation phase differences caused by line propagation. The TCU also examines the *status* characters received from the base station.

When the complete batch of pager codes has been sent to the ZTC, the PCE instructs the CCU to clear down. The CCU completes the generation of paging signals and then clears down the base station by reinstating the 3 kHz pilot tone. Finally, the *clear-down* responses from the base stations are checked and the ZTC awaits the next batch header.

TRANSMITTERS

As in the Thames Valley trial, the effective radiated power transmitted from the base stations is 100 W. It was decided that the new transmitters for London should all be of solid-state design; the specification called for a frequency stability of 1 part in 10^7 per month to enable transmitters to operate in a quasi-synchronous mode, with frequency offsets of $\pm$50 Hz relative to the nominal carrier frequency of around 150 MHz. Also required was an interface, controlled by $\pm$6 V logic, to link with the base-station control equipment being developed within the Telecommunications Development Department of the BPO. The transmitters, control equipment and power supplies were housed in type-62 equipment practice, rack assembly being undertaken by the London Telecommunications Region. At each base station, 2 complete transmit channels were provided on the 1·83 m high rack (see Fig. 5).

For signalling to digital pagers, the FSK modulator in the transmitter consists of a Wien bridge oscillator of nominal frequency 3·125 kHz. Resistors in the Wien bridge network are switched in value when data is applied to the FSK input, causing a frequency shift of $\pm$312·5 Hz. The output of the Wien bridge oscillator is then mixed with a crystal reference and the sum frequency extracted from a balanced modulator; finally, it is multiplied 16 times to produce the carrier deviation of $\pm$5 kHz. In the case of analogue pagers, appropriate signalling tones are applied to a phase-locked loop stage, the Wien bridge oscillator being set at the nominal frequency. The frequency multiplication is 160 times, giving a final deviation of $\pm$5 kHz. Although the system is fully engineered to accept tone-type pagers, none has been used because digital types now predominate and provide a greater potential for advanced facilities; for

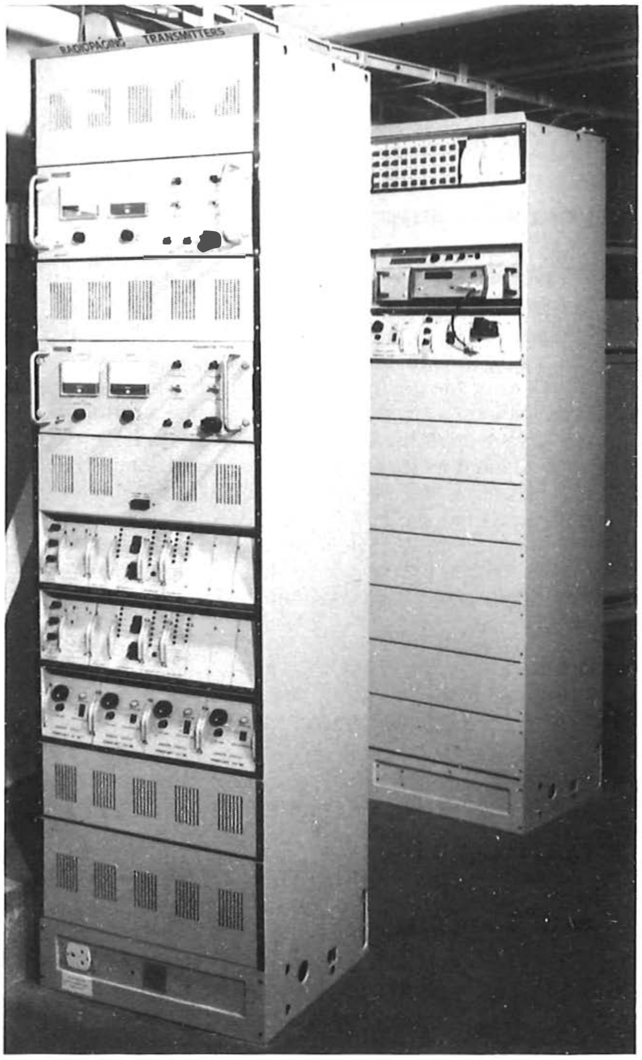


FIG. 5—Transmitter rack and central transmitter frequency measuring facility

example, message read-outs. An article describing a standard code with a message facility was published in an earlier edition of the *Journal*[3].

Within the base-station rack, a coaxial-type relay is used to switch the operational transmitter to the aerial. Generally, a 4-element collinear aerial is used to give a gain in the horizontal plane of 6 dB relative to a dipole, the aerial being encapsulated in fibreglass. Individual transmitters are adjusted over the available 25–100 W range to obtain the required effective radiated power of 100 W. The use of aerials with gain is of particular value in reducing the overall power consumption at non-BPO sites where, for security reasons, supplies are drawn from float-charged batteries.

For maintenance purposes, a frequency counter, connected to a receiver at the central transmitting station, is used to measure the frequency, off-air, of each transmitter. This is accomplished by inhibiting the clear down of the transmitter under test after a batch of paging calls has been sent. The transmitter then radiates its nominal carrier plus offset frequency, the value of which is relayed by Datel from the frequency counter (Fig. 5) to a printer mounted on the ZTC test rack. Any error exceeding 10 Hz is corrected at the transmitter, under the guidance of a technician at the ZTC. The use of a single frequency standard ensures that the relationship between the offsets is correctly maintained.

TRANSMITTER SITES AND RADIO COVERAGE

The aim was to provide reliable coverage over the Greater London area, and this has been achieved by using one central transmitting station and a ring of 8 surrounding stations on an approximate radius of 20 km. Coverage from possible sites was first estimated, and then surveyed using a repetitively-coded transmission and appropriately coded pagers as detectors. In these surveys, the boundary criterion was set at a 95% call-success rate inside buildings. With all stations operating, contiguous coverage has been achieved over a 2000 km^2 area, the measured call-success rate being better than the sum of the individual coverages. This is as expected, since there are cases where the local signal is obstructed, but one arriving from another direction is strong enough to fill the gap. However, these surveys are only indicative of the measured level of performance, and the BPO does not claim that at least 95% of calls will be received inside buildings at the boundary. The service area is shown in Fig. 6.

When possible, the transmitters were located at BPO Telecommunication sites; at 6 of these sites, the availability of protected AC supplies enabled the transmitter racks to be mains powered. At the 3 remaining stations, float-charged 200 Ah batteries of 12 cells were used to provide a nominal +27·6 V supply for powering the transmitters direct. In the event of mains power failure, the transmitters will operate satisfactorily with the battery supply voltages down to 18 V, albeit at decreased output and with some slight loss in frequency stability. Two DC–DC converters supply various regulated voltages in the 5–20 V range, at low power, for supervisory and control purposes.

PAGING ADMINISTRATION CENTRES

A paging administration centre exists at London and one is planned at Birmingham. The centres are provided with several visual display terminals, connected to the PCE by means of the

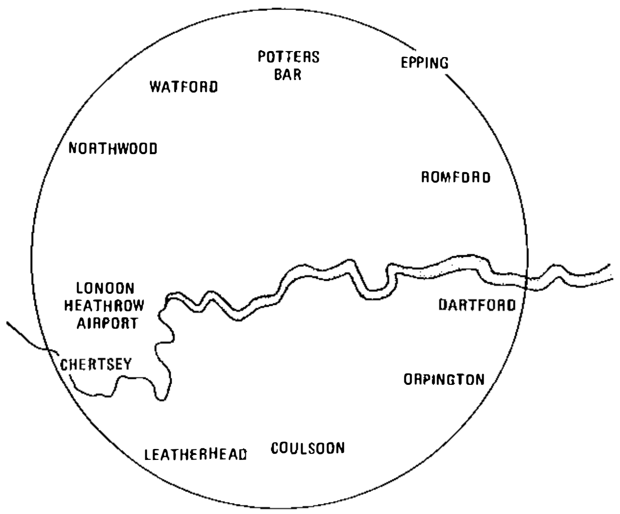


FIG. 6—Service area of London Radiopaging system

Datel 200 service. Private circuits are used, with recourse to the PSTN in case of line failure.

A password procedure prevents unauthorized access to the PCE. The circuits are routed via the PCE alarm subsystem so that they can be switched to the second processor if one processor fails.

A range of administrative commands are available at the visual display terminals, including:

(*a*) listing the service files;
(*b*) changing the information in the service files;
(*c*) scanning for a particular item (for example, a specified pager);
(*d*) traffic reports;
(*e*) paging any numbers specified;
(*f*) display-only of system parameters about which a customer might inquire.

Each service file of an assigned paging number normally contains information related to: the identity of the pager associated with that number; whether the number is active or inactive; the paging zone or combination of zones in which service is to be given; and the call count. Special service files, such as those for group-call paging numbers, contain: the group-call identifier; the activity status; and the number of members in the group.

CONCLUSIONS

During the first 18 months of operation, 12 000 paging receivers have been issued to customers and about 15% of these have been provided with an additional number alert. Some 22 organizations have requested the group-call facility, with an average group size of 5. The control equipment is now being extended to increase the present paging number capacity from 20 000 to 100 000. Other cities will be provided with service in the near future; later on, additional PCEs will be provided to cater for service over many of the populous areas of the UK. Ultimately, a generation of BPO-designed PCEs will be linked, to enable calls to be routed from the PCE in the originating area to PCEs controlling other paging zones where service has been selected by the customer.

A faster signalling code[3] will be introduced, which may include the capability for the reception of short messages; for example, by using a liquid-crystal display.

There is little doubt that the paging service will become an essential adjunct to the telephone network, and that its popularity will increase as the radio coverage and facilities expand to meet the growing needs of communication.

ACKNOWLEDGEMENTS

The authors wish to thank Motorola Electronics Ltd. for permission to publish details of the Metropage 100 radiopaging equipment.

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Lives of Plant and Depreciation

Part 2—Statistical Life Assessment

N. FERRIDAY, C.ENG., M.I.E.E.†

UDC 620.169: 657.372.3

The main factor in determining depreciation charges on capital expenditure is the assessed life of plant. Part 2 of this article outlines some statistical methods of life assessment.

INTRODUCTION

As described in Part 1[4], many British Post Office (BPO) assets are not recorded and depreciated individually, but the expenditure is aggregated in plant groups. Even in cases where asset registers record items individually, a single value of life must be used for depreciating all the items of a certain category. For these reasons, lives have to be assessed for whole groups of assets and there are basically 2 methods: statistical and judgement. Although judgement is incorporated in all assessments and is used exclusively in some, statistical methods are used whenever practicable because they can give objective and accurate lives. The concepts of statistical life assessment apply to all types of plant and are outlined in this part of the article.

DEPRECIATION, LIFE IN ONE POSITION AND TOTAL SERVICE LIFE

Expenditure is normally recorded when equipment is installed and must, therefore, be depreciated over the life in one position (LIOP); that is, the time between installation and recovery, as described in Part 1. Consequently, the assessment of LIOP is of most importance. The total service life (TSL), which is the time between purchase or brought into service date and scrapping, is used directly in a few cases, such as telephone instruments. In other cases, it is used indirectly through the net recovery value (NRV). The methods available for calculating the LIOP and TSL are exactly the same, only the data being different; however, different methods tend to be selected because of the different time scales and data involved. Frequently, however, the LIOP and TSL are the same (that is, no re-use).

All methods of life assessment attempt to measure the total life and, for any one item, this consists of an achieved life to date plus the future expected life. It is very important to appreciate that, in cases where there is considerable life in the future, the life required for depreciation is the total life that is expected. It is not the life of which the plant is capable or ought to have; for example, a physical or economic life. The assessed life should therefore take account of all the factors that can affect the plant life, but this assessment should not affect the decisions on recovering or retaining the plant. The assessed lives are thus descriptive and not prescriptive.

UNITS OF PLANT

Within a plant group, diverse equipment may be added; the choice of suitable units for statistical life assessment is difficult, but is important because the choice can affect the calculated life. A unit should have the following features:

(*a*) It should be readily identifiable so that data on additions (that is, plant added, provided or installed), recoveries and populations is consistent. A circuit is not a suitable unit, but an amplifier could be.

(*b*) The unit should be related to the cost, because a life for expenditure is ultimately required. Pair-kilometres of cable is a good measure, but a complete cable as a unit is not.

(*c*) It should be representative of all the plant. In an exchange, no one item of equipment, such as a particular relay-set or transistor, could be taken as representative, but *exchange multiple* has been used for the whole (local) exchange.

In a large complex plant group, where there is a variety of different types of plant, no one unit would be representative of the group. In such cases, lives with appropriate units are assessed for each of the major categories, and the lives are weighted together to produce an overall life for depreciation of the plant group (see Part 1). In the assessment of inland radio equipment, for example, separate statistical assessments are made of radio equipment and towers.

FREQUENCY AND SURVIVOR CURVES

The central concepts of life assessment are *frequency distributions* and *survivor curves*. If 100 units of plant are installed at one time (plant additions), the subsequent recovery will normally be spread over a considerable period. The number of units recovered in each period, such as a year, can be expressed as a fraction or percentage of the number originally installed to give a mortality or frequency ratio as shown in Table 3. The complete series of points is referred to as a frequency distribution, which is illustrated in Fig. 4.

Another way of expressing the information is to calculate for each year the number of items that survive to that year, by successive subtraction of the frequency ratios, as shown in Table 3. The points then form a *survivor curve*, which is also illustrated in Fig. 4.

The frequency distribution and survivor curve both show the spread of lives or *mortality dispersion*, and this is fundamental in life assessment. If the survivor curve is square, that is, all items are recovered after about the same life, it has a low mortality dispersion; if it is gently sloping, it has a high mortality dispersion. Examples of both types are shown in Fig. 5. An example of plant with low dispersion is motor vehicles, where certain types of van are "recovered" after 8 years. An example of plant with high dispersion is subscribers' apparatus, where the life is mainly determined by the subscribers' wishes.

Although there is often a high mortality dispersion, only the average life is used for depreciation, and evaluation of the average life is, therefore, the ultimate aim of life assessment.

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TABLE 3

Determination of Frequency Distribution, Survivor Curve and Average Life

Year	Number Recovered	Age at Recovery (Years) (L_i)	Mortality or Frequency (%) (R_i)	Frequency × Age at Recovery (R_iL_i)	Percentage Surviving at End of Year (Survivor Curve) (S_i)
0	0	0	0	0	100
1	0	1	0	0	100
2	2	2	2	4	98
3	10	3	10	30	88
4	20	4	20	80	68
5	33	5	33	165	35
6	22	6	22	132	13
7	11	7	11	77	2
8	2	8	2	16	0
9	0	9	0	0	0
Totals	100	—	100	504	504

Life from frequency distribution $= \frac{\Sigma R_i L_i}{100} = 5{\cdot}04$ years

Life from survivor curve $= \frac{\Sigma S_i}{100} = 5{\cdot}04$ years

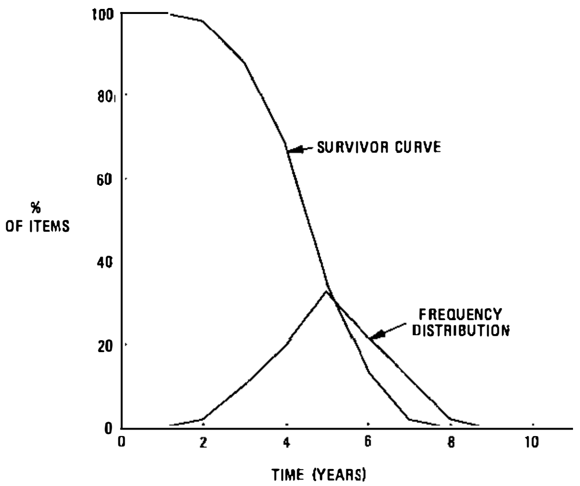


FIG. 4—Frequency distribution and survivor curve

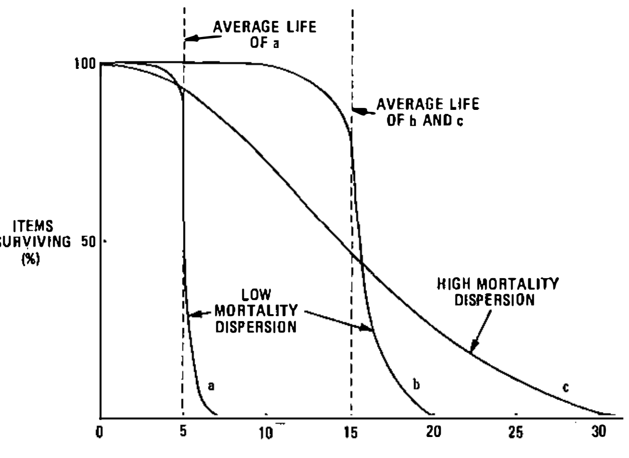


FIG. 5—Examples of survivor curves

The average life can be calculated from the frequency distribution or survivor curve, as shown in Table 3. The value is superimposed on the curves in Fig. 5 and it does not necessarily correspond with the peak of the frequency distribution or the 50% point on the survivor curve (this happens only in special cases, such as symmetrical survivor curves).

The survivor curves described above reflect the pattern of recovery of plant added at one time or, in practice, over a short period such as a year. They are thus termed *vintage survivor curves*. Plant added in other years may be assumed to have the same survivor curve and average life; in some cases, however, this is inappropriate and individual survivor curves and average lives need to be considered.

STATISTICAL METHODS OF LIFE ASSESSMENT

The various statistical methods of life assessments[3,5,6] are described below.

Actuarial Methods

A historical record of plant on an item-by-item basis is termed *actuarial data*; an example is shown in Table 4. From such data, a survivor curve can be constructed for each vintage although, for later vintages, the survivor curve will be incomplete; for example, plant added in 1977 can have a survivor curve drawn directly from the data for only the first 2 years. To complete the survivor curves and, hence, enable average lives to be calculated, extrapolation, curve fitting by standard curves, or reference to curves for earlier vintages is needed. An alternative to producing vintage survivor curves is to use the data for all vintages to produce a single survivor curve. This method has the advantage that the maximum possible section of the survivor curve (from 0–4 years in Table 4) is obtained and that statistical fluctuations are minimized. The disadvantage is that trends in vintage survivor curves and average lives (for example, caused by changing technology) are concealed.

Actuarial methods are ideal because they extract the maximum possible information on life from historical data. The records have to be detailed because the individual items must be recorded and their subsequent recovery or continuance noted. One method of avoiding the expense of such record systems or of their analysis, while enabling actuarial methods to be used, is to use sampled actuarial data. If a sample of added items is taken, and the recoveries or continuance noted, an actuarial analysis can be carried in exactly the same way as on full data. There is, however, a loss in accuracy due to the sampling procedure.

TABLE 4

Examples of Actuarial Data

Year	Plant Added (at beginning of year)	Recoveries/Survivors at Age:			
		1 Year	2 Years	3 Years	4 Years
1975	142	14/128	60/68	41/27	27/0
1976	183	23/160	69/91	49/42	
1977	67	6/61	19/42		
1978	184	22/162			

Semi-Actuarial Methods

Actuarial methods can be used only where the complete history of items has been recorded. There are some other methods, however, that use data on an item-by-item basis, but do not require a complete historical record.

Surviving-Proportion Method

The surviving-proportion method is essentially a snapshot of the population at one time. The main requirement is that the age of the population (that is, the time since the items were added) can be determined. The age may be obtainable from the plant itself (for example, by a date stamp) or by examination of relevant records. Once an age distribution, P_i, is obtained, this can be compared with the number of items added in each year, A_i, to produce a survivor curve. For example, if 287 items were known to have been added in 1970 and 190 were found to have survived at 1978, the surviving proportion $P_8/A_8 = 190/287 = 66{\cdot}2\%$ is the eighth point on the survivor curve.

Because the analysis of the population is to determine an age distribution P_i, a sample rather than the whole population may be sufficient. If a 1-in-F sample of the population is taken, the frequency ratios are simply FP_i/A_i, instead of P_i/A_i.

The advantage of this method over the actuarial methods is that a history of all items is not required. Like actuarial methods, it is direct in that lives of actual items are noted to produce the assessed average life of plant. However, it has the following disadvantages:

(*a*) If some items cannot be dated properly, the results can be biased.

(*b*) Accurate annual additions of plant, A_i, are required.

(*c*) Only one survivor curve can be produced; there is no way of producing vintage survivor curves and lives.

(*d*) When samples are taken, the sampling error in the results tends to be much larger than for sampled actuarial methods (alternatively, much larger samples need to be taken to give the same accuracy).

Age-at-Recovery Method

The age-at-recovery method is rather similar to the surviving-proportion method, but instead of an age distribution of survivors being constructed, an age distribution of recoveries is derived. If recoveries of plant are examined for, say, 1 year and the age of items determined, an age distribution of recoveries, R_i, can be built up. If this is compared with the bulk additions A_i, the frequency ratios R_i/A_i forms a frequency distribution and, hence, a survivor curve and life can be derived.

The age-at-recovery method has the advantages and disadvantages described for the surviving-proportion method. There is a problem if the recovery rate over a period is not typical, but this may be ameliorated by taking recoveries over several years. If plant from even the earliest vintages has not been fully recovered, a further difficulty arises and sampling causes additional complexities, although some allowance for these factors can be made. Most of these problems were encountered in a recent assessment of the TSL of telephones.

Bulk Data Methods

The methods described previously require data on an item-by-item basis. For most types of plant, this detailed information is not available and cannot be readily obtained. In such cases, bulk data (that is, total yearly additions, recoveries and populations) has to be used. Examples of such data are pair-kilometres of cable added, working population of telephones and modems recovered.

Turnover Method

The turnover method is conceptually simple and relies on the principle of *turning over* a population. If the population, P, is steady, and annual additions, A, and recoveries R, are constant, the life, L, is given by:

$$L = P/A = P/R.$$

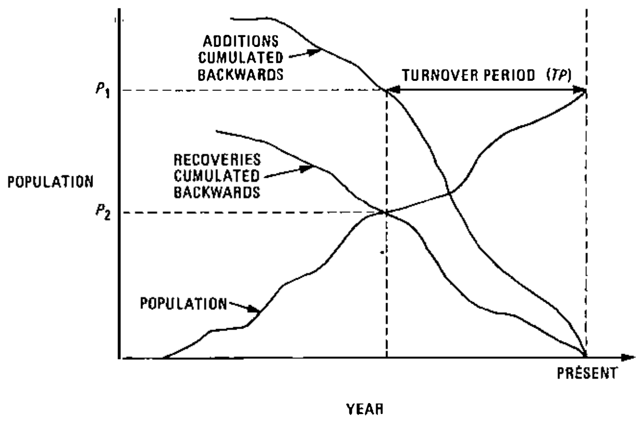


FIG. 6—Example illustrating turnover method

The method can be extended where A, R and P are not constant, as shown in Fig. 6. Assuming a first-in-first-out principle, the present population can be accounted for by cumulating additions back over a turnover period of TP years; all additions before this period will have been recovered and so TP is an estimate of life. In fact, TP is a correct estimate of life if either the population is constant, or if there is no mortality dispersion. Where neither of these conditions is met, a correction factor has to be applied to convert TP to life. This factor is a function of the growth ratio, which is the relative growth in population P_1/P_2 over the turnover period, as shown in Fig. 6. The shape of the survivor curve for the plant is also required; this is usually not directly available—if an accurate survivor curve were available, the life could be calculated directly and the turnover method would not be needed. However, a rough estimate of the shape of the survivor curve can be made from sparse data, such as small samples, or by alignment with a similar plant type whose survivor curve is known. This enables an approximate correction factor to be estimated, which is often satisfactory because the adjustment is relatively small (for example, an addition of 10% to the turnover period).

The turnover method has the advantage that it uses bulk data, which is more readily available than actuarial data and is often in convenient published form. It is also quick and simple to use. It has the disadvantages that

(*a*) a fairly long run of data is needed (up to twice the turnover period) before lives can be reliably estimated,

(*b*) high growth ratios and high (but uncertain) mortality dispersions can make the results inaccurate because of the resulting large correction factors required, and

(*c*) a single life is produced and any changes in the real underlying vintage lives or survivor curves can distort the results. (However, a series of turnover curves cumulated back from successive years and giving a trend in lives would draw attention to such a change.)

Simulated Plant Record Method

To overcome some of the disadvantages of the turnover method, a completely different approach, termed the *simulated plant record method* (SPRM), can be used; in this, the actuarial data needed for accurate life assessment is effectively simulated. A particular survivor curve is chosen and applied to the additions in each vintage. For example, if 237 units were provided in 1958, and the survivor curve falls to 43% in 20 years, the plant remaining at 1978 is 43% of 237 or 102 units. The total simulated plant remaining at 1978 is produced by adding such derived quantities from each vintage. In a similar way, the total survivors may be simulated for other earlier years. This simulated profile of population is then compared with the actual population profile and the difference between them expressed as the sum of squares. A new survivor curve (with a different life or shape, or both) is then chosen and the whole process repeated. After some iterations, the survivor curves can be tabulated in order of fit by reference to the differences of the sum of the squares. The life of the best-fitting survivor curve can then be taken as the estimate of plant life. The whole method involves much computation, and is best done by computer.

Although a certain survivor curve may fit best to the data, it is never selected without question. It frequently happens that several quite different survivor curves, with different lives, fit the actual data almost equally well. In such cases, an intelligent selection of curves is needed, and it may be possible to rule out certain survivor curves and lives; an almost square survivor curve for subscribers' apparatus would, for example, be very suspect. This problem arises because the SPRM can show only which survivor curves are consistent with the bulk data; it cannot show that a survivor curve is actually correct. Only actuarial data can reliably produce the correct curve.

Brennan Method

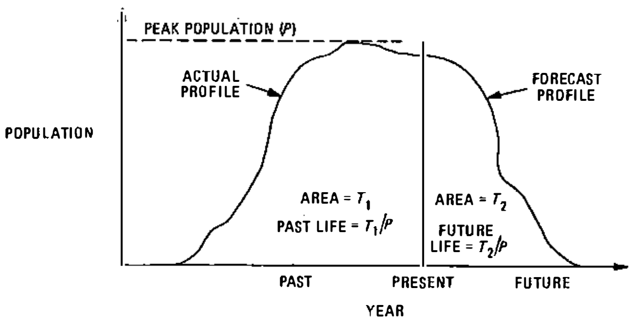
The SPRM assumes that each vintage of plant has the same survivor curve and life. If an extinction date and obsolescence profile have been decided, the lives of later vintages become progressively shorter, and the assumption of identical vintage survivor curves and lives is invalid. An extension of the SPRM, called the *Brennan method*, can then be used; in this, a different survivor curve is postulated for each vintage. The set of survivor curves is applied to the vintage additions to derive a profile of recoveries until extinction. The simulated profile is then compared with the past or forecast actual profile, a new set of survivor curves chosen, and the process repeated until satisfactory agreement between the simulated and actual profile is achieved.

As with the SPRM, the Brennan method can produce only a set of survivor curves and lives that are consistent with the bulk data; it cannot show that they are the correct ones or the only set that fit. Because there are so many possible sets of vintage survivor curves, it is necessary to limit the range examined, and to use a trial-and-error approach even with a powerful computer. This method was used in a major study of the obsolescence of Strowger exchange equipment.

Population-Profile Method

The population-profile method is particularly simple and uses a minimum of data. Only an overall population profile is needed, and this can be all past data, all future forecast data, or a mixture. The average life is simply the area under the curve (that is, item-years of plant) divided by the peak population, as shown in Fig. 7. The method is, in general, valid only where there are no recoveries before the population peak and no provisions thereafter. These conditions are not usually fully met, but they may be approximately met where a TSL is being calculated or where equipment is not re-used. It is also possible to relax one assumption and allow for losses before the peak.

The population-profile method has been used for assessing the life of frequency-division-multiplex equipment, and some telephones. The method produces a single life which is an average for all plant added, and makes no allowance for vintage life differences, which can be particularly important over the long time scales involved. It is, however, possible to obtain approximate vintage or tranche lives by building in assumptions such as first-in-first-out or recovery independent of age.



Note: Total life = past + future = $\frac{T_1 + T_2}{P}$

FIG. 7—Example illustrating population-profile method

SUMMARY OF STATISTICAL METHODS

The methods outlined above range from the actuarial methods, which need most-detailed data, down to the population-profile method, which needs least. The latter methods are less reliable and contain progressively more implicit assumptions (such as unchanging vintage lives). Table 5 summarizes the methods.

TABLE 5

Summary of Statistical Methods of Life Assessment

Method	Data Needed
Actuarial	History of all individual items
Sample actuarial	History of sample of individual items
Surviving proportion Age-at-recovery	Age of some or all individual items plus bulk additions
Turnover Simulated plant record	Bulk additions and populations
Brennan	Bulk additions, populations and recoveries
Population profile	Population profile

AVAILABILITY OF DATA

Accurate data over a long period is the basis of all statistica assessments. However, the desired statistics are usually not available, and the figures in existence are often incomplete, or do not measure the right thing. The form of data for each type of plant varies, but the following features recur constantly:

(*a*) The more financially significant the plant, the less accurate the records; the amount of local cable in the network is not accurately known, while the number of *Grinders, Bench* in garages is known to be 348.

(*b*) Although a large amount of work is often devoted to programming and forecasting the future, the actual achievement for a year is often not known.

(*c*) When there are separate returns of quantities, they often do not agree; for example, the stations figures given by edge punched card and customer rental records systems.

(*d*) Independently collected statistics of additions, recoveries and populations of an item often do not balance; for example, on the capitalization-at-purchase system of telephones.

Historical data is more readily available and is therefore used to calculate total life (that is, achieved life plus future life of items). Whenever quantified plans for the future exist, such data can be added to the historical data and used in the same way to calculate a life. This life will still be a total life, but will incorporate future trends. Existing record systems are used whenever possible because of the expense of setting up records purely for lives of plant purposes.

LIFE ASSESSMENT BY JUDGEMENT

A statistical assessment is often not made because the data is very unreliable, or there is no suitable data at all. Furthermore, where the history of plant is too short, a life cannot be calculated, even if full records have been kept. Statistical work is time-consuming and expensive and is not, therefore, justified when the financial significance of the plant in question is small.

In all such cases, judgements are used. The various factors that might cause recovery are considered and a life assessment based on engineering judgement is made. Some of the more important factors arc

(*a*) physical wear or decay; for example, wear of vehicles,
(*b*) maintenance difficulties, such as obtaining spares for valve-operated equipment,
(*c*) accommodation; for cxample, saving of space by replaccment of an equipment by an equivalent miniaturized design,
(*d*) inadequacy for growth; for example, cables,
(*e*) external factors; for example, roadworks,
(*f*) customer preference,
(*g*) safcty factors; for example, aerial masts and high-voltagc equipment, and
(*h*) obsolescence because of changed system and network requirements.

It is not possible to examine these factors in detail here because they vary from one plant group to another, but it is interesting to note that wear and decay, which arc the most obvious causes of the end of life, are usually relatively unimportant. Inadequacy and obsolescence are usually the dominant factors.

SELECTION OF METHOD OF LIFE ASSESSMENT

Where possible, statistical methods are used because they are objective, potentially accurate and take into account all the factors that affect the life. The most important factor in dctermining the method used is the data. Where sufficient actuarial data is available (for example, vehicles, and high-frequency transmitters), survivor curves are produced to give average lives. Where only bulk data is available (for cxamplc, most exchanges, local cable and modems), the turnover method and SPRM are used. Unless actuarial data is available, the life estimates tend to be approximate and more than one method may be applied; for example, the turnover method and SPRM on bulk data. To extract the maximum information from the available data, special combinations, adaptations and extensions of mcthods arc often devised for particular assessments. An example is where a small age-at-recovery sample is taken to establish the rough shape of the survivor curve. This may be too inaccurate to dctermine life directly, but the general information on the survivor curve shape could enable more accurate correction of the turnover period or more reliable results from the SPRM to be obtained.

FUTURE DEVELOPMENTS

One of the major problems in life assessment is the absence of suitable data, so an important part of Lives of Plant work is the development of suitable record systems. In the BPO, where there are huge numbers of assets, full records may be impracticable and much attention is therefore devoted to devising sampling systems for the various types of plant. The intention is to establish samples of plant, which will be updated with new additions at regular periods, and to keep track of the sample in the following years. In this way, good actuarial data will become available and regular, reliable re-assessmcnts will be possible.

Another area of activity is the development of methods of life assessment. As is clear from the descriptions of the methods, there are important imperfections in all methods of statistical life assessment, even if the data is perfect. Studies of the relative merits of the various methods, under different conditions, are being carried out by a professional statistician.[6] An area of particular interest is the Bayesian approach. In this, judgements on life and statistical data arc combined in a systematic manner. For example, when an item is introduced, only a judgemcnt on life can be made; as data accumulates, this will gradually alter the initial assessment, so the original judgement is supplemented by a statistical assessment.

As described in Part 1, there may be developments in the methods of accounting for depreciation, as well as in mcthods of life assessment. With the introduction of bulk-asset registers, it is likely that the assessment of lives and survivor curves will be related more directly to the accounting methods.

CONCLUSIONS

Part 1 of this article emphasized the importance of accounting for depreciation in the BPO, outlined the way in which it is carried out, and showcd that the main determining factor is the plant life.

This second part has outlined, briefly, life assessment for depreciation in the BPO. A survey of the morc popular mcthods of statistical asscssment has been made together with somc of the practical problems of their application. The factors affecting life have been indicated and future developments in life assessment described.

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The Accuracy of Traffic Records

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UDC 621.395.31

The accuracy of traffic measurement results depends on the traffic-recording procedure used, the traffic intensity and the mean call-holding time. The mathematical form of this relationship has been known for many years, but its practical significance has often been misunderstood because of the number of parameters involved. This article explains how measurement accuracy is influenced by these parameters.

INTRODUCTION

The criteria for determining traffic-recording procedures are complex and not easily quantified, and it is not possible to apply precise economic considerations. In particular, the question of measurement accuracy has generally been a matter for subjective judgement. This is partly because the relevant mathematical formulae have often been misinterpreted, and partly because it is difficult to determine objectively what measurement accuracy is required.

This article explains the statistical properties of measurements of telephone traffic, how these properties depend on the measurement period, scan interval, traffic intensity, and call-holding time, and their implications for traffic-recording procedures. This is preceded by discussions of traffic behaviour and traffic-recording procedures, and some explanation of the statistical concepts of variability.

In general, the article relates to conversational traffic, but the conclusions are equally applicable to short-holding-time traffic on common equipment.

TRAFFIC BEHAVIOUR

The traffic carried by a circuit group at a given time is an unpredictable quantity. The circuit group (either a route or a switching stage) may carry calls generated by a large number of subscribers, the call-behaviour activity of each subscriber being unknown. Nevertheless, in general, a consistent profile of traffic level is evident throughout each day, the traffic at any one time of day being at a similar level from one day to the next.

Clearly, it is appropriate to use a statistical model to describe this call-behaviour pattern. A constant long-term average value for the traffic at a given time of day is assumed (termed the *traffic intensity*), with daily variations from this value following an assumed probability distribution. To simplify description in this article, traffic during the busy-hour only is considered.

The distribution of carried traffic depends on the behaviour of subscribers in generating and terminating calls. Most existing dimensioning tables are based on a standard traffic model, described simply as a *random traffic* model. This model assumes that calls arrive according to a *Poisson process*, which arises naturally when calls are generated from a large group of subscribers, each with a relatively low calling rate, and who act independently of one another. The model also assumes that call-holding times have a negative exponential distribution. This assumption greatly simplifies most traffic calculations and, for most practical purposes, adequately represents observed behaviour.

The random-traffic model applies to offered traffic, which is the traffic that would be carried if there was sufficient equipment to ensure that congestion did not occur. In this article, it is assumed that congestion is negligible, enabling offered and carried traffic to be equated.

TRAFFIC MEASUREMENT PROCEDURES

Traffic recording in the British Post Office (BPO) telephone network is based on the time-consistent busy-hour principle. Measurements are taken on 5 consecutive days, Monday to Friday, during a pre-determined hour (normally the exchange busy-hour). The measurement takes the form of scanning the number of busy circuits, the scans being made at 3 min intervals. This gives 100 scans in a week, and so the carried traffic intensity may be estimated by dividing the total count by 100. Similar measurements are taken on equipment that is held for short periods only (for example, registers), but at a higher scan rate.

Measurements relating to congestion (for example, overflows and group occupancy times) have completely different properties and will not be considered in this article.

THE NATURE OF STATISTICAL VARIATION

Variance

A measured traffic value may be regarded as being a random variable whose mean value is the underlying traffic intensity; in other words, the measured traffic is an unbiased estimate of the traffic intensity. Therefore, the accuracy of a traffic record must be interpreted in terms of its variability about this mean value.

The most commonly-used measure of variability is termed the *variance*, which is the mean squared difference between the value taken by a variable and its mean value.

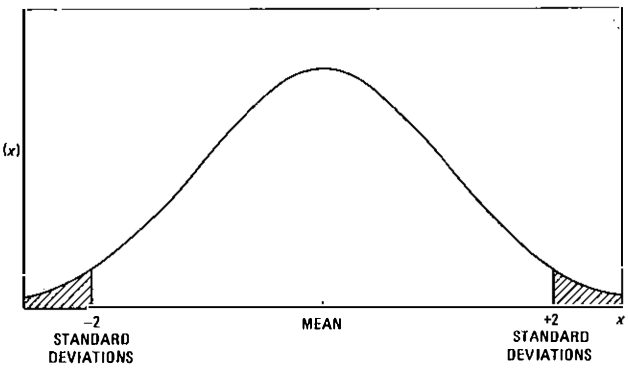

FIG. 1—The probability density function, f(x), of the normal distribution of x

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Standard Deviation

The spread of a distribution is directly proportional to the *standard deviation*, which is the square root of the variance. For example, a variable with a normal distribution will lie within 2 standard deviations of the mean for about 95% of the time. This is illustrated in Fig. 1, which shows the probability density function of the normal distribution.

TRAFFIC VARIATION

The Properties of Measured Traffic

In an examination of a long series of traffic records from one circuit group, several sources of variability will be apparent. There is likely to be a long-term trend—either of growth or decline. There is also likely to be seasonal behaviour (that is, variations that are repeated from one year to the next). Planning procedures are designed to take account of these factors. However, even after allowing for trend and seasonal variations, the traffic measured over a period of 5 d is still a variable quantity. This variation can be considered to have two components:

(*a*) The measured traffic differs from the actual carried traffic because of the scanning process. This error could be eliminated by scanning sufficiently rapidly.

(*b*) The carried traffic itself varies about the underlying intensity. This behaviour is represented by the standard traffic model.

For the purposes of equipment provision, the accuracy of the measurement depends on both of these components, not just the scanning error. In fact, it will become apparent that the scanning error is usually a relatively minor factor. It should also be emphasized that the scanning process does not generate any bias, but affects only the variability of the measurement.

Of course, the standard traffic model is an ideal representation of the true behaviour of traffic. Among other factors, day-to-day variation in traffic intensity may often result in variability greater than that predicted by the standard model. These aspects of traffic behaviour are currently being studied, but the remainder of this article is confined to the standard traffic model.

Formulae for the Variance of Measured Traffic

The variance, V, of the traffic carried in a time period, T, was derived by Riordan[1] in 1951, and is given by

$$V = \frac{2Ah^2}{T^2}\left\{\frac{T}{h} - 1 + \exp\left(-\frac{T}{h}\right)\right\},$$

where A is the traffic intensity and h is the mean call holding time.

If the observation period T is much longer than the call holding time h, then this variance is approximated by

$$V \approx \frac{2Ah}{T}.$$

This is a useful approximation to the variance of measured traffic provided the scan interval is reasonably small (that is, less than the mean call-holding time).

The effect of the scanning process was investigated by Hayward[2] in 1952, who obtained an approximate result. The correct expression for the variance of traffic measured by scanning was derived by Olsson[3] in 1959. The expression is

$$V = \frac{A}{n}\left[\frac{\exp\left(\frac{\alpha}{h}\right) + 1}{\exp\left(\frac{\alpha}{h}\right) - 1} - \frac{2\exp\left(\frac{\alpha}{h}\right)\left\{1 - \exp\left(-\frac{T}{h}\right)\right\}}{n\left\{\exp\left(\frac{\alpha}{h}\right) - 1\right\}^2}\right],$$

where α is the interval between scans and $n = T/\alpha$ is the number of scans during the measurement period T. The results given in this article are all derived from this formula.

It is important not to confuse the variance considered here with the well-known property that random traffic has variance equal to its mean. This property refers to a hypothetical variance describing the variability inherent in a single instantaneous observation of the number of calls in progress. It does not apply to a measurement extending over a period of time because of serial correlation in the traffic process. Note, however, that the variance of measured traffic is directly proportional to the mean.

A fuller discussion of the variance of measured traffic, together with tables and graphs of the various formulae, is given in 2 reports[4,5], published by the Teletraffic Division of the BPO Telecommunications Headquarters.

The Relationship between Variability and Traffic Level

Measured traffic is, approximately, normally distributed, except at very low traffic levels or for short measurement periods. Hence, the measured value can be expected to fall within ±2 standard deviations of the true traffic intensity for about 95% of the time. The standard deviation is determined by the parameters of the traffic process and the measurement procedure.

It can be seen from Fig. 2 how the variability depends on the traffic intensity, assuming a mean call-holding time of 2 min, a scan interval of 3 min, and a measurement period of 5 h. The ±2 standard deviation points are shown as percentages of the mean. For example, with a traffic intensity of 20 erlangs, the 2 standard deviation points are at 5·5% of the mean. Therefore, at this traffic intensity, it can be expected that about 95% of the 5 h traffic records will fall within the range 18·9–21·1 erlangs.

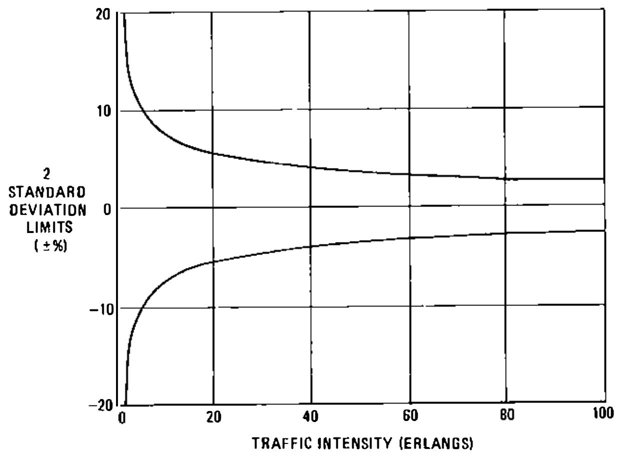

FIG. 2—The relationship between traffic intensity and variability

THE INTERPRETATION OF MEASUREMENT ACCURACY

It has been shown in Fig. 2 that measurement accuracy, in terms of the size of errors relative to the mean, is worse at lower traffic levels. In theory, it would be possible to maintain a similar accuracy at all traffic levels by varying the measurement period. This would require very long measurement periods on small circuit groups and very short measurement periods on large circuit groups. The desirability of such a procedure depends on how measurement accuracy is interpreted.

Traffic measurements are used for maintenance of grade of service and for planning purposes; in the latter case, many other uncertainties are involved besides the initial measurement errors. However, since the primary purpose of traffic recording is to provide information for use in the dimensioning of circuit groups, the importance of measurement errors should be assessed in terms of the dimensioning errors that might arise from them. A measurement that is an over-estimate of the true traffic-intensity might give rise to over-provision of circuits. An under-estimate might give rise to under-provision of circuits, in which case the significant effect is the worsening of the grade of service.

In Fig. 3, these effects are shown for a range of traffic levels. The upper curve shows, approximately, the percentage error in measured traffic that gives rise to over-provision by 2 circuits. The lower curve shows, approximately, the percentage error in measured traffic resulting in an under-provision of circuits that leads to a grade of service twice that of the design value; that is, the grade of service is worsened by a factor of 2.

It is clear from Fig. 3 that the dimensioning process is increasingly sensitive to measurement errors at higher traffic levels. However, Fig. 2 showed that measurement errors tend to be smaller (in relative terms) at higher traffic levels. In fact, the curves in Figs. 2 and 3 are similar in shape, and this indicates that the two effects tend to cancel each other out. In other words, for a given measurement period, the dimensioning errors likely to arise from measurement errors are about the same at all traffic levels.

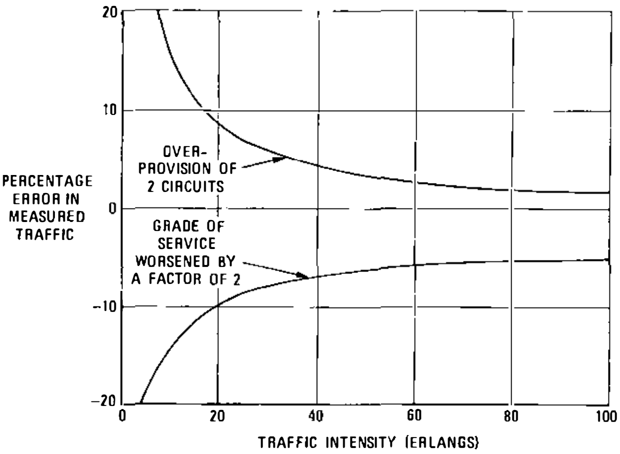

FIG. 3—The effect of measurement errors on circuit provision

THE FACTORS THAT INFLUENCE MEASUREMENT ACCURACY

Measurement Period

Dimensioning and traffic-recording procedures are based on the busy-hour traffic. The choice of a 1 h period is a compromise. If the daily measurement period were too long, the average measured traffic could be much lower than the maximum traffic intensity. If the measurement period were too short, the measured traffic value would be too variable.

The variability of the record depends also on the number of days on which measurements are taken. In Fig. 4, it is shown how the accuracy varies with the number of busy-hours measured, assuming that the traffic intensity remains constant. The results given in Fig. 4 are based on a traffic intensity of 10 erlangs, a mean call-holding time of 2 min, and a scan interval of 3 min. The diminishing returns effect is clear. Most information is obtained from the first 5–10 h, and not much more information is to be gained from a longer measurement period. In practice, the busy-hour traffic intensity does not stay constant for a large number of days. Therefore, it is sensible to record for 5 busy-hours to get a reasonable estimate of traffic intensity, and to repeat this record as often as is practicable.

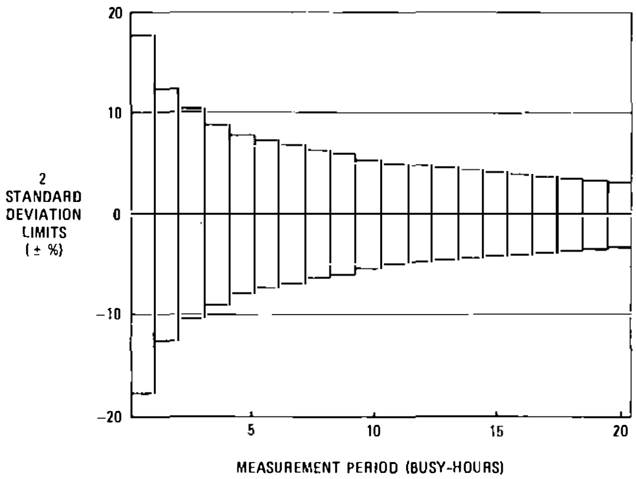

FIG. 4—The relationship between measurement period and variability

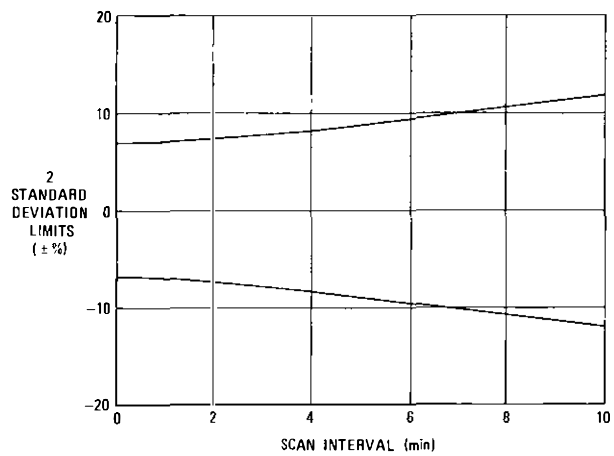

FIG. 5 -The relationship between scan interval and variability

Scan Interval

If the scan interval is reduced so that more scans are made during the record, the accuracy is improved. However, the degree of improvement possible is limited, since close-spaced scans are merely repeated observations of the same calls and will not provide additional information.

In the limit, arbitrarily fast-scanning is equivalent to exact measurement of the carried traffic. The scanning error disappears and the inaccuracy is due solely to the variability of the carried traffic.

The effect of varying the scan interval is shown in Fig. 5. This refers to a traffic intensity of 10 erlangs, a mean call-holding time of 2 min, and a measurement period of 5 h. It is evident that the accuracy is relatively insensitive to the scan interval. In particular, virtually no improvement is obtained by using a scan interval smaller than the call-holding time.

Mean Call-Holding Time

The relationship between accuracy and call holding-time is somewhat complicated. One difficulty arises from the fact that the call-holding time and the traffic intensity cannot necessarily be treated as being independent. The traffic intensity is the product of the mean call-holding time and the mean call-arrival rate. In comparing the effects of different holding times, the question arises whether it should be assumed that the traffic intensity remains the same (in which case the call-arrival rates must differ), or does the call-arrival rate stay the same (in which case the traffic intensity must vary)? Both situations are examined.

Fig. 6 shows how accuracy is related to mean call-holding time for a fixed traffic-intensity. This assumes a traffic intensity of 10 erlangs, a measurement period of 5 h, and a scan interval of 3 min. Accuracy is improved at smaller holding times since the call-arrival rate is greater.

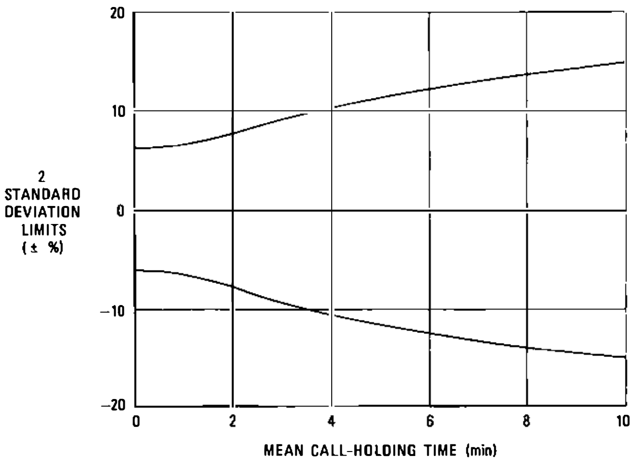

FIG. 6—The relationship between mean call-holding time and variability for fixed traffic-intensity

It is usually more appropriate to consider different holding times with the same call-arrival rate. This would arise, for example, when considering the effect of different common-control equipment holding times. The relationship between accuracy and holding time for a mean call-arrival rate of 5 calls/min is shown in Fig. 7. The traffic intensity is proportional to the holding time, and equals 10 erlangs when the holding time is 2 min. The measurement period is again 5 h and the scan interval is 3 min.

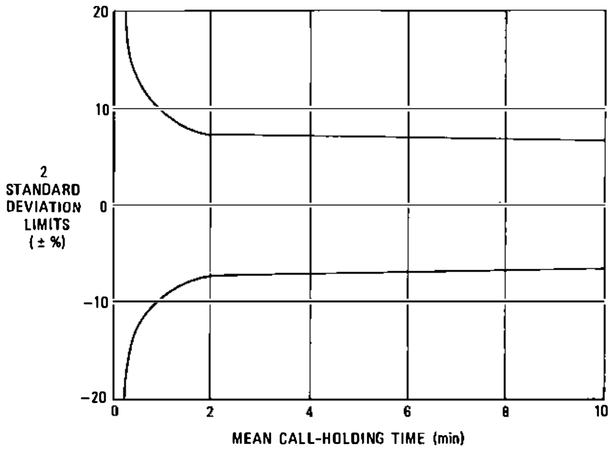

FIG. 7—The relationship between mean call-holding time and variability for fixed call-arrival rate

In this situation, the accuracy, in terms of the size of errors relative to the mean, deteriorates at small holding-times because the traffic intensity is then very low. However, the dimensioning process is less sensitive to errors at low traffic-levels (see Fig. 2) and, when the accuracy is interpreted in terms of corresponding dimensioning errors, it is found to improve as the holding time decreases.

IMPLICATIONS FOR MEASUREMENT PROCEDURES

Traffic Intensity

While traffic measurements have greater relative variability at low traffic intensities, the effects of measurement errors on equipment provisioning procedures are about the same at all traffic levels. Therefore, it is reasonable to maintain the same measurement procedures, regardless of traffic level.

Measurement Period

Aspects such as the choice of busy-hour and the use of morning, afternoon, and evening recording periods are outside the scope of this article.

The time-consistent busy-hour procedure, which comprises measurements taken over a 5 d period, is a reasonable compromise. A shorter measurement would produce substantially less accurate results. A longer measurement is not generally justified since the improvement in accuracy would be small, and measurements averaged over a large number of days would mask real variations in traffic intensity.

Scan Interval and Call-Holding Time

Measurement accuracy improves if the scan interval is decreased, and so it is desirable to scan as fast as is economically justifiable. However, relatively little improvement in accuracy is obtained by further reducing the scan interval when it is comparable with the mean call-holding time. In future traffic systems, it is likely to be economic to take more accurate traffic records than at present, either by using faster scan rates or by using a completely different form of measurement process.

Of course, it is impossible to apply precise economic criteria. The effects of measurement errors cannot properly be quantified in cost terms because such errors are normally compounded by other uncertainties in the planning process, and it is difficult to determine the cost benefits of varying levels of service to the subscriber. In addition, rapid technological development makes it difficult to quantify the relative costs of different measurement procedures.

The relationship between scan interval and call-holding time does not imply that it is necessarily worth using a scan interval as small as the call-holding time. For a given traffic intensity and scan interval, the smaller the call-holding time the greater the measurement accuracy. If the call-holding time falls for a given call-arrival process, so that the traffic intensity also falls, then the measured traffic becomes relatively more variable. However, if measurement errors are interpreted in terms of the associated provisioning errors, then the accuracy is not impaired.

These results have particular application to measurements on common equipment with short holding-times, where the holding times are primarily a function of the system operation. Here it is probably worthwhile using a reasonably small scan interval since, by decreasing the scan interval (down to a size comparable with the equipment holding-time), the accuracy can be substantially improved. However, it is certainly not worthwhile going to any great expense to maintain a scan interval equal to the holding time, since any reduction in the equipment holding-time does not effectively impair the accuracy.

CONCLUSION

This article has explained the relationship between the accuracy of measured traffic and the measurement period, scan interval, traffic intensity, and mean call-holding time. Although the relevant mathematical formulae have been known for many years, they have often been misinterpreted in practice.

Provided measurement accuracy is interpreted sensibly, measurements of small quantities of traffic are effectively no less accurate than measurements of large quantities of traffic. Similarly, a reduction in mean call-holding time does not effectively impair the accuracy of traffic measurements.

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Post Office Press Notice

HIGHEST CAPACITY CROSS-CHANNEL TELEPHONE CABLE

The British Post Office (BPO) cable ship CS *Alert* weighed anchor in September at the start of laying operations for the highest-capacity undersea cable ever laid across the English Channel. It is wholly of British design and manufacture.

Routed for 60 nautical-miles from Eastbourne to St. Valery-en-Caux, the new cable will be able to carry 4200 telephone calls at once, increasing the capacity of communications links between Britain and France by about 50%.

Planned for service early in 1979, the cable will carry telephone calls, Telex messages, data and other communications to and from France and other western European countries. Its cost is being shared between the BPO and the French General Directorate of Telecommunications.

In the laying operations, CS *Alert* connected the main section to 2 shore ends which were laid earlier by the BPO cable ship CS *Monarch*. To enable the Eastbourne end to be brought ashore, a channel had to be blasted through 20 m of rocky reef 400 m off-shore, the first operation of its kind undertaken by the BPO.

The new UK–France system is one of several submarine cable projects which the BPO, in close co-operation with the telecommunications authorities of other European countries, will be bringing into service to meet the needs of the early 1980s. These new cables, which are of the same British design and manufacture, will provide new direct links between Britain and Belgium, the Netherlands, Spain and Denmark, as well as access between the UK and other continental countries.

Speaking at Southampton before CS *Alert* sailed, Sir William Barlow, Chairman of the BPO, said that submarine cables would continue to play a vital role in the long-term growth of Britain's international telecommunications services. Referring to developments in space and technology, he said, "Satellites have undoubtedly opened up new and exciting means by which people throughout the world can communicate. But submarine systems will also provide vital arteries that will help carry international communications into the next century".

"It would be wrong," the Chairman continued, "to regard satellites and cables as rival contenders for international circuits. They are complementary transmission media, and together provide operational flexibility which safeguards against the need to put all our communication eggs in one basket."

Sir William pointed out that Britain's involvement with submarine cables and satellite communications were just two examples of the way the BPO ploughed back its profits, and much more, to benefit its customers and British industry generally.

The new UK–France cable will operate with a 45 MHz bandwidth (4200 telephone circuits), compared with cables brought into service in the early 1970s which operated with a 14 MHz bandwidth (1380 circuits). Unlike most other European systems, it will carry circuits of 2 bandwidths. These will consist of 3000 circuits at 4 kHz to provide links with the Continent, and another 1200 circuits at 3 kHz to make it possible to link up with traffic carried by transatlantic cables.

A total of 21 repeaters will be installed in the cable to provide signal amplification that matches the loss over the whole operational frequency range of the system. Because cable loss decreases with decrease of temperature, the design has to take account of the extremes of sea temperature likely to be encountered—close to freezing point in severe winter weather, and approaching 20°C in mid-summer.

The UK–France cable will incorporate automatic gain control to compensate for sea-temperature changes, using temperature-sensitive resistors fitted to the repeater casing. Part of CS *Alert*'s duties during laying operations will be to log sea temperatures. This information will enable the equipment to be adjusted to a mean temperature before the system is brought into use.

The amplifiers used in the repeaters employ 3 transistors known as the Type 40, designed and developed by the BPO Research Department, the sole manufacturer of this device.

Use of the PATHFINDER Exchange to Measure the Time for a Telephone Subscriber to Commence Keying

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UDC 621.395.345: 621.395.724

This article describes the use of the Pathfinder experimental exchange to measure the time that elapses between the lifting of the handset by a subscriber using a push-button telephone and the recognition by the exchange of the first key depression.

INTRODUCTION

The increased switching, signalling and processing speeds of stored-program control (SPC) exchanges enable subscribers to benefit from the use of multi-frequency (MF) push-button telephones. Since it is uneconomic to provide MF digit-reception capability on a per-line basis, the normal arrangement is to provide a pool of MF receivers, dimensioned on a traffic basis. A receiver is connected to a subscriber's line when required, either through a general-purpose switching network (serial trunking), or through a specialized register access switch (orthogonal trunking).

Thus, when a calling condition is detected on a subscriber's line circuit and the subscriber's class-of-service indicates that MF facilities are required, the common control allocates a free MF receiver/sender to the call and sets a path through the exchange to connect the calling-subscriber's line circuit to the marked MF equipment. Dial tone is then returned to the subscriber. This process takes a finite time, dependent on the detailed design of the exchange system. If keying is commenced before the MF receiver has been connected, there is a risk that the call will subsequently be lost or misrouted. The distribution of time between the events *handset-off* and *first-digit-arrives* is therefore of considerable interest to the exchange designer. It is to be expected that this time will differ for push-button telephones compared with rotary dial telephones for at least two reasons:

(*a*) The different nature of the action to be performed by the subscriber; that is, "stabbing" rather than "rotation".

(*b*) Push-button telephones do not provide the inherent guard period of several hundred milliseconds which the wind-up time of a rotary dial represents.

Therefore, a need was identified to obtain measurements of subscribers' time-to-commence-keying characteristics, for use as an input to teletraffic studies of modern exchange systems. Preliminary discussions indicated that the facilities of the Pathfinder experimental exchange could be used to provide a very convenient method of obtaining the desired measurements.

MEASUREMENT TECHNIQUE

The Pathfinder exchange has been described in detail in an earlier issue of this *Journal.** The control functions are divided into a 3-level hierarchy of control processors:

(*a*) microprocessors dedicated to the control of registers and supervisory units,

(*b*) a collocated pre-processor utility (PPU), supervising the establishment of simple calls through the exchange hardware, and

(*c*) a remote main processor utility, conceptually shared with other exchanges, and providing such facilities as supplementary services (such as billing) and traffic analysis.

Since the taking of the measurements was intended to be a fairly short-term experiment, it was decided to obtain them by temporary modifications to the operation of the PPU. This minimized both the cost of the experiment and the disturbance to the Pathfinder system as a whole.

Hardware Modifications

Under normal operating conditions, all telephony timing within the Pathfinder PPU is controlled by a 100 ms interrupt signal, supplied from a crystal-oscillator/divider circuit. In addition, a faster counter, slaved from the same oscillator, can be accessed by the programmer, but this is normally used solely as a software debugging aid. For this experiment, it was decided that it would be desirable to be able to time the *handset-off* and *first-digit-arrives* events more accurately than is possible with the 100 ms interrupt signals, and minor modifications were made to the external counter to enable a real-time clock of 10 ms interval to be available to the software.

Software Modifications

Changes were necessary in 3 areas of the existing PPU software. Firstly, a timing routine, specifically designed to measure intervals to an accuracy of ± 10 ms, was written to supplement the existing interrupt software. Secondly, the telephony software that processes the messages corresponding to the events *handset-off* and *first-digit-arrives* had to be modified to access the timing routine and to record the times at which these events occurred. Finally, new software was required to subtract the 2 event times for each call, accumulate the resulting values and output the results in the form of a histogram on an output printer at hourly intervals.

Accuracy of Measurements

A detailed discussion of the accuracy of the measurements is beyond the scope of this article. Very briefly, the factors to be considered are as follows.

(*a*) The recognition by the line unit of the initial loop

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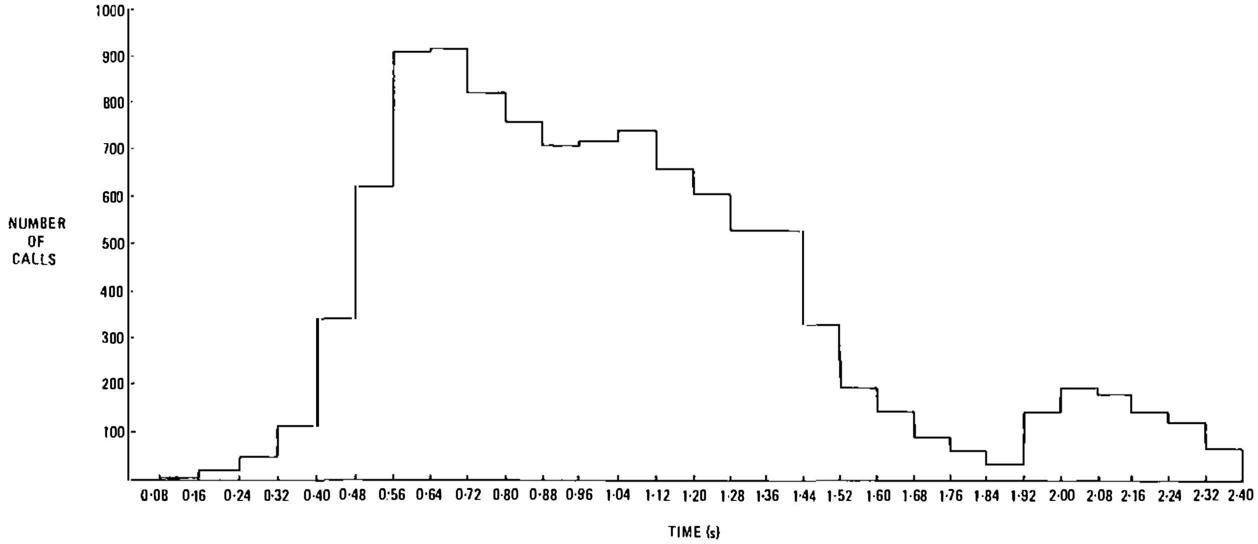
* Smith, C. S. A., and Park, I. D. C. Pathfinder: An Experimental Telephone Exchange using Stored-Program Control. *POEEJ*, Vol. 70, p. 68, July 1977



Notes: (*a*) Total sample size: 14 870 calls
(*b*) Calls where the time to commence keying was greater than 2·4 s have been excluded. There were 4007 such calls
(*c*) Calls where the handset was lifted but no digits keyed have been excluded

FIG. 1—Time to commence keying on Pathfinder exchange

condition from a subscriber's instrument is known to take approximately 45 ± 5 ms, the variation being predominantly a function of the local line resistance.

(*b*) The time taken by the MF register to detect the presence of the first keyed digit is approximately 40 ± 5 ms.

It can be seen that, for the purposes of this experiment, these two sources of systematic error largely cancel out, leaving a small random uncertainty. Further uncertainty is introduced in the PPU software, both by the inherent resolution limit of the reference clock signal (±10 ms) and by the fact that messages from the hardware may have to queue for attention by the processor.

Taking account of all these sources of error, it is estimated that the overall random error on any one call is ± 24 ms. There is a further restriction that a first digit arriving within 85 ms of the initial loop condition would not be detected, this being the time taken to connect a register to the calling line.

RESULTS

Once the modifications described above had been successfully incorporated in the Pathfinder exchange, the experiment was allowed to run throughout the day for 4 weeks. However, due to a difficulty experienced with the output printer, the results for the equivalent of only about 3 weeks were available for analysis.

The results are summarized in Fig. 1. Note that, since the primary objective of the experiment was to determine how rapidly a subscriber may commence keying, the results for keying delays greater than 2·4 s have not been included. A total of over 14 000 calls was monitored.

When this experiment was conducted, the Pathfinder exchange was providing service to approximately 100 subscribers, most of whom had been using push-button telephones for over a year. Although all the subscribers are employed at the BPO Research Centre, they include staff undertaking a wide range of both clerical and engineering duties.

Since this experiment was completed, arrangements have been made for detailed timing information for every call to be recorded on magnetic tape. It is hoped that a human-factor study based on this data will enable authoritative explanations to be provided for certain features of the results shown in Fig. 1; for example, the secondary peak in the distribution at around 2 s, and the apparent ability of some subscribers to commence keying within 300 ms.

CONCLUSIONS

The results form a useful input to the teletraffic evaluation of new switching systems. Once other studies have determined the distribution of the time taken by the switching system to connect a register, the results of this study can be used to estimate the probability of failure to connect the register before the first digit arrives.

The study has also demonstrated the inherent flexibility of SPC systems, and the value of Pathfinder as an experimental tool. Using the techniques described, it has been possible to make the required measurements much more cheaply and rapidly than would have been possible using more conventional methods.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Mr. R. J. Waughman, who carried out the detailed modifications to the software.

The Journal's Coverage of TEC and SCOTEC Courses for Technicians

A. R. LAWRENCE, C.ENG., M.I.E.R.E., and B. STAGG, C.ENG., M.I.E.E.†

UDC 374:331.86

After nearly 50 years, the Journal's *model-answer service for students of the City and Guilds of London Institute (CGLI) could be said to have become a tradition. With the introduction of Technician Education Council (TEC) and Scottish Technical Education Council (SCOTEC) courses, that tradition is to continue with a service to students following the new courses. This brief article outlines the methods which will be used and describes what the* Journal's *coverage of the new courses is designed to achieve.*

INTRODUCTION

In the *Supplement* to this issue of the *Journal*, the first sets of model questions and answers dedicated to Technician Education Council (TEC) and Scottish Technical Education Council (SCOTEC) courses are presented. The aim is to illustrate, as comprehensively as possible, the kinds of assessment procedure students are likely to meet, and to suggest how these might be tackled. In doing so, material will be provided on which students will be able to practise the skills they have learned, and which is useful also for its intrinsic educational value.

OBJECTIVE ASSESSMENT

The concept of a syllabus which takes the form of a detailed set of objectives to be achieved by a student has been introduced in a previous article in this *Journal**. This concept, which is a main foundation of TEC courses, is the result of a more rational view of the purpose of technician education.

Analytical studies are often of limited relevance to a technician's day-to-day work. In designing a technician course, it is more useful to consider the knowledge and skills a competent technician must possess in order to carry out his duties effectively; these generally involve broad principles, circuit effects and applications, plus some practical aptitudes. More academically-minded technicians subsequently have the opportunity to expand their studies by means of supplementary and higher-level studies.

The first step in designing a technician course is to decide what a student should be able to do at the end of his training that he could not do before. It is necessary to analyse the work involved and to determine very precisely the fundamental and ancillary elements of knowledge and skill involved. Each of these elements can then be described as an objective to be achieved by the student, and the objectives themselves then offer the means of progressively assessing the student's competence.

This approach has resulted in the extensive use of objective testing during TEC courses, although students are usually also expected to demonstrate communication skills in longer written answers. In addition, practical assignments and oral tests may be given, but these fall outside any help that can be given by the *Supplement*.

ASSESSMENT

Assessment procedures have been devised that seek to:

(*a*) explore a student's performance of various intellectual skills (such as originality, mastery of the objectives, ability to interrelate objectives, make use of information, and argue effectively), and

(*b*) test a student's practical skills (such as the ability to use a pocket calculator or laboratory equipment).

Thus, students are faced with assessment test papers that contain various kinds of question: objective, numerical and descriptive, the last two requiring either long or short answers. Moreover, because assessment is phased (which means that it is as near to being a continuous monitoring of progress as limited college time permits), these tests occur regularly throughout the course (in-course tests), with an embracing final (end-of-unit) test usually being given as well.

COVERAGE IN THE *JOURNAL*

Illustration of Questions

Because of the effect of complex assessment procedures on test papers, a primary aim has been to illustrate the various forms and purposes of questioning, and this will be done by publishing sets of model questions that accurately reflect the styles and standards of test papers all over the country.

TEC examinations are not centrally set; each college is devising its own test papers. So, model questions have been added to the traditional model-answer service. The *Journal* has been fortunate in securing the co-operation of a number of colleges in England, Wales and Northern Ireland, and assessment plans have been examined and in-course and end-of-unit test papers analysed. Thus, it has been possible to design sets of model questions representative of assessments actually encountered by students, and reflecting the mix of questions used.

The coverage is, therefore, exemplary of actual assessments, but it must be emphasized that, because it is based on the work of a number of colleges, it is not representative of any particular college. Students must be prepared to meet local variations. (Some colleges may rely completely on objective questions, with no end-of-unit test being given.)

† Mr. Lawrence is Assistant Editor, *POEEJ*, with special responsibility for the model-answer *Supplement*, and Mr. Stagg, previously Assistant Editor and now in the Telecommunications Systems Strategy Department, Telecommunications Headquarters, was responsible for the initial work in setting up the *POEEJ*'s coverage of TEC courses

* BLAKEY, H., and STAGG, B. The Technician Education Council. *POEEJ*, Vol. 70, p. 219, Jan. 1978

Model Answers

With the extensive use of objective and short-answer descriptive and numerical questions, students are expected to give a large number of precise or concise answers. Inevitably, rather strict time limits apply.

Because of this, and the intention to illustrate accurately the assessment procedures, a primary aim has been to give model answers that mirror exactly what would be expected of students in the time allowed. To this end, specimen time limits have been allocated to each question or group of questions.

Tutorial Function

In the past, advantage has often been taken of the opportunity to make model answers more comprehensive than was strictly demanded by the question. This made many answers suitable for revision or general reference.

In restricting answers to exactly what is demanded by the questions and, indeed, being restricted by the nature of objective questions, this facility is in danger of forfeit. Recognizing this, it is intended still to give additional educational information, where this is justified, although such information will be clearly separated from the main answer so that it does not mislead students.

Practice Material

In addition to the above primary aims, the model questions are intended to provide material on which students may exercise their knowledge before checking their answers. To this end, wherever possible, answers will be printed in such a way that they may be covered up by the student.

SCOTEC COVERAGE

Model questions and answers for SCOTEC courses will also be presented. A slightly different approach has been adopted to designing model questions and presenting model answers, in line with the SCOTEC's own policies. The primary and secondary aims described above again apply, and SCOTEC students will find the TEC coverage of help to them. The SCOTEC coverage mainly explores topics not common to both the SCOTEC and TEC syllabi.

COVERAGE OF CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS

It is intended that publication of model answers to City and Guilds of London Institute (CGLI) examinations in a subject will continue at least until the last re-sit examination in that subject has been held in the UK. However, the coverage will of necessity be less extensive. Instead of publishing 8–10 questions in each subject, space restrictions will probably impose a limit of 5 or 6 questions. However, CGLI students will find in many cases that the TEC coverage will be useful as practice material.

EVOLUTION

The TEC units which will be covered in the *Journal* during 1979, and which are included in the *Supplement* to this issue, are: Mathematics 1, Physical Science 1, Telecommunication Systems 1, and Line and Customer Apparatus 1. For SCOTEC, Mathematics 1 and 2 (two half-subjects, both taken during stage 1), Electrical and Engineering Principles 1 (a double-length subject), and Introduction to Telecommunication Systems 1 are covered.

Clearly, there are difficulties in *Supplement*-type coverage of drawing and workshop studies, but the situation will be kept under review and it may be possible at a later stage to include the written work associated with these subjects. Similarly, the possibility of covering General and Communication Studies, should more colleges adopt the standard syllabus devised by colleges in the London region, will be borne in mind.

Coverage of levels 2 and 3 will commence in 1980 and 1981 respectively, though the position regarding the Higher Certificate (levels 4 and 5) is not yet clear.

In the early years of TEC and SCOTEC courses, there are likely to be changes to syllabi and methods. Any evolutionary moves will be reflected in the *Journal*'s coverage.

After the early years of coverage have allowed illustration of the types of assessment that students will encounter, it might eventually become possible to place renewed emphasis on tutorial matter.

FEEDBACK

At this stage, it is possible for the *Journal* to cover TEC and SCOTEC courses only in a way which it is felt will be of most benefit to students. However, we must be prepared to vary our methods in the light of experience, and the only way in which we can gain that experience is by feedback from those directly and indirectly involved with the new courses. Therefore, the editors would welcome any comments from students, lecturers, training officers, or, indeed, from anyone who feels that they have a worthwhile contribution to make on the form of presentation and its value.

CONCLUSION

The philosophy of the *Journal*'s coverage, of which the preceding points are a summary, will be kept under review. It has been arrived at following discussions with college staff and training experts, and the examination of vast amounts of relevant documents.

ACKNOWLEDGEMENTS

The Board of Editors expresses its thanks to all those who have assisted with the setting up of the *Journal*'s coverage of TEC and SCOTEC courses, especially those colleges that have given the benefit of their experience and provided test papers, and those dedicated authors who have produced material for publication. Thanks are also due to the staff of various British Post Office training departments for advice and practical help, and to the staffs of the TEC and CGLI.

Autofax: A Store-and-Forward Facsimile System

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UDC 621.397.12 (08): 691.317.1: 681.31–181

The recent advances in document facsimile transmission and standardization can be combined with the advantages of microprocessor control to produce a system (AUTOFAX) *for automatically sending documents over the telephone network at night at a cheaper tariff, or at other times convenient to the user. A pre-prototype model has been successfully constructed to demonstrate such a system and to examine the various possible facilities. Commercial facsimile machines are used in order to keep the cost of the terminals as low as possible.*

INTRODUCTION

Moves towards new methods of message transmission have been occurring for many years. This has been due mainly to changes in business practice and organization, improvements in electronic technology, and increasing costs of traditional communication methods. Facsimile is capable of transmitting a wide variety of documents, and recent developments have led to faster transmission times, better copy quality and improved compatibility between different machines.[1]

The two main modes of document facsimile transmission which have been standardized by the CCITT, are shown in Table 1. Digital systems have the advantage of working at higher speeds than analogue systems, but analogue machines are cheaper and are widely used, although they take 3 min to transmit an A4 document. By incorporating microprocessor control, the advantages of user convenience and cost reduction can be obtained, since the addition of a fast scanner and a memory unit then allows many documents to be stored during office hours for automatic transmission at reduced tariffs during the night.

TABLE 1

CCITT Classification of Facsimile Apparatus for Document Transmission

	Analogue Transmission	Digital Transmission
CCITT Group	2	3
Time to transmit A4 document	3 min	1 min
Scanning density	3·85 lines/mm (100 lines/inch)	3·85 lines/mm (100 lines/inch)
Horizontal resolution	Nominally 4 picture elements per millimetre grey scale	7·7 picture elements per millimetre, 1728 picture elements per line, each picture element is quantized into either black or white
Transmission method	Amplitude modulation Phase modulation Vestigial side-band carrier frequency 2100 Hz	Data reduction by run-length coding using separate modified Huffman codes for black and white runs. Transmitted using 4·8 kbit/s modem to achieve an average transmission time of 1 min.

† Research Department, Telecommunications Headquarters

STORE-AND-FORWARD FACSIMILE

The 2 main requirements for a store-and-forward facsimile system are that,

(a) it should be easy to use, and
(b) it should provide a high grade of service.

The former can be satisfied by the use of microprocessor control, which removes the need for a trained operator while providing a comprehensive and fast service for the user. A high grade of service is provided by making multiple attempts to set up the call should it be necessary to do so, combined with a sophisticated monitoring system which records the outcome of each attempt. When a call is eventually established, it is important to ensure that the document is transmitted to its correct destination. Therefore, each terminal is assigned an exclusive identity code based on its national telephone number, and this is checked by the calling machine to confirm the destination before transmission of the document proceeds.

TERMINAL OPERATION

The Storage Phase

A document is placed in the scanner and the telephone number of the addressee is entered using the keypad on the control-board; a visual display is provided for verification. Under microprocessor control, the telephone number is recorded on magnetic tape as a header, and the document is scanned and recorded on the tape in about 12 s. The original document is then removed and the scanner is immediately available to accept a further document. This simple procedure is performed as required throughout the day.

The Transmission Phase

At some convenient time, perhaps at night when tariffs are lower, the system is activated automatically by a built-in time clock, and the first header is read from the tape. Once a connexion has been established, a digital sequence (known as *handshaking*) checks the identity of the called terminal before document transmission takes place. If, for any reason, it is not possible to establish the call, the controller stores details of the failure. When all calls have been attempted, the tape is rewound automatically and the sequence is repeated, ignoring those calls successfully completed previously. This phase is completed when all the stored documents have been transmitted, or when all repeat call attempts

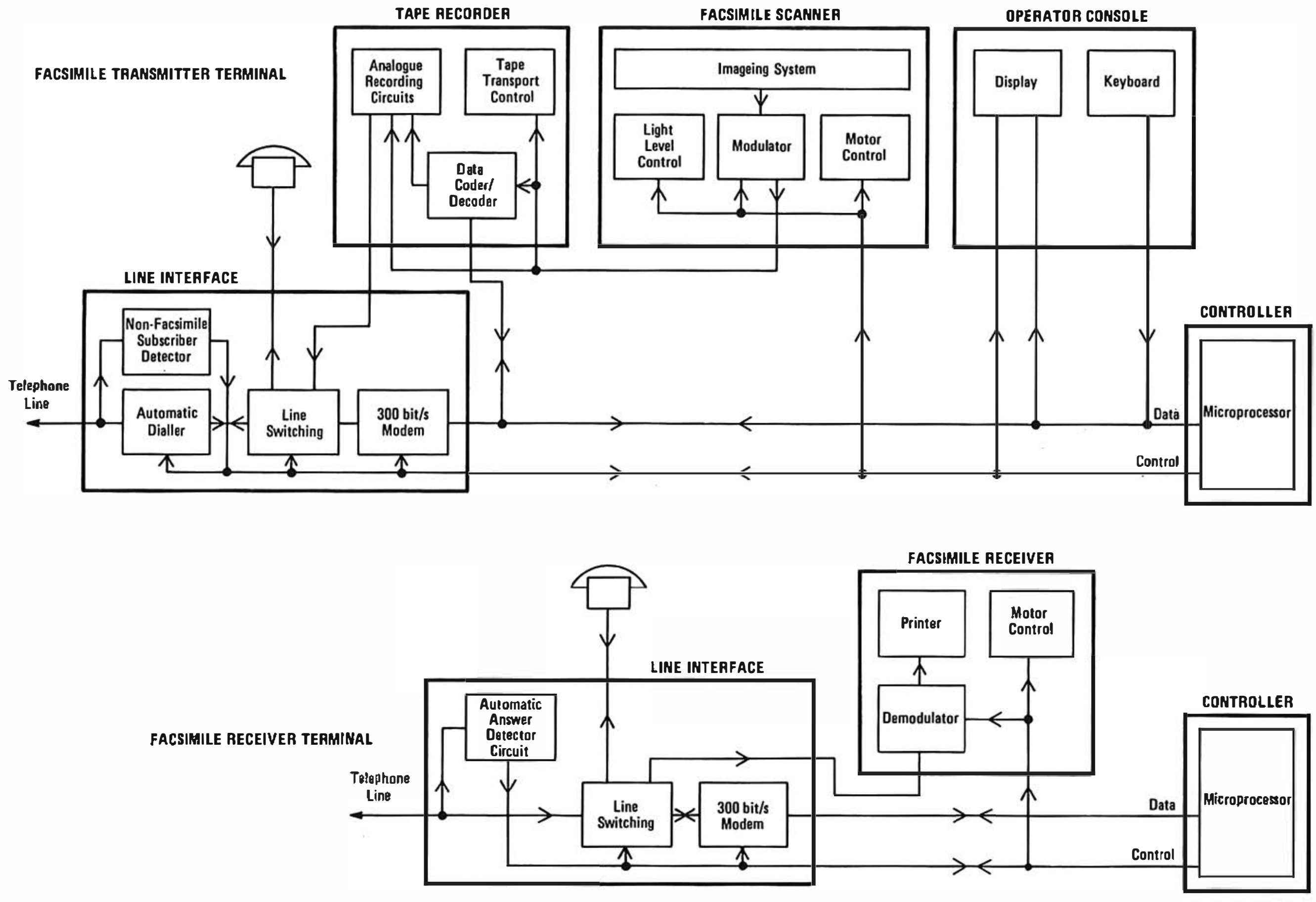


FIG. 1—Autofax terminals

have been made. The transmitting station is able to send a little under 20 A4 documents per hour since each document requires 3 min transmission time.

The following morning the terminal is interrogated by an operator who can check, by use of the keyboard and visual display, the contents of a *call outcome* store to see which messages, if any, have not been sent. If urgent, the operator can instruct the Autofax station to transmit any failed messages immediately. Finally, the operator uses a keyswitch to erase the tape and the system automatically re-enters the storage phase.

THE PRE-PROTOTYPE SYSTEM

A pre-prototype laboratory system has been constructed and a block diagram is shown in Fig. 1. The transmitting terminal consists of a high-speed scanner, a tape recorder, a line interface unit and a microprocessor-based controller (see Fig. 2). A receiving terminal is simpler and needs only a facsimile receiver, a line interface unit and a simplified controller.

FIG. 2—An Autofax transmitter

The High-Speed Scanner

In order to ensure a fast service for the user, it is necessary to provide a machine which can scan an A4 document in under 12 s. To provide this facility, an office photocopier was modified and a linear photodiode sensing array was installed. Although this approach was successful in the pre-prototype system, it is probable that future scanners will use commercial facsimile transmitters which have been modified to work at the required speed. This can be achieved easily, since many new facsimile machines use electronic scanning techniques which are inherently faster than their earlier electromechanical counterparts.

The Tape Recorder

Use of a fast scanning facility meant that the tape recorder had to record at a high speed and yet be able to replay the recorded signal at a slow speed to conform with the 3 min analogue transmission standard dictated by the limited bandwidth of the telephone network. This dual speed operation, combined with the need to store at least 50 documents, and the need for a speed accuracy of 1 part in 10^5 meant that the only suitable recorders readily available were very expensive. Therefore, a special machine was developed to perform this function based on a modified *Elcaset* tape recorder as this had a much higher performance than standard cassette machines. This is due to the fact that it uses 6·4 mm (¼ inch), wide tape rather than 3·2 mm (⅛ inch), and the tape transport is a high quality mechanism incorporating dual capstan drive. The Elcaset tapes also give double the playing time of standard cassette tapes. The tape recorder is controlled by the microprocessor, and the interface between them is at a very basic level, such that all the finer details of timing are carried out in the microprocessor. This means that, in the future, any additional facilities can be easily implemented by enhancing the software without the need to add extra hardware.

Two types of signal are recorded on the tape—data and facsimile. The former is recorded as a header preceding each document, and contains the telephone number to be dialled, an identification code and facilities information. To format this data into a serial stream the microprocessor uses a serial input/output (SIO) interface chip. This device adds stop/start and parity bits and its use, when recording, allows for a *read-after-write* operation, so that the data can be checked as it is written.

The facsimile information employs vestigial-sideband amplitude-modulation preceded by a baseband coder to reduce the analogue information rate. The modulating frequencies were chosen to be 16 times those recommended by the CCITT; thus, when the tape is replayed at one-sixteenth of the recording speed, the signals require no demodulation or further signal processing before passing to line.

The Microprocessor Controller

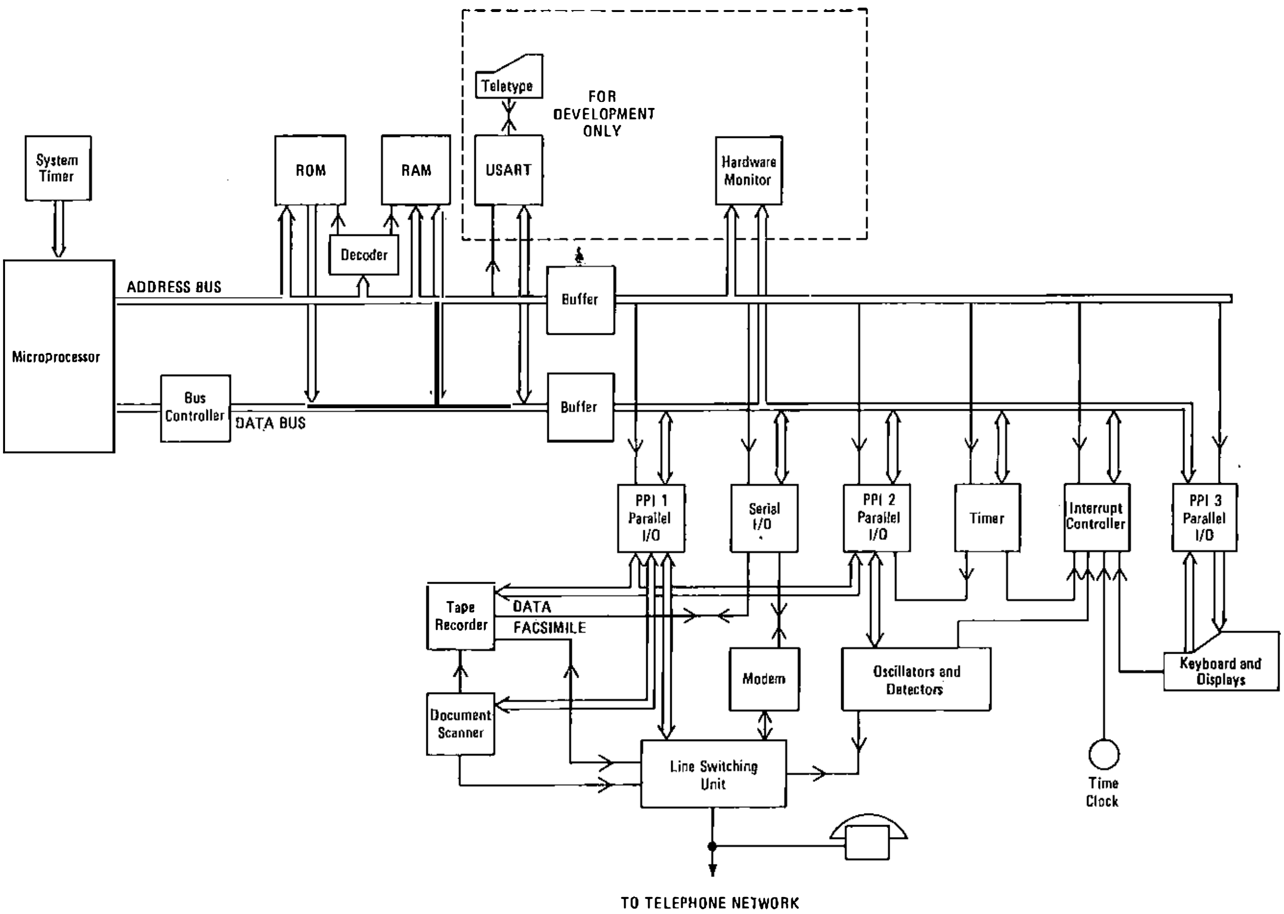
Each terminal is controlled by a microcomputer based on an Intel 8080 microprocessor[2] as shown in Fig. 3.

The controller was built using a microprocessor development system produced in the British Post Office (BPO) Research Department, since this made it possible to construct and test each module separately, with the relevant program being held in a random-access memory (RAM) so that it could be easily changed using a Teletype. Once the subsystems had been cleared of faults (debugged), they were brought together and the program was loaded into a non-volatile read-only memory (ROM).

To communicate with the various units in the terminal, the processor uses 3 parallel peripheral interface units (PPIs) which convert the bytes of computer data into electronic pulses suitable for driving displays and relays. The display used is a 40-character plasma panel, which is used extensively to convey messages and prompts to the user in order to allow simple selection of some of the comprehensive facilities.

NON-FACSIMILE SUBSCRIBER DETECTION

Since the system can make calls automatically during the night, it is necessary to take steps to minimize any inadvertant disturbance of private subscribers. Should a wrong number be accessed, it is important that the disturbance should be made as short as possible and that it should not be repeated. To do this, the microprocessor is programmed to monitor the line when dialling has been completed and to look for the presence of ringing tone. Should 2 full bursts of ringing tone be detected, it is assumed that that an Autofax terminal has not been accessed, since these are designed to respond immediately on receipt of ringing current. The microprocessor marks the header associated with that call



I/O: Input/output RAM: Random-access memory
PPI: Parallel peripheral interface ROM: Read-only memory
USART: Universal synchronous/asynchronous receiver and transmitter

FIG. 3—Block diagram of Autofax transmitter

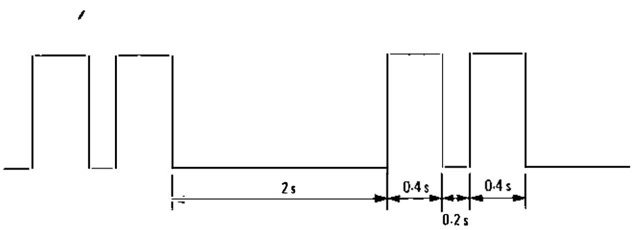


FIG. 4—Cadence of British Post Office ringing tone

FLAG	ADDRESS	CONTROL FIELD	INFORMATION FIELD	FRAME CHECK SEQUENCE	FLAG
01111110	11111111	11001000	8 – 32 bit	FCS CODE	01111110

FIG. 5—A high-level-data-link-control frame

and on subsequent passes through the tape the call is ignored.

To discriminate between ringing tone and all the other national and international tones, it is necessary to examine the cadence of the received tone bursts. Fig. 4 shows the cadence of BPO ringing tone. Nearly all countries use ringing tones around 400 Hz and these consist of bursts of tone with a silent period of at least 2s between bursts; all other tones have repetition rates shorter than 1s. By programming the microprocessor to examine the gaps between bursts, it is possible to detect international ringing tones with a high degree of confidence.

SIGNALLING

When a facsimile call has been established, it is necessary to have a period of signalling between the terminals to decide which of the modes of operation and which facilities are to be selected. The CCITT have recently agreed a comprehensive recommendation (T30) covering the signalling between facsimile machines. The recommendation is split into 2 sections: for analogue transmission, as used by Autofax, a tonal signalling system is recommended, while, for the more sophisticated Group 3 machines, a digital protocol is recommended. To interwork with the inexpensive facsimile receivers, Autofax is equipped with the tonal signalling system. However, since it is desirable to have automatic answer-back identification, the digital procedure is also implemented to provide this added facility.

This digital data is transmitted using a simple half-duplex synchronous modem and employs the frame structure of *high level data link control* (HDLC) to format the commands and responses specified in recommendation T30; the frame structure is shown in Fig. 5.

Each frame consists of

(*a*) a flag field to establish word synchronization,
(*b*) an address field to identify a particular destination,
(*c*) a control field which contains the purpose of the frame,
(*d*) an information field where the facsimile control messages are inserted,
(*e*) a frame check sequence for error detection, and
(*f*) a closing flag.

Use of this structure will ease compatibility of Autofax with emerging data networks and may simplify interworking between facsimile and other message handling systems, such as word processors.

To format and interpret these data streams, the microprocessor uses an SIO chip which inserts all the flags, addresses and check fields automatically, although this function could be performed by the use of additional software.

SOFTWARE DEVELOPMENT

All the software was written in assembler language[3], since the available high level languages were not readily accessible and were less efficient. The programs were developed on the BPO IBM computer and were then assembled on that machine to produce the machine code suitable for loading into the Intel 8080 microprocessor's memory. Recent work has been undertaken on the Hewlett Packard computers in the BPO Research Department since it is possible to directly interconnect the microprocessor with that system, thereby enhancing the program debugging facilities.

In order to maximize system reliability, it was decided to reduce the number of interrupt lines that could access the microprocessor. Although use of interrupts can shorten program length and complexity, spurious noise on these lines could have had a catastrophic effect on program flow. Therefore, considerable care was taken to physically and electrically isolate the relays and transformers that switch the 50 V telephone line, thereby reducing possible interference.

Preliminary experience of real-time programming had shown the importance of designing the software so that it was easy to debug. To this end, the philosophies of structured programming were adopted, to try to reduce re-entrant routines and to make the flow of the program similar to the state of the terminal's activities. It was also found that a highly optimized code could be more difficult to debug and document, while a more straightforward approach was easier for non-specialist programmers to understand.

CONCLUSIONS

The pre-prototype Autofax equipment has shown the viability of store-and-forward document transmission and has prompted further development.

With the growth of digital facsimile transmission, it is possible that different configurations of Autofax could emerge offering compatibility with other text transmission systems, such as word processors and Telex, although it is not yet clear how such interworking is to be standardized.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to colleagues in the BPO Research Department, for their assistance with the project and with the preparation of this article.

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Institution of Post Office Electrical Engineers

General Secretary: Mr. R. Farr, THQ/NP 8.3.2, Room S 04, River Plate House, Finsbury Circus, London EC2M 7LY; Tel.: 01-432 1954

CENTRE PROGRAMMES 1978–79

East Midlands

Meetings will be held at Nottingham University or at the Technical College, Peterborough, commencing at 14.00 hours.

7 February (Nottingham): *Accommodation Services for Modern Telecommunication Systems* by D. A. Spurgin.

7 March (Nottingham): *The Importance and Influence of Engineers in General Management* by A. P. Parsons.

5 April (Peterborough): *Modernization of UK Telecommunications* by J. S. Whyte, C.B.E., M.SC.(ENG.), C.ENG., F.I.E.E. (President of IPOEE, Senior Director of Development).

South Eastern

Meetings will be held at: the Conference Room, 46 Holland Road, Hove; St. Saviour's Church Hall, Lees Road, Guildford; Ypres Hall, Town Hall, Central Avenue, Sittingbourne or the Social Centre, Rear of Tunbridge Wells Automatic Telephone Exchange. All meetings commence at 14.00 hours.

25 January (Guildford): *External Plant Maintenance—Are the Changes Successful?* by F. Smith.

7 February (Sittingbourne): *External Plant Maintenance—Are the Changes Successful?* by F. Smith.

22 February (Guildford): *Method of Introduction of Digital Operation in the Local Network* by J. M. Griffiths.

7 March (Hove): *Modern Facsimile Systems* by A. J. Bott.

22 March (Guildford): *CDSS1: A New Digital PABX System for the BPO Rental Range* by R. C. Gibbs.

28 March (Tunbridge Wells): *Methods of Introduction of Digital Operation in the Local Network* by J. M. Griffiths.

Notes and Comments

CORRESPONDENCE

Oxford Telephone Area

Dear Sir,

I have been following your articles on the 30-channel pulse-code modulation (PCM) system with great interest and I am sure that many of your readers will be interested to know that the first such systems in the UK have been installed, commissioned and brought into service in the Oxford Telephone Area. The first public call was made on 8 September 1978.

A number of problems were encountered during installation and commissioning but they were resolved by co-operation between the Area, Region, THQ and the manufacturers.

At the time of writing, no problems have been experienced since the systems were put into service.

Yours faithfully,
B. V. Wilsden

External Telecommunications Executive

Dear Sir,

I am sure that readers of the *Post Office Electrical Engineers' Journal* have noticed the increasing use of codes to abbreviate technical terms used in the text of technical articles. Although I agree that some codes are acceptable, I think they should be limited to technical terms only and should be kept to a minimum. In a recent article, for example, *COW* was used to abbreviate *class of work* (most engineers now accept *COW* to be *Clerk of Works*). I feel that if this habit continues to spread, readers will lose interest and will not fully read the text.

I do not know if these articles are written in this way by the authors, or whether it is a whim of the Editor. May I suggest that codes be used to abbreviate only proper nouns relating to technical terms and that they are used sparingly.

Yours faithfully,
K. P. Wiskin

The Editor replies: The responsibility for the presentation of an article rests with the Editors. Over the years it has been adopted as a *Journal* standard that, where an abbreviation is considered necessary, at its first appearance the term is quoted in full with its abbreviation appearing in brackets; subsequent appearances then use only the abbreviation. By this means, it is felt that those familiar with the abbreviation will not be bored by continual repetition of a familiar term, while those not familiar with the abbreviation will have had it defined. However, I take the point of the letter, particularly where an abbreviation may have more than one common application, and will bear it in mind for the future.

Publication of Correspondence

The Board of Editors would like to publish correspondence on engineering, technical or other aspects of articles published in the *Journal*, or on related topics. Letters of sufficient interest will be published under Notes and Comments.

Letters intended for publication should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

CONTRIBUTIONS TO THE JOURNAL

Contributions to the *POEEJ* are always welcome. In particular, the Board of Editors would like to reaffirm its desire to continue to receive contributions from Regions and Areas, and from those Headquarters departments that are traditionally modest about their work.

Anyone who feels that he or she could contribute an article (short or long) of technical, managerial or general interest to engineers in the Post Office is invited to contact the Managing Editor at the address given below. The editors will always be pleased to give advice and try to arrange for help with the preparation of an article, if needed.

GUIOANCE FOR AUTHORS

Some guiding notes are available to authors to help them prepare manuscripts of *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal*'s editors, printer and illustrators, and help ensure that authors' wishes are easily interpreted. Any author preparing an article is invited to write to the Managing Editor, at the address given below, to obtain a copy.

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

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

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

Contributions should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

The Associate Section National Committee Report

ANNUAL CONFERENCE

The annual conference took place at the Technical Training College, Stone, on 20 May 1978, when the following officers were elected for 1978–79.

Chairman: E. W. H. Philcox.
Vice-Chairman: B. W. Headley.
Secretary: M. E. Dibden.
Assistant Secretary: R. V. Parton.
Treasurer: C. J. Webb.
Editor: B. Harlow.
Project Organizer/Visits Secretary: J. J. F. Anning.

The main business of the meeting was to approve a new set of rules. These had taken a year to compile from two original sets and many amendments submitted by regional committees. As the remainder of the meeting was taken up with officers' and regional reports, it was decided to hold a full meeting of the National Committee during October to put some new ideas before the National Executive Committee.

OCTOBER MEETING

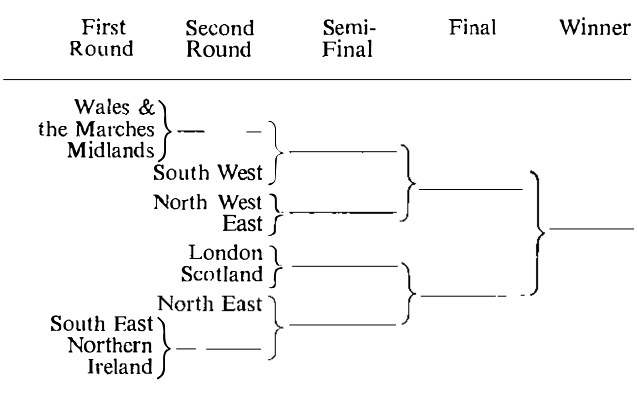
The National Committee's full meeting at the Technical Training College, Stone, on 7 October was well attended by delegates and officers, and the encouraging results of their deliberations should be seen later in the session.

NATIONAL TECHNICAL QUIZ COMPETITION

The draw for the 1978–79 National Technical Quiz took place during the October committee meeting. The result of the draw is shown below.

The first round should have been played by the end of 1978, the second round by 16 February 1979 and the semi-final by 16 March. The final will be held at the Institution of Electrical Engineers, Savoy Place, London, on Friday 20 April 1979. The presentation of the Bray Trophy to the winners will be made by Mr. P. F. Benton, Managing Director, Telecommunications.

May I ask that any would-be writers of quiz questions contact regional or national quiz organizers—help however small would be welcome. This topic arises at many meetings and promises are made; perhaps 1979 will be the year of action and the questions will flood in.



NATIONAL PROJECT COMPETITION

The 1978–79 National Project Competition, *Design a telephone combining the maximum number of facilities for use by disabled customers*, is nearing its final stage. All entries must be submitted by 31 January 1979 for judging by a panel at the National Executive committee meeting in February. The presentation of the E. W. Fudge Trophy will be made on the occasion of the National Quiz final.

PUBLIC LIABILITY INSURANCE COVER

The Treasurer has now effected public liability insurance cover. The salient points will be circulated when they become available; all centres affiliated to the National Committee were covered from 12.00 hours on 17 October 1978. This cover is in addition to the Personal Insurance cover already enjoyed by centres affiliated to the National Committee.

NATIONAL DIRECTORY

The national directory is found by some people to be a very useful document and, to keep that way, must be kept up to date. I would be grateful if any local or regional changes are notified to me so that the appropriate pages can be updated.

M. E. DIBDEN
General Secretary

Associate Section Notes

LONDON CENTRE

Although, on the surface, the summer activities have been quiet, there have been some notable exceptions. One of these took place on 28 May 1978 with the presentation of a portable television set to Bcneden Hospital. Mr. Norman V. Clark, Treasurer of the London Centre, made the presentation on behalf of the Centre.

On 6 June, South Telephone Area of the London Telecommunications Region unveiled their TXE4 Simulator project. The result of 2½ years work made an impressive sight, with the demonstration being well received by Associate and Senior Section members alike.

The first meeting of the session was held on 4 October, with the support of projects high on the list of priorities. A total of £800 was granted to 2 Areas in support of microcomputer projects. The draw for the inter-area quiz was carried out but, sadly, this year's TT(A) quiz will be a little thin due to the low level of recruitment. For the National Quiz Competition, East Area will once again represent London.

After a break, the London Centre will be reviving the organizing of trips abroad. The first trip planned will be a weekend in Paris. Already, a block booking for 250 people has been made; the cost will be a little under £30 per person and the date will be late in 1979, leaving on a Friday night and returning on the Sunday night. Any members of Associate Sections who are interested in the trip should contact their regional secretary, who should then contact me for further information. It must be made clear, however, that the policy on allocation of places to members from outside London has still to be settled.

After the meeting, Mr. Bob Beadle of South Area, gave an excellent lecture with the aid of the new simulator on the subject of TXE4. South Area is to be congratulated on this achievement.

L. Wood

COLWYN BAY AND RHYL

A lecture on the *Bloxham Tapes* was given by Mr. Jeff Iverson, a television producer for the BBC, at the Royal British Legion Club, Llandudno, on 25 September. Some 75 members enjoyed the lecture, which explored the phenomenon of people having more than one life. At the meeting, a presentation was also made by the chairman, Mr. N. Williams, and the secretary, Mr. M. Thomas, to our ex-secretary, Mr. E. Doylerush, in recognition of his 9 years loyal service to the centre.

M. L. Thomas

Book Reviews

Introduction to Communication Command and Control Systems. D. J. Morris, Pergamon Press Ltd. 350 pp. 222 ills. £15·00.

This book was written as an introduction to communications, systems and networks, dealing principally with those carrying data and controlled by computers. The author, a senior lecturer at the Ben Gurion University of the Negev, Israel, sets out to discuss the general aspects of design theory and the features considered essential for the proper implementation of such systems.

Fourteen sections lead the reader through a range of topics from initial operational specification to system and network design, data collection and transmission, organization and operation of computers, single and multiprocessor configurations, line control procedures, security and reliability. The characteristics of circuit, message and packet switching centres are outlined, together with those of loop transmission systems, which are considered by the author as being superior to message switching for many digital communications networks. Error detection and correction codes are described, from simple parity-bit to complex polynomials. One section deals with the secrecy and privacy aspects of data while held in a computer, and in transit over a network.

The book is well-balanced, comprehensive and adequately supported by diagrams. Occasionally, the phraseology and sequence of presentation, for example as when dealing with message switching and the use of "programme" when discussing software, requires concentration if the argument is to be followed without misinterpretation. Some statements are controversial, some emphatic; they may be read as indicating the preferred approach, and could be misleading for readers new to the subject—and at whom the book is presumably aimed.

Complete system design is inevitably the result of a number of compromises; these need to be established for each new system and application, particularly with changing requirements and the progress of technology. For example, the effect of microcomputers must be considered when reading the sections dealing with multiplexors and concentrators, distributed computer resources, terminals and redundancy.

Provided that this is borne in mind by the reader, the book provides a very good, single-source, insight to the wide range of topics associated with the design of a computer-controlled communications system. Its contents are applicable to a wider range of systems than the title would suggest.

J. H. M.

Radio Systems II. D. C. Green, M.TECH., C.ENG., M.I.E.R.E. Pitman. 116 pp. 101 ills. £3·00.

This book claims to provide a basic course in the principles and practice of radio communication systems for technicians, and to completely cover the requirements of the Radio Systems II unit of the Technician Education Council. This claim is justified. It presents, in a clear format, chapters on transmission lines, aerials, propagation, receiver circuits, receivers, transmitters and communications systems. The text is accompanied by clear illustrations and each chapter concludes with a range of exercises. The sections on aerials, propagation and transmission lines are especially valuable, as they provide concise explanations of subjects which many students find particularly difficult. The author has achieved a successful balance both as regards the amount of detail in his explanations and in giving equitable treatment to each of the topics.

In what is basically a very sound book, it is unfortunate, therefore, that there are some minor errors and misleading statements. These, even in total, are not of great significance but could cause problems for anyone working privately from the book without outside supervision.

M. Goddard

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

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

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

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

W. F. SEARLE

Semiconductor Circuit Design (Third Edition). J. Watson, B.SC., S.M., PH.D., F.I.E.E. Adam Hilger Ltd. xi + 536 pp. 393 ills. £7·50 (cloth).

Apart from some outstanding exceptions, there is not generally a great deal to choose between textbooks devoted to electronics for students, which is what this book really is. The author has taken care, in this edition, to give some emphasis to microelectronics, and the book could be said to be more comprehensive than some. It is also, perhaps, a little purer in its coverage, in that it confines itself to analogue (linear) electronics.

In common with many introductory works on electronics, the mathematics used is straightforward and well presented, and the book is suitable for undergraduate and equivalent courses. The treatment of transistors retains the familiar pattern: physical principles, characteristics, equivalent circuits and parameters, and small-signal and feedback amplifiers. The discussion is thorough, and the section on feedback includes an introduction to operational and DC amplifiers. A later chapter brings together these 2 topics in a more detailed discussion of what the author describes as, "arguably the most useful and versatile (configuration) in the entire field of circuit design". Descriptions of a wide range of devices are illustrated by typical applications, carefully explained.

Noise, frequency-selective amplifiers and oscillators, power amplifiers, field-effect transistors and power supplies each have a chapter to themselves. One 46-page chapter deals with semiconductor transducers, ranging from thermistors, through photo-electric effects (including light-emitting diodes), to pressure transducers and gas sensors.

The book ends with a very brief summary of the major characteristics of a typical electronic "system", but this is only an illustrative example, not a lecture on system synthesis. This final chapter appears complementary to the first, in which the capabilities of various semiconductor devices are listed. The intention is to show that practically any circuit function can be realized by suitable combinations of devices—a novel and instructive beginning which defines electronics in an uncluttered manner.

Although the book is subtitled "for Audio-Frequency and DC Amplification and Switching", the author has deliberately made no attempt to cover the vast subject of digital electronics and logic applications. The one chapter dealing with the transistor as a switch confines itself to the mechanism of switching in a bipolar transistor, and to applications not strictly associated with digital technology.

I found this book readable and explicit, and the author's efforts to keep it up to date are reassuring. One gets the impression that the author has taken pains to consider what to include, and how the information should be presented so as to be most useful to students.

B. STAGG

Post Office Press Notices

DIRECTORY ENQUIRIES BY COMPUTER

A new system for handling directory enquiries which will free operators from thumbing through telephone directories, is to be tried out by the British Post Office (BPO) at Leatherhead and Leeds. For the trial system, directory entries will be stored in a computer instead of printed in books.

At present, each operator sits at a desk provided with a set of directories—more than 60 volumes in all—and can quickly pull out the right volume for the number required. However, as the number of subscribers increases, the number of directory entries increases; at present, by about 1 million a year. The records are now reaching a size where it becomes impossible to house a complete set within easy reach of each directory-enquiry operator.

Each operator at Leatherhead and Leeds will use a visual display unit (VDU) linked to the computer. The operator will key-in abbreviated details of the information given by the caller, usually the town, name and address of the customer whose number is wanted: the computer will respond by displaying the required number on the screen.

Operators will have access through their VDUs to about half the national total of 15-million directory entries. This will enable them to answer between 80% and 85% of enquiries using the computer system. They will deal with the remainder by consulting directories.

The trial started in November 1978 and will last about 3 months. The information it gives will provide a basis for decisions about the future shape of the directory-enquiry service throughout the UK. If the BPO decides to go ahead with a national computer scheme, such a scheme could be in operation by the mid-1980s.

In the meantime, the BPO is planning to reduce the size of its directory records by storing the information on microfiche. In this system, approximately 68 pages of directory information will be stored on a piece of microfilm measuring 148 mm by 105 mm. The operator will be able to select the fiche containing the required information and project it onto a viewing screen, and read off the desired number. The BPO plans to introduce the directory-enquiry microfiche system nationally early in 1980.

HUGE GROWTH IN EUROPE'S DATA SERVICES

Digital data services will become widely available in western Europe within the next 5 years, using both packet and circuit switching. This clearly emerges from a survey outlining the future plans of 13 European telecommunications administrations, including the British Post Office.

According to figures given in the survey, by 1982 there could be in Europe more than 80 000 digital-data terminals of all kinds, made up of more than 55 000 terminals on circuit-switched services, and nearly 30 000 on packet-switched networks.

Twelve countries have, or are planning, circuit-switched services by 1982 and the remaining country intends to introduce such a service after that date. Eleven of the 13 have plans for packet-switching.

Information is also included on message-switched networks or sub-networks, and of private leased circuits employing digital-data transmission.

The survey, of great value for future planning by the computing and computing-using industries involved in data transmission in western Europe, is the second edition of *Public Data Networks* published for the CEPT (European Conference of Posts and Telecommunications Administrations) by the Eurodata Foundation. The results will enable data communications users to co-ordinate their own systems and plans with those offered by the 13 telecommunications authorities.

In the UK, copies of the book may be obtained at £10 per copy from:

The Eurodata Foundation,
Lutyens House,
Finsbury Circus,
London EC2M 7LY.

POEEJ: SUBSCRIPTION ORDER FORM

Those wishing to subscribe to *The Post Office Electrical Engineers' Journal* can do so by completing the relevant section of the order form below. British Post Office (BPO) staff should complete the upper section and send it to their local *POEEJ* agent or, in case of doubt, to the address shown; non-BPO staff should complete the lower section. A photocopy of this form is acceptable.

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Further details can be obtained from the conference department of the organizing Institution.

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Television Measurement
21–23 May 1979
The Commonwealth Institute, London

Video and Data Recording
24–27 July 1979
The University of Southampton

Land Mobile Radio
4–7 September 1979
The University of Lancaster

Institution of Mechanical Engineers, 1 Birdcage Walk, London, SW1H 9JJ. Telephone: 01–839 1211

International Progress in Postal Mechanization
6–8 November 1979
The Institution of Mechanical Engineers, London.

Institution of Electrical Engineers, Savoy Place, London WC2R 0BL. Telephone: 01–240 1871

Trends in On-Line Computer Control Systems
27–29 March 1979
University of Sheffield

Electronic Test and Measuring Instrumentation
19–21 June 1979
Wembley Conference Centre

Computer-Aided Design and Manufacture of Electronic Components, Circuits and Systems
3–5 July 1979
University of Sussex

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The price to British Post Office staff is 36p per copy.
Back numbers will be supplied if available, price 55p (80p including postage and packaging). At present, copies are available of all issues from April 1974 to date with the exception of the April and October 1975 issues; copies of the July 1970 and April and October 1973 issues are also still available.
Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.
Employees of the British Post Office can obtain the *Journal* through local agents.

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Readers can have their copies bound at a cost of £5·25, including return postage, by sending the complete set of parts, with a remittance, to Press Binders Ltd., 4 Iliffe Yard, London SE17 3QA.

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Advertisements

All enquires relating to advertisement space reservations should be addressed to Mrs. S. Underwood, Advertisement Manager, The Kemps Group, Forge House, Bell Lane, Brightwell-cum-Sotwell, Wallingford, Oxon. (Telephone: 0491 35448 or 0491 39370).
Advertisement copy should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 10.1.4, Room S08, River Plate House, Finsbury Circus, London EC2M 7LY.

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Model-Answer Books

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

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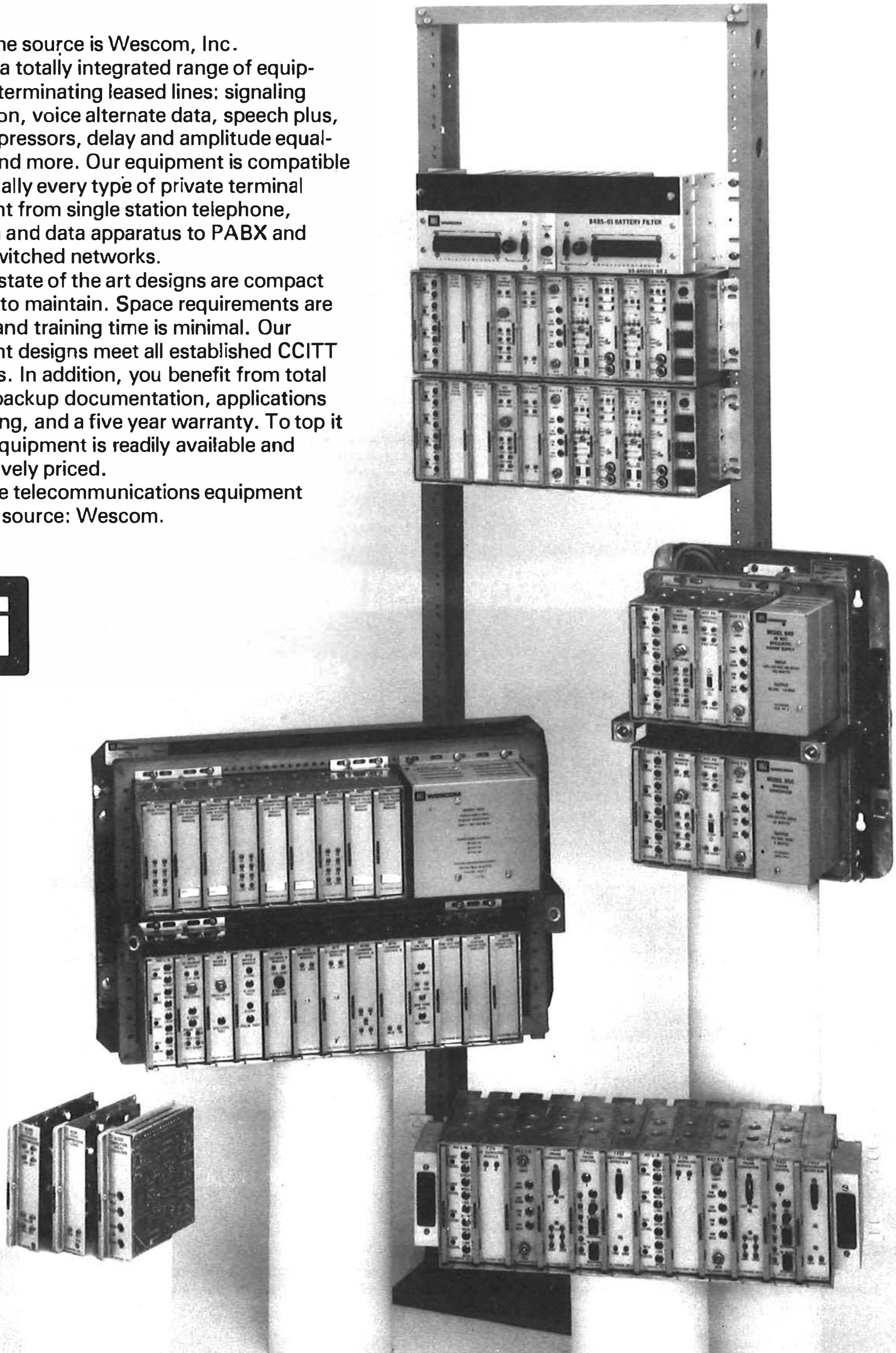

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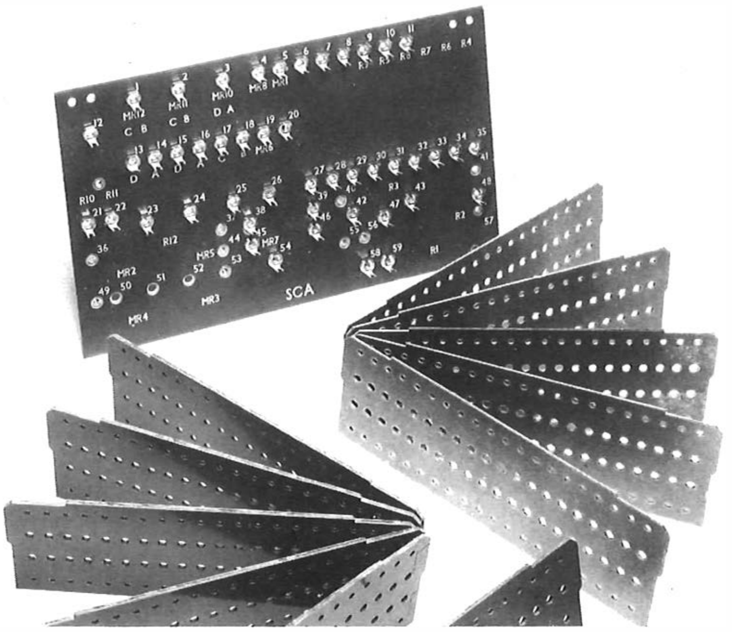

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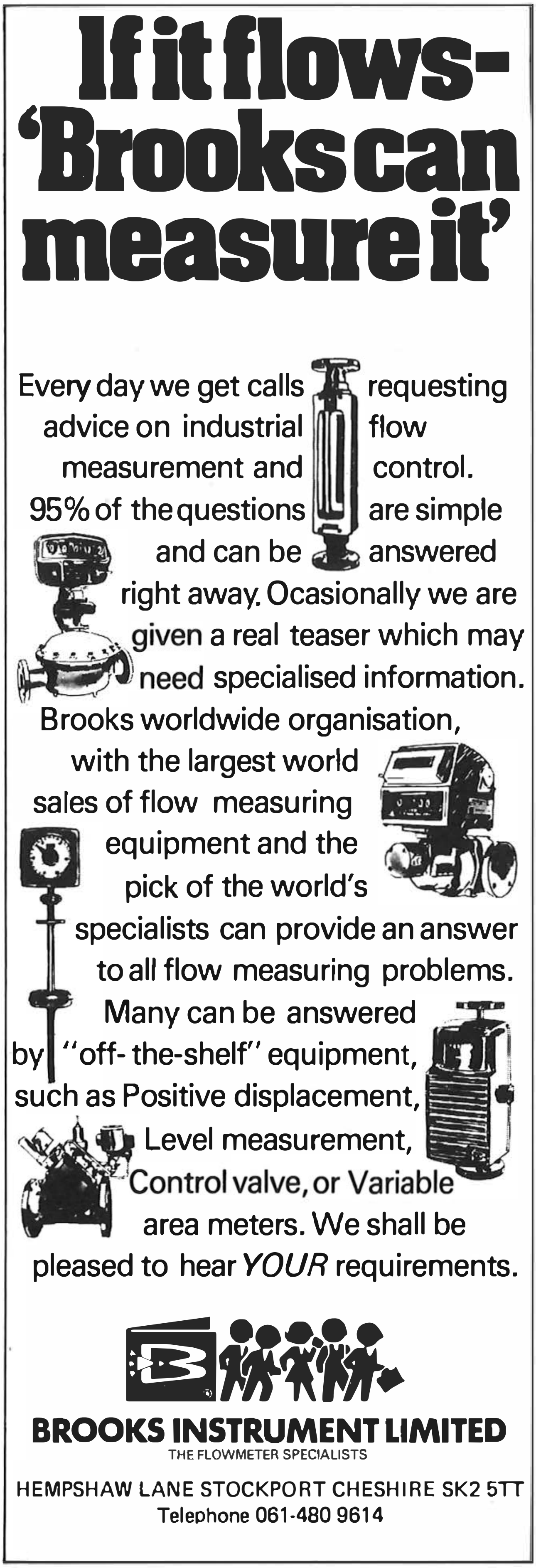

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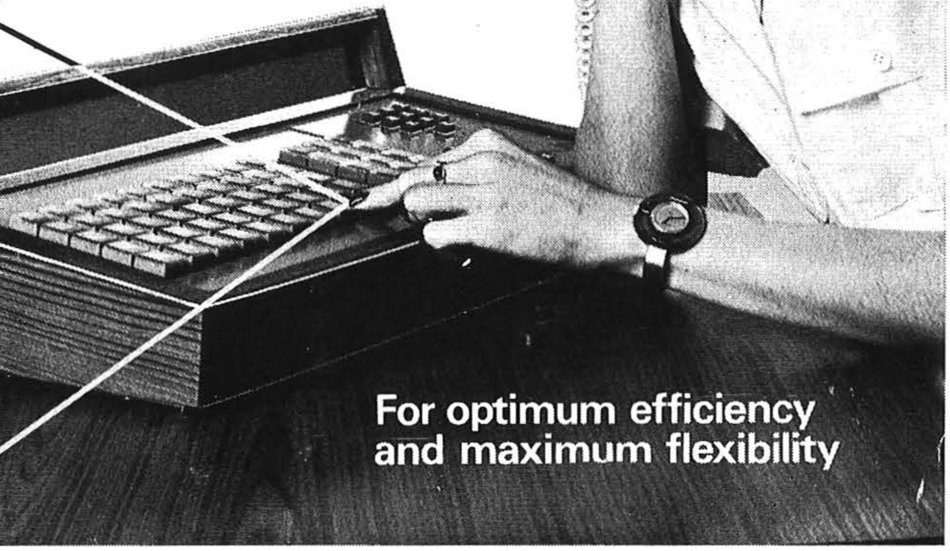

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