Electronic exchange system

Part 1—Structure

T. H. Flowers, M.B.E., B.Sc., C.Eng., F.I.E.E.

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Abstract

Continuing from another paper, the equipment for the structure of an electronic telephone exchange is described together with the reasons for the choices made. Analogue circuits are switched by p.a.m./t.d.m. (pulse-amplitude-modulation/time-division-multiplex) switches and p.c.m. (pulse-code-modulation) circuits by t.d.m. switches of the same kind. The use of t.d.m. switches profoundly influences the choice of processors for supervisory, signalling and other low-level functions, which, in turn, have some effect on the high-level common and unique common processors which are the subject of Pt. 2 of the paper.

1 Introduction

A telephone exchange is composed of two sections, a structure, comprising switches which interconnect the transmission circuits terminated on the exchange and perform some other operations incidental to the functioning of the exchange, and a control section, which controls the structure to perform the required functions. The two sections may not be physically very separate and their problems and solutions are certainly not independent, but the functions are not difficult to distinguish. A system to supersede an already existing system must have advantages over that system and be compatible with it for the extension of existing exchanges with which the new system must interwork. The economic problems of competing on costs with existing systems under all circumstances is at present the greatest difficulty which electronic systems encounter. Another paper[1] concluded that a new system must be competitive with existing systems in both structure and control sections separately and together. It also concluded that the system had to be optimised for its particular application, hence the objective of any system must be clearly defined.

The objective of the system of this paper is a system able to supersede existing electromechanical systems in already well developed areas to provide better service at costs no higher than at present, by installation as new exchanges and extensions to existing exchanges without requiring or imposing changes to existing planning practices. The significance of this objective is that it allows networks to continue developing naturally as at present and does not require them to be planned to suit the exchanges nor to suffer a discontinuity in growth by starting an overlay network. Constraints to natural network growth[1] add effective costs to exchanges which the new system specifically seeks to avoid.

The description of the system is divided into two parts, this part being concerned with the structure and Pt. 2 with the control.

2 Principles

The system is basically wired-logic controlled with information storage alterable by remote control.

Wired-logic control implies, as a secondary principle, the minimisation of processing. Processing is minimised by

(*a*) shared logic with clock-controlled interfaces
(*b*) guide-wire path search and connection
(*c*) a large number (17) of speech-path-associated signals
(*d*) straightforward trunking and speech-path selection and establishment, which means no path changing, to economise in switches, or systematic trunking involving processing in the path searching.

Security is obtained by distribution of control and a small amount of duplication. Fault detection relies primarily on checks made during the normal operation of the system.

The wired-logic processing may be substituted by stored-program processing to any desired extent which in practice is determined by economics. The substitution of stored-program processors will normally occur in the following stages:

(i) a processor remotely located from and serving a number of exchanges and providing processing for minor, new and changed services, maintenance routining and diagnostics,
(ii) a processor in the exchange substituting the unique common processor and some, possibly all, of the functions of the above processor,
(iii) a processor in the exchange as for the immediately preceding processor with the addition of some of the common processor functions.

The important point is that the system can work without stored-program processors, or with them, at any point, to achieve competitive cost levels over a wide range of network conditions.

3 Organisation

The organisation of the system is shown schematically in Fig. 1. The transmission circuits connected to the exchange for interconnection comprise exchange lines and junctions. Exchange lines requiring five different kinds of service are shown, namely

(*a*) ordinary lines providing service from a telephone instrument over a single line, with directory-number sending by rotary dial or pushbuttons
(*b*) party lines with two parties, X and Y, either of which can receive calls or make calls and be separately billed for them
(*c*) lines with private meters at the stations and operated by pulses from the exchange over the exchange-line earthed phantom to provide a local record of the exchange metering record
(*d*) lines with coin boxes at the stations, coins deposited in the boxes being signalled to the exchange and coin collection signals being sent from the exchange
(*e*) lines connecting p.a.b.x.s to the exchange, the p.a.b.x.s providing, without the intervention of an operator, direct access both ways between the extensions and the exchange.

Junctions between the exchange and another electronic exchange enter the exchange as either audio or 32-channel p.c.m. systems, in all cases with either data-link or order-wire signalling. Junctions to existing exchanges are audio with existing signalling which is speech-path associated and limited in its capacity. Order-wire signalling is speech-path associated at the exchange ends but not over the interventing junctions and is not limited in the number of signals which can be used. Data-link signalling is similarly unlimited and is also independent of the junction speech paths.

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Mr. Flowers is with Standard Telephones & Cables Ltd., New Southgate, London N11, England

The structure comprises analogue and digital switch networks (each shown within chain lines) through both of which associated but otherwise independent speech and signal transmission is provided. The control section comprises processors at different levels of control, i.e.

(i) circuit processors for exchange lines, for calling, coin box and other signals and comprising line equipments (l.e.), meter and other control and information-storage equipment contained within the broken line marked 'terminal unit'

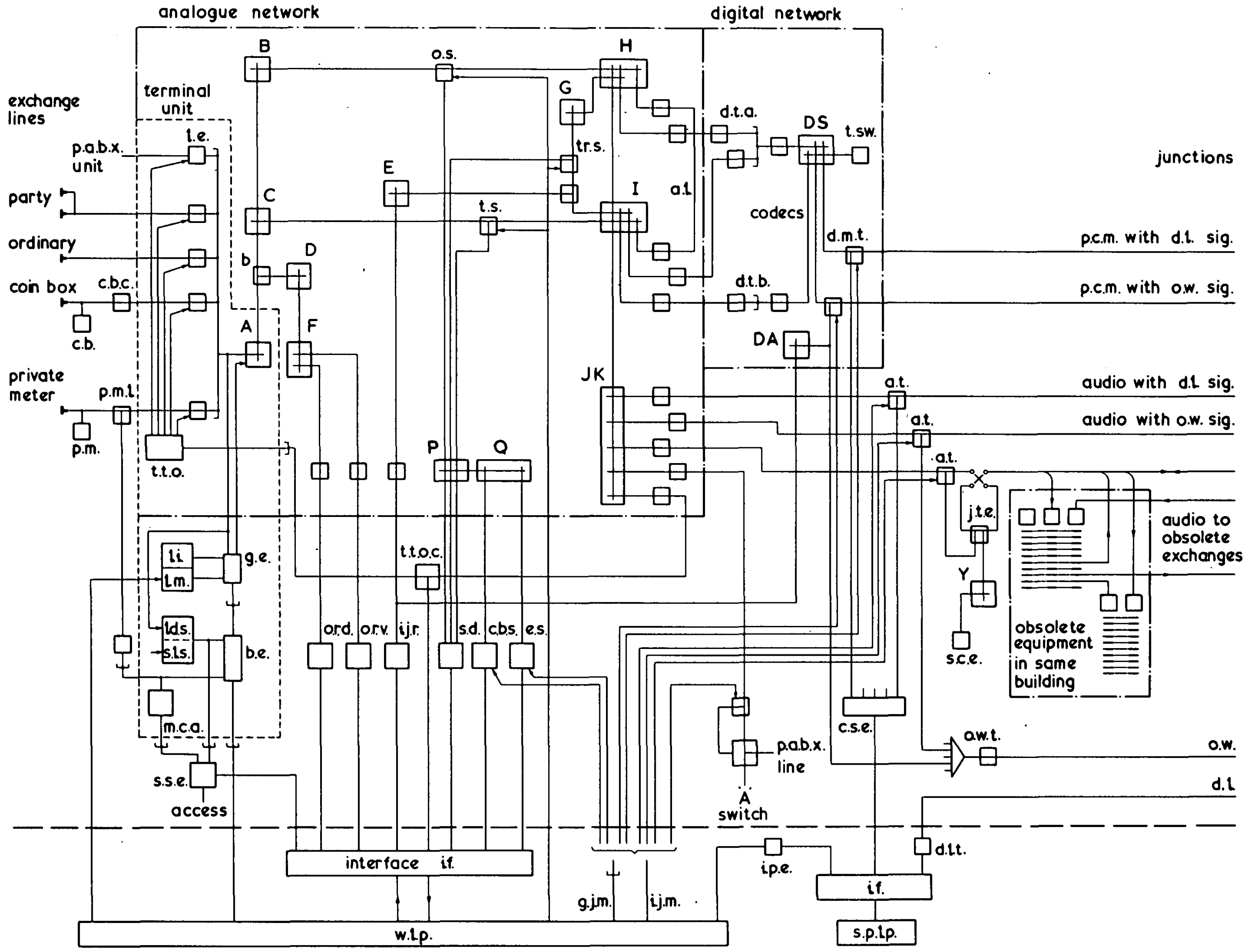

Fig. 1
Exchange organisation

(ii) circuit processors for speech-path-associated signals are included in audio junction terminal equipments (a.t. and j.t.e.) and in p.c.m. terminals (d.m.t.) for the channels of p.c.m. systems

(iii) trunk processors (o.s., t.s. and tr.s.) for the supervision respectively of originating, terminating and transit calls

(iv) common processors as exchange-line (o.r.d. and o.r.v.) originating registers and junction (i.j.r.) registers, coin-box supervision and other equipments (c.b.s., s.d. and e.s.) and signal-conversion equipments (s.c.e.)

(v) path search and connection processors contained within the switching networks

(vi) signal processors (o.w.t. and d.l.t.), which code and decode the signals over order wires and data links respectively

(vii) a unique common processor (below the horizontal broken line) having overall control of the exchange and of data-link signalling between exchanges. This and some processors in the path search and connection equipment are the only processors which have to be duplicated for security.

The choice of equipment for any part of a system is dependent on the other parts which causes discussion to be highly complicated. In this paper some general topics are first exposed, then the structure possibilities and the decisions which follow almost inevitably from the assumed objectives of the system and technical points discussed elsewhere. Finally the equipment of the system of the paper is described.

4 Extensions to existing exchanges

It is assumed that with the introduction of an electronic system the existing system becomes obsolete and is phased out of production as quickly as possible. Existing exchanges which have not reached the limit of their growth will need to be extended with the new system and without addition of old type equipment. There are some difficulties with outgoing junctions if joint access by the old and the new equipments is not possible, which is usually the case. Separate groups of junctions are not so efficient as common groups, but, by dividing the junctions between the old and the new equipments with overflow from the new to the old, not much is lost.

There are also problems due to traffic-distribution changes as the exchange grows, a greater proportion of traffic which terminates on the obsolete exchange having originated on the new exchange as time goes on; which situation can be met by trunking the new exchange traffic to later ranks of switches in the old exchange as shown in Fig. 1. There is a corresponding increase of traffic from the old to the new exchange which requires the redistribution of the outlets from the old exchange.

5 External control

The design of an exchange system has to take into account that the exchange operations will be controlled not only by the customers from peripheral stations but also by the administration from centralised control centres and by engineers from centralised maintenance centres.

The fault rate of electronic exchanges will be so low (of the order of one fault per day per 6000 lines) that continuous staffing will be the exception and no exchange will be staffed for 24 hours a day. It is assumed that maintenance centres will cover considerable areas and will queue faults to attain a high work occupancy of the staff. Hence it may take up to several hours to get a man actually to an exchange to clear faults or take any action whatever to rectify an unusual condition. Exchanges must therefore be self-protecting against the effects of faults. Administration will be similarly exerted from a relatively few centres from which much of the information stored in exchanges must be readable and some at least changed directly by remote control. The most advantageous division of the control between administration and engineering is not without problems. For example, the connection of exchange lines to the equipment by jumper wires on an m.d.f. (main distribution frame) is unavoidable. The man making the connection is very easily able to make the corresponding line-information-store entry by another wire between directory and equipment number tags, he is already located in the exchange and may not be skilled to perform the operation in any other way. This conflicts with those situations, such as a new customer taking over an existing line and station, which require a change only of stored information which is most economically performed from a remote centre. Some at least of these problems are taken into account in the solutions proposed in the paper.

The following subsections describe the most important of the administrative and engineering activities.

5.1 Call accounting and line identification

Mechanised accounting and billing is an administrative requirement. Variable-pulse-rate metering of national calls, the pulses being integrated on a mechanical meter, is a common present practice and the equivalent must be available in a new system. The most direct equivalent is storage on ferrite cores; it is important that the record shall not be lost by power failures or other hazards and that failures shall be rare and overmetering practically impossible. The record should be readable directly from an accounting centre with no delay, or delay limited to one day at most, for the rendering of accounts to subscribers about to move away. Magnetic tape is a possible, but not a very suitable recording medium: it is expensive for small exchanges, there are delays in retrieving the information, it needs a considerable amount of processing, and the maintenance costs are high, hence ferrite cores are preferred.

Pulse metering and bulk billing is satisfactory up to a point, but there comes a distance beyond which locally held information is not able to determine rates for the calls, and for which bulk billing is not acceptable. These calls are controlled from exchanges of high hierarchic level such as international exchanges, at which call recording for accounting purposes is best accomplished and is not restricted by costs. To this end, the high-level exchange needs to know the directory number, usually called the line identification, of the line making the call, which may be forwarded along with the called number when the call is set up. Line identification after a call is set up is, however, important for call tracing under a number of circumstances, administrative and engineering.

The preferred arrangement is therefore a line-identification signal which, when sent toward an exchange line from any point in a connection to the exchange line, provokes the return of the directory number of the exchange line back over the same path.

5.2 Trunk offering

A means by which access from manual switchboards can be had to exchange lines, and possibly junctions, without using the normal exchange switches is a valuable administrative facility, for example, when doubts are cast on the correct operation of the system. It is available in existing systems as the trunk-offering facility, but this not being its only use, it must be included in a new system even though trunk offering as such is rendered obsolete by line identification.

5.3 State of line

States of line are temporary exchange-line conditions, some the results of customer action and some under the control of the administration. An example of the first is parking by the exchange of an exchange line which is permanently looped. The second includes outgoing service barred and line temporarily out of service, and must be controllable from an administrative centre (and some from the maintenance centre).

5.4 Line testing

When service to an exchange line fails it is important that it should be possible to make a test from the maintenance centre to determine whether the fault is in the exchange or in the outside line plant, in order to instruct the appropriate maintenance man. The tests required are for loops, contacts and insulation, which, particularly the last, present, for electronic switches, some difficulties which have to be circumvented.

5.5 Line data and other information

Changes to all forms of semipermanently stored information have to be expected and preferably made without actually visiting the exchange, as already mentioned for exchange-line data storage. Stores for these data are preferably of the read-only type, immune from accidental alteration and therefore often of a form, commonly wire on tag, which is not alterable by remote action. A solution which satisfies these conflicting requirements is to write the new information into a common store and substitute it for the existing information whenever that is called for, and until, at some convenient time, the new information is entered into the semipermanent store.

6 Exchange switches

Exchange switches are required to switch analogue and digital speech circuits and associated but independent signal circuits over which a large number (17 has been chosen) of different signals may be communicated. The digital switches are inevitably 4-wire and time-division-multiplexed. The analogue switches can be 2- or 4-wire space or t.d.m. type, the transmission problems of which are discussed elsewhere.[2,3] Briefly, 2-wire space and t.d.m. switches have difficulty in satisfying the low-loss and high crosstalk attenuation requirements when used for large exchanges, 4-wire space switches with unbalanced transmission fail on crosstalk in large exchanges, and in balanced 4-wire form are too expensive in components and wiring for independent speech and signalling paths. 4-wire t.d.m. switch transmission is satisfactory for all sizes of installations, no other kind of switch has a lower cost and one design will satisfy both analogue and digital switching needs. The minimisation of processing essential to the control system is more easily and cheaply achieved by t.d.m. switches and pulse transmission than by space switches and audio transmission. 4-wire t.d.m. is thus the choice for the system of the paper.

T.D.M. switching costs are low because the crosspoints are cheap, one transistor for each direction of unbalanced transmission being sufficient, and are reduced in number,[6] compared with space switching crosspoints, roughly in the ratio of the number of channels in the multiplex. The multiplex terminals which modulate and demodulate the analogue transmissions are costly items which reduce the overall economy but occur only once in transmission across a switching network no matter how many switching stages are needed. These features, together with the effects of faults and the requirements of security of operation, have a decisive influence on the trunking used.

Fig. 2 shows the t.d.m. switch in principle. A crosspoint comprises two bipolar transistors VT_1 and VT_2 driven by a third VT_3 and clamped by a fourth VT_4. The transistors VT_3 of a column (or row) of crosspoints of a switch are controlled by a group of stores, PS, each of which, given a pulse in a repetitive cycle of n pulses, reproduces that pulse in every succeeding cycle until controlled to stop. The outputs from the stores are combined two at a time in gate G_8 (using the conventional NAND–NOR logic of integrated circuits) the outputs of which cause transistors VT_3 to conduct and switch the crosspoints. When switched to the *on* state, a crosspoint will transmit both ways the p.a.m. pulses of an analogue transmission or the p.c.m. pulses of a digital transmission; in both cases an associated but independent signalling path is provided by a slot preceding the speech path slot within the same channel slot. The type of transmission is determined by the terminals which contain either p.a.m. or p.c.m. modems. A p.c.m. terminal includes a p.a.m. modem, not necessarily the same as an analogue modem, with a p.c.m. codec (coder and decoder) between it and the multiplex trunk (see Fig. 1).

6.1 Trunking[6]

T.D.M. switches require the exchange lines to be multiplexed in groups. There are two ways in which this may be done. In one, the exchange lines are grouped into n line groups, each line being permanently allocated a channel in an n-channel multiplex. In the other, the exchange lines are grouped in quantity to produce traffic sufficient to load n-channel multiplexes, the lines being allocated channels only when they are active. Much work has been done on both systems.[4–6] The attraction of the variable-channel arrangement is that it reduces the number of multiplex highways required,

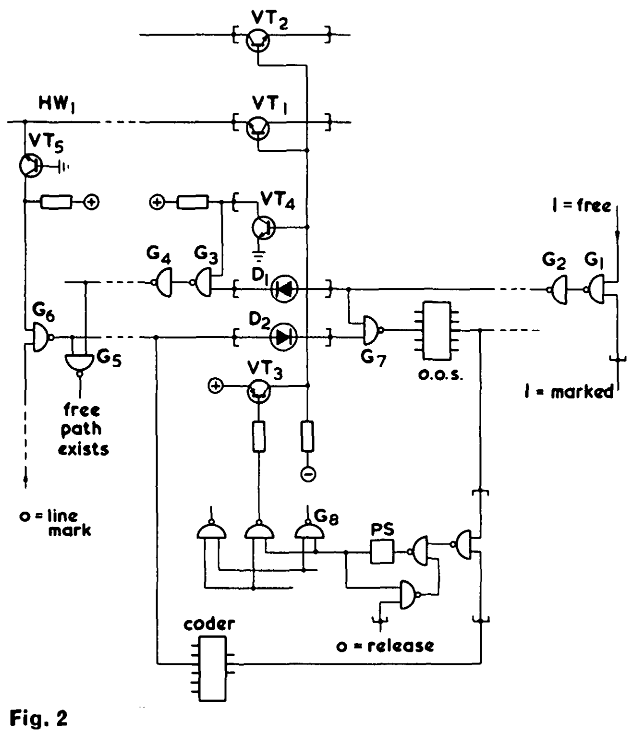

Fig. 2
T.D.M. switch in principle

but, for that reason, it encounters security difficulties and there are also complications in connecting two lines in the same multiplex group. When all problems have been solved, the permanently allocated channel system is cheaper and so much simpler and easier to control and make secure that it becomes the choice of the system of the paper. Other circuits connect through the switches to exchange lines by variably allocated channels to match the exchange-line terminals. Effectively the exchange lines are divided between n subexchanges, each served by one channel of the multiplex. As a result, the trunking is always relatively inefficient when measured as traffic carried per channel; this is economically possible because of the low cost of the switches, and it confers the incidental advantages of maximum tolerance to traffic overloading and to the effects of faults in the trunks. The permanently allocated channels of the exchange lines and the transmission of large numbers of signals through the switches are two of the most distinguishing features of the system, which contribute to a third, namely that the total amount of processing required is minimal.

Referring to Fig. 1, the exchange-line traffic is concentrated by the A rank of switches, then extended for outgoing traffic via ranks B and H to audio links (a.l.) directly, and audio junctions via another rank of switches JK. Traffic incoming to exchange lines from audio links uses switches I and C and from audio junctions the JK as well as switches I and C.

The switching of p.c.m. junctions is analogous to that of exchange lines in respect of permanently allocated channels. Multiplex transmission lines terminate in digital multiplex terminals, (d.m.t.), which retime the channels to the exchange clock time and connect them to the digital switch DS, by which they are switched to channels in a time switch (t.sw.), where they are stored in digital form, or via codecs to digital channel terminals (d.t.a.) with permanently allocated channels and forming part of an audio link between the analogue and digital switches. Most of the channel bits stored in the time switch, are transmitted in digital form to another p.c.m. junction in a d.m.t. terminal for transit calls. A second stage of switching between the d.m.t. terminals and the switch DS will sometimes be needed in very large exchanges. Exceptionally, incoming p.c.m. junction connections to the analogue switches are made through the switch DS to t.sw., and thence a second time through the switch DS to d.t.b. terminals, when blocking is encountered on the more direct connection.

The audio links at their analogue ends have variable-channel means to provide slot-changing facilities for speech and signals between circuits with permanently allocated channels. Audio-junction terminals also have variable-channel means to permit them to work to circuits with permanently allocated channels. One of the advantages of permanently allocated channels is simplification of the control because the channels to be used are predetermined for all connections except those to incoming junction registers and for junction transit connections involving at least one audio junction for which channel selection is necessary before switching through the exchange can be commenced.

Registers o.r.d. and o.r.v. are provided for originated calls with, respectively, rotary dial and v.f. (voice-frequency) number sending. The registers are connected from transmission bridges *b* through switches D and F, using the allocated channels of the lines. Audio junctions not using data-link signalling connect for incoming calls through the JK, I and E switches to incoming junction registers (i.j.r.); channels which can be used for such a connection are indicated to free registers; selection is made first of a channel then of a register and then of a path through the switches to a junction. If the call ultimately extends to another junction, the channel is retained for the connection; if to an exchange line the channel is changed to that of the exchange line to avoid demodulation and remodulation to a different channel. Incoming p.c.m.-junction calls with order-wire signalling operate similarly through switches DA to registers i.j.r. For incoming junction calls using data-link signalling, the details of each call are received into the unique processor before any exchange switching takes place. When sufficient information has been received, an appropriate path through the exchange is established in one operation.

The signal-path trunking parallels the speech paths except for data links which operate between data-link terminals (d.l.t.) and the unique common processors of exchanges. Signalling for junctions in tandem, both junctions having speech-path associated signalling, either order wire or an obsolete system, use the signal paths provided through the switches. One junction with data-link signalling in tandem with another with speech-path associated signalling must also use the signalling path through the switches. For this purpose, common signalling equipment (c.s.e.) is used with access from the unique common processor on one side and to the signal paths through the switches on the other, whereby signals can be exchanged between data links and speech-path-associated signalling equipments. The facility existing, it becomes the preferred method of interchanging signals between data links on tandem calls, the total processing being minimised because no record of connection through the exchange need be kept other than that inevitably existing as established speech paths.

6.2 Analogue switches

The p.a.m./t.d.m. analogue switches provide 32 channels at 16 kHz p.r.f. (pulse repetition frequency) resulting in a digit rate of 512kHz and a channel (slot) time of $1\cdot95\,\mu$s. The slot time is divided as shown in Fig. 3*a* into a blanking time of $0\cdot325\,\mu$s during which crosspoints release and operate and multiplex highways are normalised, $0\cdot65\,\mu$s for for signal transmission the second half being strobed, the remainder of the slot time being devoted to speech transmission, only the last $0\cdot49\,\mu$s being strobed into the demodulators. The modulators are simple transistor gates preceded by an active filter with attenuation/frequency characteristic shown in curve *a* of Fig. 4. Exchange-line demodulators are of boxcar type producing audio and sideband outputs attenuated as in curve *b* of Fig. 4, and followed by an active filter of characteristic as curve *a*. Junction modulators and input filters are effectively the same as in the exchange-line equipments: the demodulators are pulse 'stretchers' more linear than the exchange-line boxcar type, and followed by a derived-*m* filter section with attenuation peak at 16kHz and a cutoff frequency of 5kHz. The analogue-switch terminals of audio links between analogue and p.c.m. channels are the same as audio junction terminals.

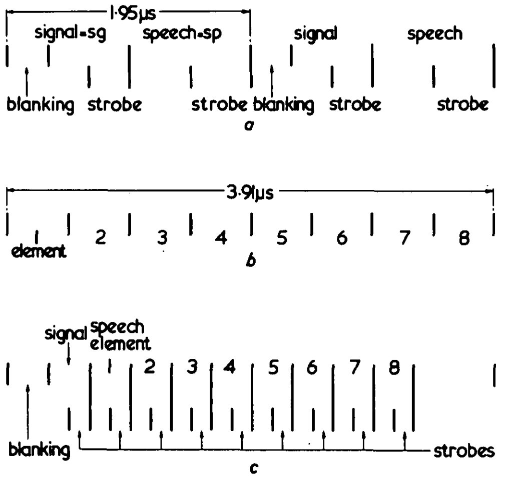

Fig. 3
P.A.M. and p.c.m. multiplexes

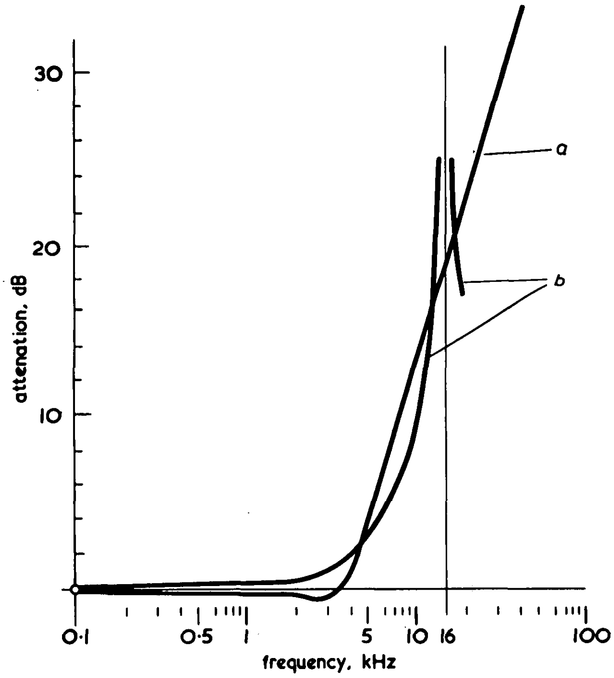

Fig. 4
Attenuation against frequency

Six successive speech multiplex cycles are allocated to each signal in the signal channels, and a cycle of 17 signals (occupying 102 multiplex cycles and lasting $6\cdot375$ms) is provided to convey an adequate number of signals through the switches. Each signal extends over six multiplex cycles to allow for possible time delay when slot changing is involved in a connection.

6.3 Digital switches

The p.c.m. switches operate at the digit rate of the p.c.m. transmission systems assumed to be 32 channels at 8kHz p.r.f., resulting in a channel rate of 256kHz and a channel time of $3\cdot91\,\mu$s (Fig. 3*b*). The p.a.m. and p.c.m. multiplexes are in exact 2 : 1 speed ratio and frame alignment as shown in Fig. 3. Each p.c.m. channel contains eight elements, each 488ns long. One channel in each system is allocated to signalling. The signalling channels may be used as data links between unique common processors in the exchanges at the two ends or as order wires each serving the speech circuits in the same multiplex and considered with them as forming one security unit. Fig. 5 illustrates the second case. P.C.M. multiplex lines are terminated in group equipments d.m.t. (Fig. 1) which include a store of 30 rows of 12bit onto 8 of which the incoming channel bits are written at the line-multiplex clock time and out of which they are read at the exchange-multiplex times thus allowing for the variable time displacements of the line and exchange multiplexes. Signals received over the signal channel define signals for specific channels, the signals being written into the remaining 4bit of the row in the store corresponding to the channel (only 15 of the 17 possible signals can be transmitted over junctions). The signal is transmitted through the switch and the store bits cancelled the next time that the signal appears in the signal cycle, which is $3 \times 17 = 51$ p.c.m. cycles long to correspond with the 6×17 cycles of the p.a.m. multiplexes operating at twice the speed.

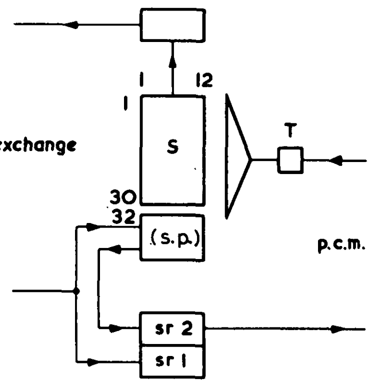

Fig. 5
P.C.M. terminal d.m.t.

Transmission through the switches is illustrated in Fig. 3*c* in which the $3\cdot9\,\mu$s channel time is divided into a $0\cdot325\,\mu$s blanking time for the crosspoints to be switched, and one signal element and eight speech elements in the next $2\cdot93\,\mu$s, leaving $0\cdot65\,\mu$s for processing within the channel time. This timing assumes that the transmission time from terminal to terminal is small compared with the $0\cdot325\,\mu$s signal element time of the transmission, say $0\cdot03\,\mu$s which represents about 6m of cable. This is adequate for a maximum of three racks each 1m wide, which suffices for most exchanges; for large exchanges, transmission over paths in parallel with a proportionate reduction in signalling speed would be used.

Referring again to Fig. 5, which represents a d.m.t. terminal in greater detail, the incoming p.c.m. bit stream after element, channel and frame identification in equipment T is distributed to the store S in p.c.m. system channel order. The speech bits are read out and transmitted through the switches as their channels occur in exchange time, using elements 1 to 8 of the transmission. Signals over the 32nd channel are received into the signal processor (s.p.) which codes and writes them into the store in the channel row to which they refer, and from which they are read out as a pulse in the signal element of the through switch transmission during the appropriate signalling cycles.

Speech signals received in the eight speech elements of the transmission through the switches are stored in an 8bit store (sr_1), transferred to store sr_2 and sent out over the p.c.m. transmit channel; while serial transmission from sr_2 is taking place, sr_1 can be receiving from the next channel. When logic 1 is received in the signal element of any channel it is accepted by the processor s.p., coded into an order-wire message and sent over the 32nd channel of the p.c.m. multiplex. If data-link signalling is used, the equipment of Fig. 5 is modified to the extent that the signal processor does not send and receive signals over the 32nd channel of the multiplex, but via the unique common processor and the data link.

7 Path searching and connecting

The searching for free paths and the connecting of paths is controlled by guide wires illustrated in Fig. 2, in conjunction with the crosspoints and for one mode of operation using NAND–NOR integrated-circuit logic. First, all the possible terminating points of a required path are marked by continuous channel pulses occupying the first half of each channel time and applied to gates G_1. The terminating points may be originating registers, audio junctions being selected for an outgoing call, or audio links. The marking pulses are inhibited by gates G_1 for those terminating points already engaged; the outputs from the others are applied after inversion in gates G_2 to diodes D_1 in all the crosspoints to which the terminating points have access. The pulses emerge on the other sides of the crosspoints to mark the trunks to which free terminating points have access through the crosspoints, the markings being inhibitied by transistors VT_4 and gates G_3 for all channels for which the trunks are engaged. After inversion in gates G_4, the marking proceeds through successive switches to the starting point where the other end of the connection is marked. The starting end of the connection is a single point for which the channel to be used is predetermined. The starting point marking pulse occurs at the predetermined channel time, and, if it coincides with a marking pulse in the other direction, as in gate G_5, a free path exists. There may, in fact, be more than one free path; therefore the starting point marking pulse is applied to diodes D_2 through the crosspoints to emerge on the other sides and coincide with the marking pulses in gates G_7. The outputs from the gates G_7 define the trunks on free paths and are applied to a one-only selector (o.o.s.) which permits only one pulse to emerge, and this pulse in co-operation with the outputs of a coder operated by the starting pulse writes into the appropriate combination of stores to operate the corresponding crosspoint. The one-only selectors and coders have to be secured by duplication and dispersion. The output pulse from the one-only selector is also the marking pulse for the next rank of switches, and so on, the selection and connection of crosspoints proceeding until a terminal point is reached.

The starting marking pulses can originate in a number of ways. An exchange line starts a call by looping the line which switches on the channel pulse allocated to the line. This channel pulse will appear (see Pt. 2) on the trunk HW_1 in Fig. 2 of a switch to which the line is connected. If no crosspoint of the switch is operated at the channel time, the channel pulse will steer itself into the emitter of a transistor VT_5, the output from the collector constituting the single starting pulse. When a crosspoint operates to that channel pulse it receives the pulse and thereby steers it away from transistor VT_5. For a line to be selected for a terminating call, a line marker (l.m., Fig. 1), given the directory number of the line, produces an exactly similar unique marking pulse. In a third case, typified by a line already connected to an originating register and to be extended to a junction by the register, the register applies the necessary marking pulse to the bridge *b* of the trunk involved at the channel time at which it is connected to the calling line.

The description given illustrates the principles. The details include a means of overcoming marking pulse transmission delays and of preventing faults from causing false connections. Because of transmission delays, not more than two crosspoints are set during one channel time; the marking pulse is then stored and regenerated at the channel time in the next cycle. Complete selection and connection thus takes up to two, or at most three, multiplex cycles from audio circuit to audio circuit, local connections taking twice as long because they are set up in two operations, first from the called line to an audio link and then from the bridge *b* to the audio link. The use of marking pulses rather than continuous marking permits a.c. couplings to be used in the marking paths as part of the means of preventing faults, in this case contacts producing steady potentials, from causing difficulties.

In another mode of selection, the terminating point of the selection is a unique circuit and there are a number of possible starting points using a channel to be selected. This occurs with incoming junctions to be connected to a free register, and elsewhere. P.C.M. junctions introduce further modes; slot changing occurs on all calls and requires storage in the trunks which are available for connection. For example, when a p.c.m. channel on a junction route is to be connected for an outgoing call, all the p.c.m. systems on the route are marked, the engaged channels are inhibited and the free channel pulses communicated to trunks, to t.sw. switches and d.t.a. and d.t.b. terminals. Engaged channels of those trunks inhibit the corresponding marking pulses finally to produce marking pulses on trunks having access to free junctions in the required route. These pulses are stretched to continuous outputs which gate marking pulses to the next rank of switches.

The important point is that the guide-wire selection takes care of all the selection and connection control needed once the starting and terminating end points have been determined. Any pattern of connections can be used which allows the number of crosspoints to be minimised; connection and re-arrangement of the trunks is simple. Trunks can be busied for maintenance or rearrangement by simple earthing of the appropriate guide wire, as in existing practice, and also automatically for crosspoint faults. Guide wire is a universal method usable in all situations at a cost in t.d.m. form not exceeding that of any other method and therefore chosen as the method to be used in the system of the paper.

The end marking which provokes the path searching and selection is considered to be part of the control system (see Pt. 2).

8 Post-selection supervision

For most calls set up through an exchange, the number of possible subsequent operations is very limited and easily satisfied by wired-logic processors. In Fig. 1, processors which perform these operations are the originating (o.s.), terminating (t.s.) and transit (tr.s.) supervisory equipments located in trunks between switches. A supervisory processor comprises means of detecting signals, and remembering past events, of performing logical operations based on the signals and the memorised information and transmitting signals as the result. In the supervisories of Fig. 1, all but the memory means are time-shared among all the channels of a multiplex; memory individual to each channel is necessary but, being cyclic, can use the cheapest kind, m.o.s. dynamic for example. Again, this is a universal and also the cheapest solution to this particular control problem, given that the speech paths are already multiplexed. A small proportion of calls will need additional supervision (*a*) known at the time of setting up the call, for example, coin-box calls, and (*b*) signalled during the progress of the call, for example enquiry and transfer. For these facilities, supervisory units each capable of dealing with one call at a time are associated with the calls via switches P and Q. For type (*a*) supervision, a unit is connected as the call is set up, for example a c.b.s. unit for coin-box supervision. A signal indicating that type (*b*) supervision is required is detected by the signal detector s.d., which will either provide the facility or connect a unit e.s. to the connection. Control of the units s.d., c.b.s. and e.s. is divided as convenient and economic between the units themselves and the unique common processor.

9 Peripheral operations

The operation of the exchange primarily concerns the exchange lines and peripheral stations which originate calls and receive calls. Call origination starts with the looping of a line at the station by cradle-switch operation or its equivalent. Call reception commences with ringing being sent over the exchange line from the exchange, the ringing comprising a.c. of audio frequency and power; or for direct dialling into p.a.b.x.s, the calling signal is a loop at the exchange end of the line.

Exchange lines are scanned periodically for new originating calls. Scanning comprises examination of each line in turn. The looping of a line has the effect of establishing a pulse in the channel allocated to the line in the multiplex group to which the line is connected, the pulse being modulated by speech for transmission through the switches. The channel pulses existing in the common multiplex transmission circuit therefore indicate the active channels from which those already connected through the switch are eliminated as described (Fig. 2). The remainder represents lines looped but not connected, some of which may be parked because of a permanent loop or denied service for some reason. Processing determines if a line is to be connected and whether it uses rotary-dial or pushbutton number sending or both at different times. If allowed, connection results to a register, o.r.d. or o.r.v., or both kinds according to the number sending means. If both, one is released as soon as a directory-number digit is received into the other. If the calling line is a two-party line, connection awaits the party-identification signal and when connected the identity of the calling party is stored in the state of line store (s.l.s.), for subsequent allocation of charges.

A register about to set up a call applies forward from the bridge *b* to which it is connected, a marking pulse at the channel time of the calling line to which it is already connected. The marking pulse is transmitted from the bridge *b* through the crosspoints and over free trunks to all the audio links to which the register has access at that time. If the call is local, end marking is applied to all audio links and is effective at all links which are free and to which the register has access. At the same time, the directory number of the called line is applied to line markers (l.m.), which produce unique marking pulses corresponding to lines with that number, and which co-operate with the marked audio links to connect a free exchange line to a marked audio link; a connection is then made from the bridge *b* to the audio link to complete the connection. If the call is to be extended over an audio junction, all the junctions on the route are marked over group junction marker (g.j.m.) leads; selection starts at the bridge *b* through switches B, H and JK to a free junction. If a p.c.m. junction is implied, the group marking is applied to appropriate multiplex systems, free channels of which are marked through the switch DS to corresponding free channels in the terminals d.t.a. and thence to the p.a.m. channels to one of which connection takes place as for outgoing junctions. The connection is then extended from the d.t.a. channel to a free outgoing p.c.m. channel on the required route.

As a call is set up, the charge rate is signalled to all the originating supervisories and stored in the one which becomes included in the connection. If the call terminates in the exchange, a terminating supervisory (t.s.) will also be involved and instructed to ring the called line and send a ring tone back to the calling line. If the call is routed out of the exchange, the register stays in circuit long enough to receive all the digits from the calling line and to transmit such as are needed to the next exchange. If order-wire or an obsolete signalling system is in use over the junction, the signals are transmitted from the register through the switches to the junction signalling equipments. If data link is in use, the signals are sent through the switches to the common signalling equipment (c.s.e.), and thence to the data links; alternatively, in large exchanges, the registers may receive dialled digits from the calling lines, the storage taking place in the unique common processor, and the processor accessing the data link directly for the sending of further information concerning outgoing junction calls. By very similar methods, incoming junction calls are set up to exchange lines or other junctions, data links using the unique common processor and order wires and obsolete system signals using incoming junction registers (i.j.r.). Calls to p.a.b.x.s with direct dialling-in facilities are operated as transit calls. The called-line answer is used to control the start of metering and the clear to force release of the connection if the calling line fails to do so. A coinbox requires coin supervision which is applied by coinbox supervisory equipment (c.b.s.), connected through the P and Q switches when a call is set up. The c.b.s. equipments may use wired logic or be served by the unique common processor according to the size and equipment of the exchange. The meter records of exchange lines accepting the charges from coinbox callers are controlled by signals through the switches, such calls usually being set up by operators. Meter pulses for exchange lines equipped with private meters are relayed over the exchange lines to the private meters.

Services requested after calls are set up, for example enquiry and call transfer, are provided by units e.s. brought into a connection after the detection of an appropriate signal by the s.d. equipment. The e.s. equipments may also use wired logic or be served by the unique common processor.

Other operations not described are conventional; all services can be provided.

10 Administrative operations

The system has to perform a number of operations defined by the administration and not under control from the peripheral stations directly or at all. Section 5 has described the most usual operations. Call accounting is a universal requirement. Others tend to be individual to administrations.

In Fig. 1, meter call accounting is provided by a ferrite-core store (m.c.a.) with words of 17 bit, one word for each exchange line or each party for a party line. Meter pulses transmitted through the switches are steered into the store in channel and group order and integrated with already existing records. The meter pulses are normally generated by an originating supervisory (o.s.). Small exchanges may not have the means of determining rates other than for the lowest rate. The control of metering for other calls is then invested with a higher-level exchange which sends meter pulse signals over the junctions and through the switches to the store m.c.a. Calls via the manual board can be similarly charged.

The administration is able to read the meter records at any time by accessing store supervision equipment (s.s.e), to which the directory number of the record to be read is communicated. Access to the equipment is via a data link or via a junction using a class of service not available to any but authorised stations. The meter records of all lines with the defined directory number are sent back in reply. The records for all working numbers for periodic billing are obtained by sending the numbers one after another, limited only by the rate at which the signalling channel can transmit the information, the normal operation of the exchange not being disturbed.

The directory numbers of lines connected through the switches are made available by a line-identification signal sent, for example, from a manual board or international exchange. The directory number is made available in common equipment (l.i.), in response to a signal over an order

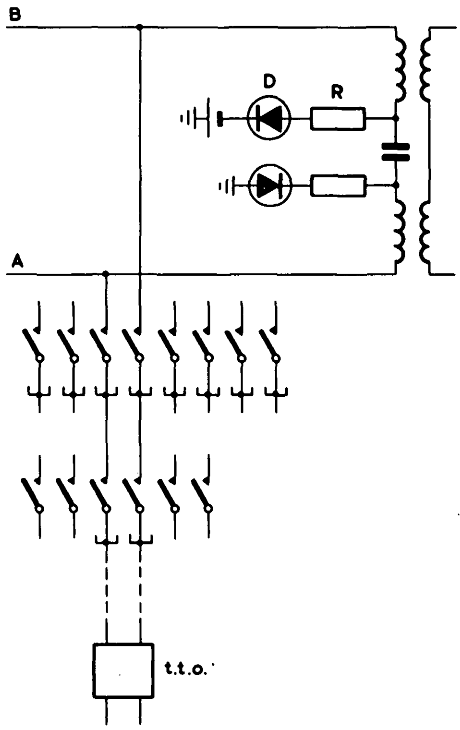

Fig. 6
T.T.O. equipment

wire and through the switches or over a data link and thence from the common signalling equipment (c.s.e.) through the switches to the l.i. equipment. The directory number is sent back over the same route as the identification request signal is received. Line identification is also used in other operations such as malicious call tracing.

Trunk offering is combined with the maintenance operation of line testing. Metallic contact is made via selected lines by equipments t.t.o. controlled by equipment t.t.o.c. in Fig. 1. Because speech may be involved, the t.t.o.c. equipment is accessed over a junction using ordinary junction access with a distinctive class of service. The t.t.o.c. equipment, given the directory number of an exchange line, and its serial number in a group if more than one line has the directory number, operates a relay in the appropriate t.t.o. line equipment to connect the line wires of the line in question to itself and thence to the junction. The elements of the equipment are shown in Fig. 6. A and B are the conductors of an exchange line terminated in a transformer transmission bridge supplying current via resistors *R* and diodes D. One relay for four lines has pairs of contacts each connected to one of four lines. A tree arrangement of contacts on relays concentrates all such relays to a pair of wires to a t.t.o. equipment and thence to the t.t.o.c. equipment, to which any line may be connected at a cost of little more than one quarter of a relay per line. Miniature relays mounted directly on the printed-circuit boards of the line equipments are used. The number of simultaneous t.t.o. calls which can be made is equal to the number of t.t.o.c. equipments; two usually suffice because the traffic is small. This and the equivalent for physical junctions are the only places in the system where metal contacts are used; they cannot be avoided because of the requirements for line testing for which purpose the diodes D are provided as described in the following Section.

Changes to semipermanently stored information consequent upon new lines and changes in directory numbers of existing lines, and junction rerouting because of faults and other causes, are important administrative operations which are required to be controlled from remote centres and to be immediate. Similar facilities are also required for information in temporary stores for putting lines temporarily out of service and so forth. Means of reading the stored information from a remote location is necessary for checking and statistical purposes. For these operations, the s.s.e. equipment is accessed and given the directory number and serial number of an exchange line with instructions to write new information or to read the existing information in the store corresponding to the directory number. Information which is read can be transmitted back to the calling point.

Traffic recording and service observation are other facilities included in the administrative operations.

11 Maintenance operations

Maintenance operations are mainly concerned with testing for the existence and locations of faults. Exchange-line testing uses the t.t.o.c. equipments already described to gain access to selected lines and by subsequent commands to detect contacts, disconnections and low insulation. For the last, the normal current-feeding resistors must be disconnected which is the purpose of the diodes D in Fig. 6. By applying voltages which reverse-bias the diodes, the lines are effectively isolated for insulation and other testing. Physical junctions can be tested in much the same way, from one end being sufficient. In order to identify junctions for testing, individual junctions can be marked over the leads i.j.m.

Transmission testing is another maintenance operation.

Correct functioning of the exchange is monitored by checks during normal operations and routines at convenient times. Checks include parity tests of digital information, continuity tests of transmission and signalling paths, signals returned as the result of signals transmitted, and so forth. When a fault has been proved to exist, further operations to find it depend on the size of the exchange and the processing power available, from simple manual testers to diagnostic programs under the control of a common processor.

Some administrative and engineering installation operations required to be performed instantly and from remote locations will use temporary storage and processing until the exchange is visited for maintenance when all such operations will be normalised and the equipment updated.

12 Engineering

A system has to be satisfactory, not only in its transmission performance and the facilities that it provides, but also in practical engineering which concerns size, weight, power consumption, equipment installation and extension to satisfy growth, the integration of the system into the existing system and its maintenance. Electronic exchanges and t.d.m. types in particular have many engineering advantages which are indicated by a brief outline description of an exchange according to the system of the paper.

An invariable part of all exchanges are the terminal units to which exchange lines are connected for traffic concentration and which advantageously include as much as possible of the equipment which is individual to exchange lines. The equipment is shown enclosed in a broken line in Fig. 1 and has been described[7] in some detail previously. One rack 3 ft wide and 10 ft 6 in high accommodates 1024 line equipments, their line information and state-of-line stores, meter stores, l.m., l.i., and t.t.o. apparatus and some common control equipment. Exchanges with 10000 numbers commonly have 12000 lines for which 12 terminal units, t.u. in Fig. 7, would be used and

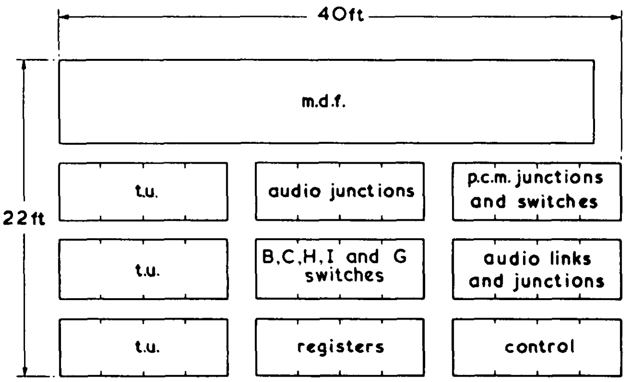

Fig. 7
Layout of equipment

disposed relative to the m.d.f. as shown. Clearly the cabling between the racks and the m.d.f. is minimal. The trunks between the units and the B, C, switches are only eight per rack because they are multiplex trunks. 36 racks suffice for the exchange in its final form; the floor space occupied including the m.d.f. is 40 ft by 22 ft. The limiting length for the multiplex trunks, 150 ft, is not even approached in exchanges of this size, in fact exchanges up to 50000 lines are contemplated. Growth from an initial installation of about 20% of the final equipment comprises adding racks of multiplex exchange lines and junction terminals: the multiplex switches (B, C, H, I) are constructed by plug-in boards and grow sideways by the addition of plug-in units. Some rearrangement of the trunks as well as additions, are necessary as the exchange grows, but being multiplex trunks they are few in number and easily rewired. In the early stages, some conversion equipments for interworking with existing plant will be necessary but should have largely disappeared by the time the exchange is fully developed.

13 Conclusion

The structure of electronic exchanges can differ from that of all existing systems in the provision of 4-wire switching at all exchanges with amplification available to any desired extent, with significant advantages. This performance at an economical cost in exchanges of all sizes can be realised at present only by t.d.m. switching. Partly for these reasons, in the system of the paper, analogue circuits are time-division-multiplexed in order that they may be switched, the modulation being by pulse amplitude. P.C.M. transmission being already time-division multiplexed, the same kind of switch is used for both kinds of transmission. Additional reasons for choosing t.d.m. switches include the fact that transmission through the exchange in t.d.m. form makes guide-wire path selection and trunk processors (supervisory and terminal unit processors as described) the cheapest form of control for the functions performed by those equipments. Given supervisory trunk processors and that data-link or order-wire signalling over junctions is essential to provide enough signalling capacity, order-wire signalling continued through the switches to supervisories and also to registers, becomes a natural choice for small exchanges; the possibility of both order-wire and data-link signalling in one exchange makes signalling through the switches attractive for data-link junction signalling, for uniformity with order-wire signalling and with some incidental simplification of the processing. Thus there is a step-by-step chain of reasoning for the structure and much of what is termed the low-level control. The main problem of the high-level control by registers and unique common processor is that of achieving cost in proportion to size of exchange with only a small constant cost irrespective of size, which subject is included in Pt. 2 of the paper. Here it may be observed that the numbers of registers are approximately proportional to the sizes of the exchanges, and much of the constant cost resides in the duplicated unique common processors. With the prospect of large-scale integration producing cheap wired-logic processors, the use of registers, as shown in this paper, to reduce the cost of the unique common control is also logically justified.

14 Acknowledgment

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