Electronic exchange system

Part 2—Control

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Abstract

The structure and low-level control equipment of an electronic telephone-exchange system are described in Pt. 1 of the paper. Pt. 2 expands the control to the higher levels of register and unique common control and describes the operation of the whole system. The main problem and objective of the control system is to be economical for all sizes of exchange, for which purpose its cost must be approximately proportional to the size of exchange with only a small constant cost independent of size. To this end, advantage is taken of the low cost, concomitant with the use of t.d.m. (time-division multiplex) switches, of guide-wire path selection and distributed processors to reduce the cost of the unique common processor, the cost of which is minimised by a combination of wired and stored-program logic, the stored-program-logic part being remotely located and shared with other exchanges if an exchange is too small to support it alone.

1 Introduction

This paper is a continuation of a series (see Pt. 1 and Reference 1) concerned with a telephone-exchange system having as its objective the superseding of existing electromechanical systems in already well developed areas, by installation as new exchanges and extensions to existing exchanges. The structure of the system has been described in Pt. 1. This part is concerned with the control equipment.

2 General principles

The structure and control sections of an exchange system are not independent; the best system is undoubtedly one in which the two integrate with the maximum smoothness. For this reason, the structure already described includes some of the control equipment in the form of circuit and distributed processors. The control problem to be solved is that of the unique common processor which accounts for most of the economic differences between systems. The principle of the control involved is the cyclic association of units of control with a unique common processor, during which times the existing state of a unit is sensed, the past state is read from stores, the state information thus assembled is processed, commands are issued and stores updated. The periods of association must be less than the minimum times between changes of state of the units and the durations of association, or processor dwell times, sufficient for all the operations detailed to take place. The cyclic association can be clock-controlled, i.e. 'synchronous', or clock- and processor-controlled, i.e. 'asynchronous'; the interface and processing costs are much less in the first case, which applies to the system being described in which also the past states of the units being processed are held in stores in the units themselves and presented to the unique common processor during the processor dwell. The unique common processor, thus given all the necessary information simultaneously, processes it by wired combinational logic; the processor is little more than a combinational-logic unit which, given input information, emits corresponding output. It operates very quickly, so that the dwell times are small and many units of control can be processed during the cycle times. Nevertheless, the necessary dwell times vary over such a wide range that to choose one satisfactory to all would limit the quantity of units that could be processed. For this reason, multicycles comprising cycles within longer cycles are used to suit the conditions involved, as described in Section 3.

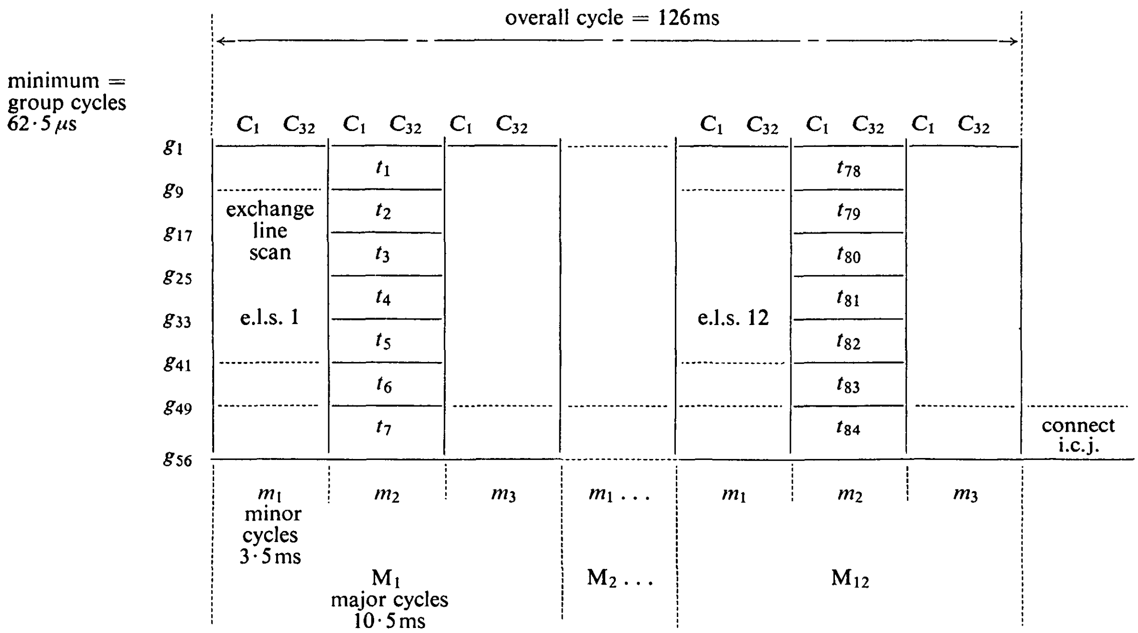

Fig. 1
Timing cycles

An exchange with a wired-logic unique common processor can operate as an independent unit and economically provide

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all services except some of the least essential. It will also detect faults and give some indication of their location, final location and clearing, depending upon a maintenance man equipped with simple aids. All services and more elaborate maintenance aids can be provided, as economic circumstances permit, by supplementary and substitution stored-program processors, as described in Pt. 1 of the paper.

quency of 8 Hz. Within the m_2 minor cycles there are seven test cycles each of eight group cycles and designated t_1 to t_{84} for all the test cycles in the overall cycle. These various cycles have been arranged to suit the rates of change of state of the various items of equipment and the processing times involved as will be eventually apparent, as will the fact that they are adequate for exchanges up to at least 50000 lines.

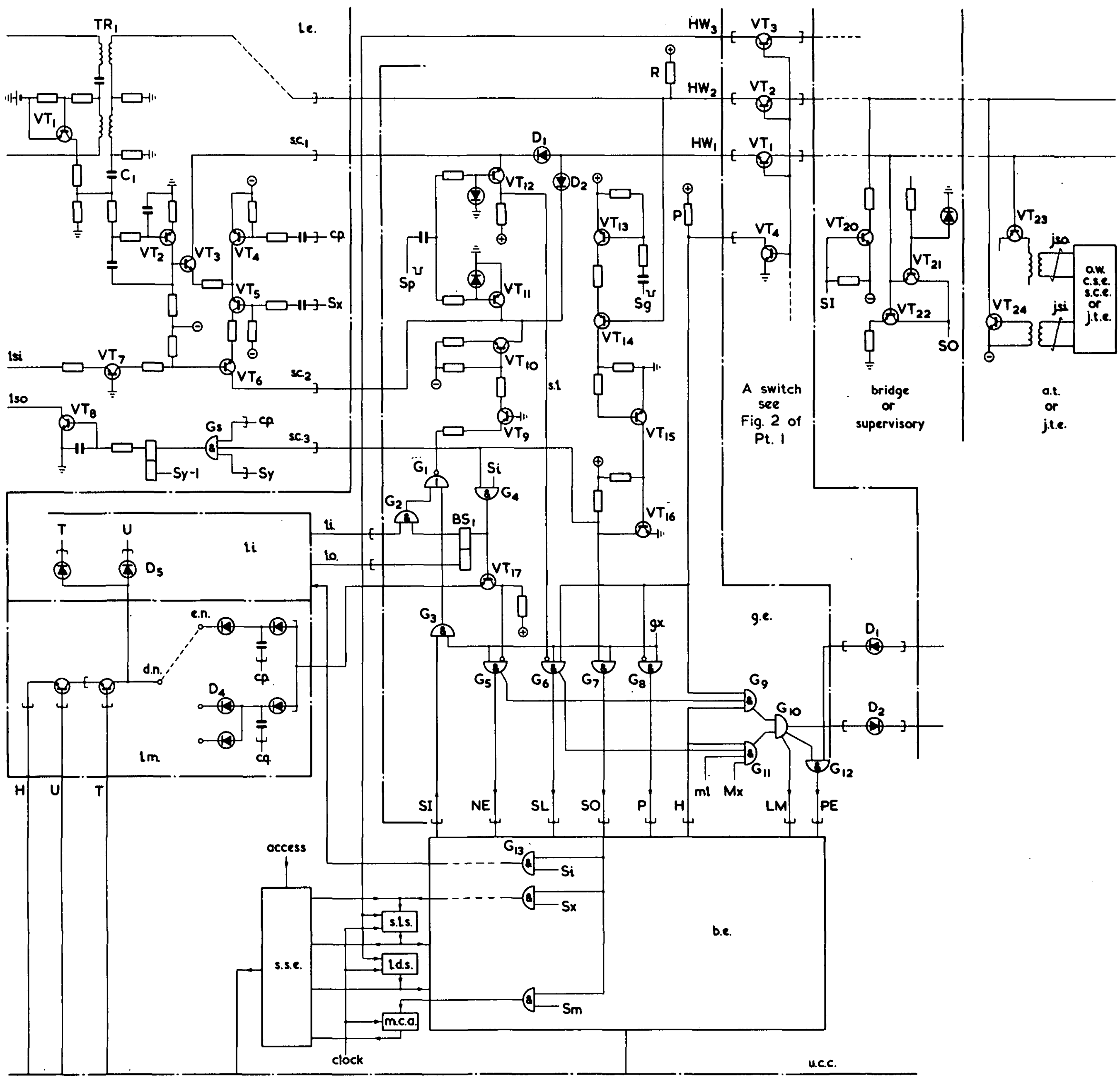

Fig. 2 *Signalling and control schematic*

3 Unique common control cycles

The synchronous t.d.m. control cycles are illustrated in Fig. 1. They are produced by successive division of a master clock pulse, which also produces the pulses for the speech-path switch multiplexes. A group cycle is one cycle of the analogue speech multiplex which has a duration of 62·5 μs divided into 32 channel times designated C_1 to C_{32} in Fig. 1. A minor cycle is 56 group cycles designated g_1 to g_{56} and with a duration of 3·5 ms. A major cycle comprises three minor cycles m_1, m_2 and m_3 and lasts 10·5 ms. The overall cycle is 12 major cycles M_1 to M_{12} with a period of 126 ms or a fre-

4 Signalling cycles

One signalling channel in each direction of transmission through the switches is time-division multiplexed to provide 17 different signals defined by signalling pulses S_1 to S_{17}. The signalling multiplexes are exactly related to the speech and control multiplexes, the duration of each signal pulse being six group cycles, and the period of the signalling cycles being 102 group cycles or 6·375 ms, which defines the maximum signalling speed. A prime number is chosen, 17, so that the signal slots vernier with the group pulses g_1 to g_{56} so that every group pulse will regularly coincide with every signal pulse, which it does once every 56×17 minimum cycles, or every 59·5ms, which feature is concerned with writing into synchronous stores.

5 Signalling

Fig. 2 shows the signalling paths through the exchange switches. Some equipment is shown in symbolic-logic form using positive logic. Part of the A switch (Pt. 1, Fig. 1) is included and will be recognised from Pt. 1, Fig. 2; the common ouput P from the collectors of transistors VT_4 is normally at logic 1 but changes to logic 0 to indicate that a crosspoint is operated. Exchange lines are terminated on transformers TR_1 which are part of the line equipment (l.e. in Pt. 1, Fig. 1). The exchange line, when looped, causes transistor VT_1 to saturate and thus to switch on transistor VT_2 which, with its associated circuitry, forms an active lowpass filter. The transistor VT_2 drives VT_3 which is switched to the conducting condition by transistor VT_4 actuated by the channel pulse (c.p.), allocated to the line. The collectors of all VT_3transistors of a 32-line group are connected to the speech common (s.c.$_1$). Current in the common flows in the emitter of transistor VT_{12} until an s.p. pulse (Pt. 1, Fig. 3*a*) occurs when the current transfers to diode D_1 and the group multiplex highway HW_1 and hence to the A switch crosspoints as a loop signal to supervisory and other processors, and as a speech-transmission pulse by being modulated by speech currents through capacitor C_1. Current prior to the s.p. pulse causes the transistor VT_{12} to saturate; thus VT_{12} indicates by its collector potential the states of the loops (s.l.) of all the lines in the group. Signal currents are applied to the common lead s.c.$_2$ from some line equipments of a group, the currents passing via the diode D_2 to the highway HW_1 except during the s.p. pulse which causes the transistor VT_{11} to catch the signalling currents. Signals from the block equipment (b.e.) over the SI lead are directed into a group equipment by a group pulse *g* using gate G_3, and signal pulses from line-identification (l.i.) equipment over lead l.i. are selected by a group equipment with an operated bistable circuit BS_1, using gate G_2. The outputs from the gates G_2 and G_3 are combined in gate G_1 and flow to the emitter of transistor VT_9 to produce out of VT_{10} signal currents which take the same path as those from the common lead s.c.$_2$.

Speech and signal pulses are received from the A switch into a resistor *R* and multiplex highway HW_2. The speech pulses are distributed to the line equipments where they are demodulated and applied to transformers TR_1. The potential across resistor *R* is also applied to the base of transistor VT_{14}, the emitter circuit of which is completed during the sg signal pulse times (Pt. 1, Fig. 3*a*) by transistor VT_{13}. Hence, in the collector of VT_{16} and over the signal output lead s.c.$_3$, appear all the signal pulses received for all the lines in the group. These pulses are gated in gate G_7 with a group pulse *g* to appear in channel and group order over lead SO to the block common equipment.

A small proportion of the line equipments will have signal inputs, l.s.i., and outputs, l.s.o., individual to themselves, for coin signals, private meters and so forth. Signals over the common lead s.c.$_3$ are gated in gates Gs with a signal pulse Sy defining the signal, and a channel pulse (c.p.) defining the line, to operate a bistable circuit which is restored by the Sy-l signal pulse, the output of the bistable being smoothed to a continuous l.s.o. output from transistor VT_8 for as long as the signal through the switch is maintained. Inputs l.s.i. cause current to flow in the collector of a transistor VT_7 and in the signalling common s.c.$_2$ on the coincidence of a channel pulse (c.p.), of the line concerned and signalling pulse Sx defining the signal.

At a bridge or supervisory point between exchange switches, signals are injected as required from a signal input SI via transistor VT_{20}: and read out to a signal output SO without affecting the transmission, by a transistor, VT_{22}, tapped on the highway. The transmission is split by pulsing the base of transistor VT_{21} to slightly above earth potential, the emitter then taking all the highway current and the collector providing the signal output SO the transistor VT_{22} being cut-off.

The speech and signalling transmissions are similarly separated in audio junction terminals (a.t.), the outgoing j.s.o. signals being emitted via a transformer as channel pulses balanced with respect to earth and occurring within the signalling pulses S which define their significance, and the incoming j.s.i. signals also with balanced transmission via a transformer, having an equal ratio on/off waveform synchronous with the channel slots and duration of the appropriate signals S. The j.s.i. and j.s.o. signals respectively originate and terminate in order-wire, c.s.e., s.c.e. or j.t.e. units. Audio links provide slot changing for signals as well as speech, to which end the signals are brought out on channels which are the same as the j.s.o. channels of the j.t.e., the signals being 'stretched' and applied to j.s.i. channels of the terminals at the other ends of the links.

The sending and receiving of signals over pulse-code modulated (p.c.m.) multiplexed channels, (Pt. 1, Fig. 1), involves o.w.t. or c.s.e. signalling equipments and a p.c.m. terminal equipment (d.m.t.) to inject and receive the signals in their appropriate channels. Slot changing is involved in p.c.m.–p.c.m. tandem connections and in connections via the d.t.b. audio links, and is provided by the time switch (t.sw.), which stores a received signal in one slot and sends it out in another slot. To give sufficient time for slot changing to be effective, and bearing in mind that a signal between a p.c.m. channel in a d.m. terminal via a d.t.b. terminal to an I switch channel has to be slot changed twice, the signal pulses, S, have a duration of three p.c.m. multiplex cycles and six audio multiplex cycles.

6 Exchange-line scanning

Exchange-line scanning is a function of the terminal unit[2] shown in Pt. 1, Fig. 1 and in more detail in Fig. 2, the same equipments in the two diagrams carrying the same designations.

Exchange lines are arranged in multiplex groups of 32, and the groups in blocks of 32 groups of 1024 lines, each group being allocated a group pulse *g*. There is a wired-logic group equipment (g.e.) individual to each group, and block equipment (b.e.) for the whole block. Associated with each block is a semipermanent line data store (l.d.s.) in several sections with entries per line in each section, and ferrite-core state of line (s.l.s.) and meter call accounting (m.c.a.) stores with an entry per line and per party per line, respectively.

6.1 Originating calls

Each block of lines is scanned for new originating calls once every overall cycle, during the m_1 minor cycle within one of the major cycles M. The state of loop signals, (s.l.) and crosspoint signals P are applied to gate G_6 together with the group pulse *g* of the group. The output SL from the gates G_6, of a block of lines is the state of loop of all the lines not connected through the switch A, presented in channel and group order continuously to common equipment. The lines connected through the switch are similarly indicated to common equipment by gating the P signals from the switches with group pulses in gates G_8. The SL and P leads together contain information concerning the states of all lines in the block. The information is used for line scanning during an m_1 minor cycle within an allocated major cycle, Mx. The SL information within a group is applied to gate G_{11} which has as its other inputs the m_1 and Mx pulses and an output H from the block equipment (b.e.), the H output being normally at logic 1. An output of gate G_{11} inputs to the OR gate G_{10}, the output of which is applied to the A switch as a marking pulse which is unique since no two lines can be scanned at the same time. An output from gate G_{10} over common lead LM informs the block equipment and unique common control that a free line was marked for connection. During line scanning for new originating calls, which is every m_1 pulse time, all the originating registers o.r.d. and o.r.v., are marked as terminating points for the guide-wire path search and connecting equipment. If, when a marking pulse issues from a gate G_{10}, a free path to a free register exists, a marking pulse will be present through a diode D_1 of an A switch crosspoint. The combination of this pulse in gate G_{12} with the pulse from gate G_{10} informs the block equipment and the unique common control that a free path PE exists. Synchronously with the line scanning, the line, data and state-of-line stores are addressed by the exchange clock and read out to the block equipment (and over bus leads to other equipments). The block equipment processes the store information with the loop information to decide if the call is allowable or prohibited because it is permanently looped and therefore parked or barred service for some administrative reason. If it is not allowable, the block equipment removes the logic 1 from lead H and thus inhibits the connection. All these operations take place within the channel time of a line; the groups are scanned in order using group pulses g_9 to g_{40} (Fig. 1), during which time the whole block is scanned; there being 12 major cycles M, a total of 12000 lines can be scanned eight times per second.

It is not difficult to arrange that, with a high probability, the logic 1 on the lead H is not removed if the group equipment or its associated stores develop a fault. Service to the customer is not interrupted (in fact service to which a customer is not not entitled may be given), which means that the only equipment common to the block which needs to be duplicated is that which ensures that the block equipment fails safe.

If the line data indicate for the line being scanned the kind of number sending to be expected, either rotary dial or v.f. pushbutton, the unique common control removes the marking from the other kind of register; otherwise, one of each kind of register is connected until a directory digit is received, when the unwanted register is released.

If no free path to a free register exists, a line remains unconnected until connection can be made.

6.2 Terminating calls

Exchange lines to be connected for terminating calls are identified by their directory numbers. Some directory numbers define more than one line, chiefly p.a.b.x. groups of lines; some lines have more than one directory number, party lines and those with night-service numbers, for example. The lines are identified for connection by scanning in group and channel order similar to that of originating calls except that all blocks are scanned simultaneously.

To simplify line identification, the 1024 lines in a block are all given the same thousands digit. A decoder in the unique common control, given an exchange-line directory number, produces corresponding marks (signals) on one of ten units wires U, one of ten tens wires T and one of as many hundreds wires H as there are hundred number groups. These signals are applied to the line markers (l.m.) which have one terminal, (d.n.) per directory number and one or more terminals (e.n.) per exchange line equipment and usually termed equipment number. The terminals used are those of standard shelf sockets. Directory and equipment numbers are associated by wire wrapping a strap between appropriate directory and equipment number terminals. By judicious arrangement, most straps are very short. As many equipment terminals as required may be connected to one directory-number terminal; for a proportion of line equipments, two marking terminals are provided to connect two directory numbers to one equipment number. Sections of directory numbers are allocated to party-line X parties and other sections to Y parties; using which information, the line marker, when a party line is called, signals the X or Y party to the block equipment (b.e.) and unique common control which selects the type of ringing to be sent. The effect of signals applied to H, T and U leads (Fig. 2) is to lower the potential of one corresponding directory-number terminal, and thus to change the bias on capacitors decoupled by diodes D_4 connected in group order to the emitters of transistors VT_{17} in the group equipments. Each capacitor receives a negative-going pulse at the channel time of the line to which it refers. Hence, during one scan comprising group pulses g_9 to g_{40}, the channel pulses of all lines with the defined directory number will appear in their groups and also in group order by gating them with their group pulses in gates G_5. An output from those gates to the common lead NE informs the common control that a working line with that directory-number exists. It also allows the common control to count the lines with that number to identify a particular line in a group by its serial number. Another output from G_5 is gated in G_9 with the output from the group busy lead P which is at logic 1 unless the line is already connected through the A switch, and with the block equipment signal on the H common which is normally at logic 1. An output from gate G_9 continues through the OR gate G_{10} to the LM common to indicate that the line is free and connection is allowable and also as a mark to the A switch, to start a connection to an already marked terminating point or points if a free path exists; if no connection can be made, the scanning continues. In this way, all the lines of a group are tested in a preferred order, which is the usual requirement for p.a.b.x. lines. For traffic and security reasons, the lines in one directory-number group would be spread over different multiplex groups and channels. Connection to a line not allowed to be connected is inhibited by the block equipment by means of a signal over the lead H, as for originating calls.

7 Exchange-line identification

The directory number of an exchange line connected through the switches is identified by a line-identification signal through the switches at signal time Si. Signal pulses through the switches are gated with signal pulses Si in gate G_4 which has the effect of raising the emitter potential of transistor VT_{17} at the same time as the channel pulse is reducing that of the capacitor of the line concerned, which gives the capacitor a charge. When the channel pulse ceases, the capacitor charge is dissipated through diodes D_5, which indicate to common equipment the tens and units digits of the directory number of the line; the hundreds and thousands are added from other circuitry to assemble the complete number which is coded and emitted over the common lead l.i. in pulses occurring on the same channel as was received into the l.i. equipment. The pulse out of gate G_4 also sets a bistable circuit BS_1, the output from which is gated with l.i. in gate G_2, the output from which, via OR gate G_1, operates transistor VT_9 thus transmitting the line-identification number signals over the highway HW_1 as already described. The line-identification pulse over common SO is also gated with an Si pulse in gate G_{13} in the block equipment to cause any other relevant information, such as the class of service or the party of a party line, available to the block equipment, to be communicated to the l.i. equipment and added to the identification transmission. When sending is completed, a pulse over lead l.o. restores the bistable circuit BS_1. Clearly, line-identification equipment which is common to a block of lines can deal with only one call at a time, which is normally adequate, the traffic being very low. If a second demand is received while a first is still in progress, the demand is ineffective and must be repeated after a delay of a second or so.

8 Line-equipment identification

An exchange line is identified by a directory number and serial number, the latter distinguishing lines having the same directory number. The line equipment or equipment number to which a line with a given directory and serial number is connected is frequently required to be identified and is available by operating the line markers as for a terminating call. Line-equipment-identification apparatus, when given the directory and serial numbers of a line, operates the line markers through the unique common equipment with the result that pulses appear over the common lead NE at the channel times within the group times of the lines with that directory number, and on counting the pulses up to the serial number, the required line equipment is identified by block, group and channel. An address obtained in this way is used to read synchronous stores as will appear hereafter. It is also used to operate the relays of Fig. 6 in Pt. I to connect individual lines to test and trunk-offering equipment; and also, when a party line originates a call, to connect the line by relays to party-identification relays by which the calling party is identified, this information being written into the state-of-line store and the relays released.

9 Exchange-line information storage and operation

Line information requires semipermanent stores for the data and temporary stores for the state of line and meter call accounting. The quantity of storage varies with the line and the information. State of line needs one word per equipment terminal, the word length being the same for all entries. The meter store requires one fixed-length word per party which means more entries than line-equipment terminals. Excluding d.n. to e.n. translation and the inverse, which are provided by the line marker (l.m.) and line-identification equipment (l.i.) respectively, line data storage varies from 1 bit for every line to hundreds of bits for some few lines. The availability of the information on reading the stores varies with the information. Some line data and some state of line information are necessary instantly, as lines are scanned for originating or terminating calls, and some less urgently, as calls are in process of being finally set up. Meter information is needed only at rare intervals and under close control to avoid mistakes and unauthorised access to the records. It must be possible for the administration by remote control to cancel existing or enter new information into the line-data stores, and to read all the stored information. Information changes to the state-of-line stores must similarly be possible by the administration, and also by exchange processors during normal exchange operations. The meter store records pulses occurring during calls in progress; operation must be rendered secure by a persistence check or other means, and no other means of changing the information is allowable.

With such varied requirements and quantities, it is unlikely that one uniform method of information storage will be satisfactory and economical for all purposes. In the system of the paper, the storage is divided into areas and operated as now described.

9.1 Exchange-line data

Typical line data to be stored are listed in Table 1 as data necessary to originating and to terminating calls, in two sections according to the process time, namely data instantly required during scanning and to be processed within the channel time, and data required during setting up of calls. for other data which are particularly important for directory addressing is essential. Other forms of addressing can be used for other data, which is particularly important for directory numbers referenced by abbreviated dialling codes, and for transfer directory numbers. Data available during scanning for originating calls are also needed when subsequently setting up the connection, for which purpose, a means of asynchronous reading of the s.l. and l.d. stores is provided and comprise a signal over a channel specially provided for the purpose, from the registers through the switches to the group equipments on multiplex highways HW_3. By this means, a pulse within the group and at the channel time of the line concerned provides an address for the store.

Table 1

EXCHANGE-LINE DATA

Time required	Originating calls	Terminating calls
At scan	Class of service: rotary dial v.f. pushbutton rotary dial or v.f. pushbutton no dialling (disabled subscriber) party line coin box	Party line X Party line Y Freefone Last party release Changed number interception
At call set-up	Class of service: barred s.t.d. barred international unabbreviated d.n.s. (maximum 100)	Transfer d.n.s. (maximum 5)

The data required at scan time are provided by wire connections between line-equipment jack terminals and terminals in a data field. The numbers of connections are small because most lines need only one wire and that a common running along all the units to define the type of dialling; some other data, notably party line, apply to complete 32-line groups and need only one wire per group.

Line data required during the setting up of calls are the most variable in quantity per line and in distribution over the lines, but are flexible in their methods of provision. A Dimond ring or other wired store is suitable as is a common-processor store if a common processor exists in the exchange.

Line-data information which is stored by wiring requires manual attention at the exchange and cannot be altered by remote control. The rate at which the information changes is, however, so low that it becomes possible to achieve the same result as remote control of the line-data information by writing by remote control into the state-of-line store that the data store information for that line is to be disregarded and reference made to a central store where the true information is to be found.

The information read out of the data store is made available to the block equipment and the unique common control. The administration can ascertain the entry against any line by accessing a store supervision equipment (s.s.e.) to which the directory numbers and serial numbers of the line are communicated and by which the line equipment is identified as described in Section 8, the store output synchronously occurring being the required information.

9.2 State of line

Each block of line equipments has a ferrite-core store of 1024 words of sufficient bits per line for the number of states of line which have to be stored. The store is read synchronously in channel and group order once every minor cycle by addressing provided by the exchange clock and asynchronously by signals over multiplex highways HW_3. Some information is written into the store as part of the exchange operation and some by the administration. The bits of each word may be coded in conjunction with information from the data store as specified by the administration and as shown in the example in Table 2, using seven bits per line. Reference has already been made and is made in the Table to a central store which is part of the common control yet to be described. It is expected that eventually central stores will be available to all exchanges but possibly not for small ones initially. Until a central store is available, the facilities shown as needing the store cannot be given but are not essential. The use of a central store effectively extends the state of line as well as the data store to any desired extent.

The state-of-line store (s.l.s.) is read synchronously with the scanning and the information made available to the block equipment, the unique common control and the store-supervision equipment. The information is rewritten either unchanged or changed as the result of processing in the block equipment or instruction from the store-supervision equipment (s.s.e.). For example, a line which is looped is connected to a register, but, if no dialling follows, the register times out, sends a parking signal Sp through the switches for at least 59·5 ms so that it emerges at least once over the SO common lead at the same time that the state-of-line information is about to be rewritten. The block equipment therefore writes into the store the parking code which remains until, during a subsequent scan, the signal over the SL common shows the line no longer to be looped.

When the store is read asynchronously by a pulse over an HW_3 lead, the relevant word is read out to the unique common control via the block equipment which rewrites the information unchanged.

For the contents of the store to be read or altered by the administration, access is gained through the switches or over a data link to the s.s.e., to which the directory number and serial number of a line is communicated. The equipment then operates as previously described to indicate the synchronous address of the line in question. The store is thus read and the word rewritten under the control of the s.s.e. equipment.

9.3 Meter-call accounting

The meter-call-accounting store[2] has one 17 bit word per party, and 1280 words per block of 1024 lines to allow for 25% of the lines to have two parties. The store is addressed synchronously but not read unless an addition has to be made to the record, or an instruction is received from the administration. Meter pulses are transmitted through the switches

Table 2

STATE-OF-LINE INFORMATION CODES

Class of service	Bit 1	2	3	4	5	6	7	Significance	Under the control of
Any class of service	0	0	0	0	0	0	0	Normal service	
Any but party line	0	x	x	0	0	1	x	Incoming calls to transfer d.n.1	Customer
	0	x	x	0	1	0	x	Incoming calls to transfer d.n.2	Customer
	0	x	x	0	1	1	x	Incoming calls to transfer d.n.3	Customer
	0	x	x	1	0	0	x	Incoming calls to transfer d.n.4	Customer
	0	x	x	1	0	1	x	Incoming calls to transfer d.n.5	Customer
	0	x	x	1	1	0	x	Refer incoming calls to central store	Administration
	0	x	x	1	1	1	x	Incoming calls to be intercepted	Administration
	0	1	0	x	x	x	x	O.C.B.	Administration
	0	0	1	x	x	x	x	T.O.S.	Administration
	1	x	x	x	x	x	x	Parked	Exchange
Party line	x	x	x	x	1	0	x	X party connected	Exchange
	x	x	x	x	0	1	x	Y party connected	Exchange
	x	x	x	x	1	1	x	Parked	Exchange
	x	x	0	1	x	x	x	X party o.c.b.	Exchange
	x	x	1	0	x	x	x	X party incoming calls to be intercepted	Administration
	x	x	1	1	x	x	x	X party t.o.s.	Administration
	0	1	x	x	x	x	x	Y party o.c.b.	Administration
	1	0	x	x	x	x	x	Y party incoming calls to be intercepted	Administration
	1	1	x	x	x	x	x	Y party t.o.s.	Administration
Any	x	x	x	x	x	x	1	Refer all calls to central store	Administration

Note x = 0 or 1
O.C.B. = outgoing calls barred
T.O.S. = temporarily out of service

under the control of a processor; each pulse is maintained for 200 ms to be long enough to operate a private meter via an l.s.o. outlet, and thus cause a minimum of three pulses over the SO common at the meter pulse signal time Sm. The several signal pulses provide a persistence safeguard against false metering; a meter pulse having been validated, it is added to the previous total. No other means of changing the record is allowed, for security of the record. The administraion is able to read the record by accessing the store supervision equipment (s.s.e.), which, given the directory number and serial number of a line, operates the line markers to identify the synchronous time at which the meter store word relevant to the line is being addressed by the clock. The meter call account of one line, or of all lines of a group or the whole exchange are obtained by supplying the appropriate directory and serial numbers, one after another, a procedure which is compatible with machine processing and billing.

10 Junction operation

There are some obvious similarities between junction and exchange-line information and operating requirements but the differences are even more marked and justify a different treatment. Junctions are available in general for all classes of call and thus need no data storage except to associate them with directory numbers for selection on outgoing calls. Incoming calls have a class of service, but this is determined at the point of origin and communicated prior to the directory number as part of the incoming-call information. The association of directory numbers and junction routes is part of the unique-common-control operation; it is manifest to the junctions as marking signals on g.j.m. leads (Pt. 1, Fig. 1) to mark all the junctions on a given route. The inverse of line marking is call trace, which is analogous to line identification of exchange lines and a maintenance operation not shown in the Figure. A call-trace signal received into a junction terminal equipment from the line or the exchange side emits a coded signal to an equipment which records the signal and thus the location of the junction.

For junctions with data-link signalling, the state-of-line information is stored in the unique common control. For other junctions, the storage is part of the a.t. and j.t. equipments, (Pt. 1, Fig. 1), and is limited to free or engaged, or out of service, which are most economically stored in the junction terminal equipments.

Incoming calls on junctions with data-link signalling are received into the unique common control. The junction is guarded against seizure for an outgoing call, but is not otherwise involved until sufficient information has been received for a connection to be made through the exchange, which the unique common control will make during an m_3 minor cycle as described later.

Incoming calls over junctions without data-link signalling are initiated by any signal coming from the junction; normally the class of service is the first signal to be received, and will have the effect of busying the junction a.t. or j.t. equipment or channel in the d.m.t. equipment, and producing a connection to a register i.j.r. Referring to Fig. 1, during the minimum cycles g_{49} to g_{56} of every m minor cycle, the i.j.r. are all marked by a clock pulse for connection of a new incoming junction call if one exists. A calling signal stored in an a.t. or j.t.e. or d.m.t. equipment is also gated with the clock pulse from g_{49} to g_{56} to produce a guide-wire marking signal for the junction. The mark is propagated over the guide wires and appears in any register which has a free path to the calling junction, at the channel times of the free path or paths. Gating the received marks with the free signals of the registers determines whether a free path to a free register exists. Usually free paths to more than one register exist, and at more than one channel time. By wired-logic selection, one of the channels is chosen, then a register with a free path at the selected channel time, and a mark at this time from the register is used as a starting mark for selection towards the junctions. As a result, a calling junction will be connected to a register; if more than one calling junction exists, only one will be connected during that m pulse, and others will be connected during the next and succeeding m pulses. In this way, no queueing is necessary and no double connections are possible. A register, when connected, sends back a proceed to send signal S_{13}, which causes the sending again of the class-of-service digit, from the distant end or s.c.e. This digit is stored in the receiving point (o.w.t. or s.c.e. or d.m. terminal) until transmitted through the switches to the register at the next appropriate signal time S, whereupon the register sends the 'proceed to send' signal again, which cancels the received digit in store and provokes the next digit from the distant end or s.c.e.

11 Test and processing cycles

The description given so far has been concerned with the transfer of information to registers and to equipments such as s.s.e. The information needs processing when sufficient has been received. To determine when registers have received sufficient information, each is allocated a test period per overall cycle, one of the 84 cycles t of Fig. 1. During every one of its test periods, the register has sole use of the unique common processor, to which it communicates the received information and receives a decision either that the information is sufficient for processing or it is not. The register continues to present the received information during successive test periods until it is sufficient or the equipment is released by time-out or other means. When sufficient, the equipment joins a waiting list of registers and other equipments waiting for processing. During every m_3 minor cycle one call from the list can be processed, and has the whole exchange control for the whole minor cycle in which to complete the processing. There are 343000 m_3 minor cycles per hour; if half of these are active processing times, the average waiting time for processing to commence is 10·5ms and the chance of having to wait more than 0·25s is 0·001, which is acceptable even without queueing. If 90% of the active times produce connections through the exchange of an average duration of 2·5min, the total traffic-handling capacity of the exchange is 6000 erlangs, which is sufficient for exchanges of 30000 to 100000 lines depending on the traffic per line. 84 test periods for registers are sufficient for only about 2000 erlangs of total traffic, and require to be augmented for the largest exchanges. Registers are able to be tested simultaneously with originating line scanning during m_1 as well as m_2 minor cycles, which doubles the number of test periods, and the number can be doubled again by halving the frequency of testing, with negligible effect on service. The maximum number of exchange lines in the line scanning cycles is 12000, which requires parallel scanning for larger numbers. Using these devices there is no difficulty in reaching the quantities of lines quoted for exchanges with mainly subscriber traffic or the same quantity of traffic including junction tandem switching. At the other end of the scale, exchanges down to 1000 and even 500 lines are economically possible. The flexibility in size is due partly to the structure and distributed control costs being closely proportional to traffic, and partly to flexibility in the provision of the unique common control which becomes only a small part of the total and proportional to traffic plus only a small constant cost irrespective of traffic. In respect of both structure and control equipment the cost characteristics are thus similar to those of existing systems with which it has to compete.

12 Unique common control

The unique common processor is in two parts, as shown in Pt. 1, Fig. 1. One part comprises a wired-logic processor, (w.l.p.), and is accessed through an interface (i.f.) by registers, each during a regularly occurring and allocated test period, and as required by registers and other common processors during m_3 processing times. The other part comprises a stored-program logic processor (s.p.l.p), which is accessed through an interface (i.f.) as required by the wired-logic processor via the interprocessor equipment (i.p.e) by data-link terminals (d.l.t.) and common signalling equipments (c.s.e.). All exchanges have duplicated w.l. processors. Large exchanges have duplicated w.l. and s.p.l. processors, with data links and other forms of information communication with other exchanges and control centres. Small exchanges have only duplicated w.l. processors, each of which in a well developed area will have access to an s.p.l.p in a remote location, the s.p.l.p. for the two w.l.p. being possibly in different locations. The small exchanges will have no data-link signalling but will nevertheless render the full range of services to the customers. Small exchanges in less well developed areas may have no s.p.l.p. backing, in which case they may render the full range of services by special hardware provision, or less than the full range pending the availability of an s.p.l.p. later.

12.1 Wired-logic processor

The interface between the wired-logic processor and a register comprises gates located in the register itself. Two gates provide serial transmission of information both ways between the register and the w.l.p., shift-register storage being used in the register. The gates are operated during test and processing periods.

Directory-number digits are received into a register from an exchange line or a junction and stored on a shift register with a capacity of 18 decimal digits. An incoming junction will also send information such as class of service and processing instructions which are also stored. Items of information received in these ways are primary data which might be needed for a second trial if the first were unsuccessful and is therefore not destroyed in subsequent operations until the register is finally released. When a register is connected to the w.l.p. it communicates all the information it holds to the w.l.p. which also receives information from other parts of the system. The w.l.p. processes the information and sends instructions back to the register for the furtherance of the call.

The register gates are operated during each allotted test period t_n, the directory number digits received by the register are examined by the w.l.p., and if they are insufficient to determine a connection to be made, no action takes place. When they are sufficient, the processor writes into the register stores information defining the connection to be made and any other relevant information, such as the digits to be sent to the next register for an outgoing junction call. The register will then apply for a processing period and when it succeeds it is connected again to the w.l.p., to which it again gives all the information it contains. The register also marks the starting point of a connection to be made through the switches, and an originating register sends back a signal over the HW_3 channel so that the w.l.p. is given the line data and state-of-line information including the class of service of the calling line. Having processed the information, the w.l.p. usually proceeds to mark the guide-wire terminating points of a connection through the switches, to monitor the progress of the connection and issue instructions to the register so that, by the end of the processing period, the register is able to release or proceed with the next stage of setting up the call. Exceptionally, the information presented to the w.l.p. will be insufficient for a connection to be made and it will require reference to be made to another processor as described later.

Registers are concerned with the establishment of connections through the structure of the exchange. The structure itself will make a connection if the starting point and suitable terminating points are marked. It will also take up other information such as call-charging rate as connections are made. Control after a call has been set up does not normally involve the unique common processor. The main function of the register is the collection of information from exchange line and junction peripherals. Other information concerning exchange lines is contained in the line data and state-of-line stores. Junction routing and other administrative information is contained within the wired-logic part of the unique common processor. Hence when a register is connected to the w.l.p. and, in the case of an originating call, the line information store has been read, the w.l.p. has all the information necessary to decide the connection to be made. This involves processing, much of which can be accomplished by combinational logic and hence within the channel time of the multiplex. For this reason, called exchange-line connections can use scanning as for originating calls and as described in Section 6.2. The directory number of an exchange line or group of lines is decoded in the w.l.p. and the output is applied to all the line markers (l.m.), which produce marking pulses in group and channel order for all lines with that number as for originating calls. As each line is marked, its status (i.e. whether it is connectable) is determined, and, if it is, it is connected, all within the multiplex channel time, whereby the total amount of processing is drastically reduced.

The information-storage and handling capabilities of the wired-logic processor, together with the ability to write information into the register, is sufficient to satisfy all the requirements for all facilities up to the establishment of connections and after the establishment of connections where they can be inferred from the primary information.

Other equipments, for example s.s.e. and e.s., have access to the wired-logic processor via the waiting list as described, for line-equipment identification (Section 8) and some other purposes.

12.2 Stored-program-logic processor

The part played by a stored-program-logic processor (s.p.l.p.) in the operation of an exchange depends on a number of factors, but chiefly on the size of the exchange. A large exchange will have its own duplicated processors. The distributed stores and processors in the exchange-line blocks will remain but will be limited to basic information and operations universal to all lines. Nonuniversal information will be stored and operations will be controlled by the s.p.l.p., including routing and charging, except for local calls and calls to neighbouring exchanges. Data-link signalling would be the preferred method between exchanges. Small exchanges will not contain an s.p.l.p., but will be as self-contained as possible. They will have access through a data link to an s.p.l.p to obtain stored information and instructions which they themselves are unable to accommodate. The amount of information required by a small exchange, for example for routing and charge determining, is small and is easily handled by wired logic, and the possibilities of rerouting or other administrative action in the event of faults and other emergencies are almost negligible. Order-wire signalling to other exchanges avoids the need for an s.p.l. processor. Hence, to a small exchange, the value of an s.p.l.p. is mainly as a central store of information concerning changes to its own line-information stores.

The processing of calls using registers starts with the wired-logic processor as already described, and, in a proportion of cases, it is completed without recourse to the s.p.l.p. The proportion varies from perhaps 99% in small exchanges to 50% in large exchanges. If the w.l.p. cannot complete the processing, it accesses the s.p.l.p. and communicates the directory-number digits which it has received, with class of service and any other relevant information, and receives in reply some information or instruction by which it can further the call. If the reply is received quickly enough for the w.l.p. to finish processing in that processing period, it proceeds to do so. If not, the identity of the register involved is stored in the s.p.l.p., and the register is informed to wait for instructions. When the required information is available from the s.p.l.p., the register is given the information during one of its test periods or is caused to be connected again to the w.l.p. during an m_3 period and is given the information.

Calls which are received into the s.p.l.p over data links are set up by the s.p.l.p. by communicating information to the w.l.p. in a manner similar to a register, with subsequent control via the common signal equipment (c.s.e.) (Pt. 1, Fig. 1).

As an example of the use of the s.p.l.p., an originating call when it comes to be set up may be found to have the state of line that all calls should be referred to the central store (s.p.l.p.). On doing so, maybe it is recorded that the line is under observation and all calls must be routed via observation equipment, which the w.l.p. proceeds to do.

13 Administrative operations

Some administrative operations comprise setting up connections using the normal exchange facilities; these present no difficulties. Others have already been described. They comprise gaining access to some special equipment, s.s.e. or t.t.o.c. or other, supplying information to the equipment, which performs some specified task and returns the result. Some other operations depend upon it having been written into the state-of-line store that reference should be made to the s.p.l.p. for instructions. By various means, all the requirements can be satisfied.

14 Maintenance and fault detection

Maintenance comprises three activities, first to detect that a fault exists, second to localise the fault and third to clear the fault.

Much of the fault detection is the result of checks made during the normal processing that conditions are as they should be. The signals provided by the block equipments as calls are processed enable the unique common processor to monitor the progress of calls and detect abnormal conditions. Continuity tests and the receipt of signals in the right sequences, proceed-to-send signals for example, all contribute to the general knowledge of the equipment operation. Operational checks are supplemented by routine tests made by the s.p.l.p as a low-level activity. Faults not detected by these means are finally reported by the customers, exchange-line disconnections for example.

Knowing that a fault exists and some information about it, usually a diagnostic program in the s.p.l.p. is invoked to isolate the fault to a particular plug-in card; otherwise, as a last resource, a man with a cathode-ray oscilloscope or other general test gear has to be involved. The clearance of faults is normally limited to plugging in a spare card, and the faulty card being sent to a specialist repair centre.

The important points are that, for the electronic system, fault detection and clearance are not more difficult than for any other system; the maintenance cost is low because of the low fault rate; and the system is very fault-tolerant by virtue of the distributed controls and the general simplicity of the system of operation, and also because much of the control system is not necessary to basic service which is usually available even though there may be faults on the system.

15 Conclusions

National telephone networks develop naturally under economic forces into exchanges of a wide range of sizes and traffic characteristics, with junctions of greatly varying proportions of analogue and digital transmission circuits. Growth is continuous and requires the continuous installation of new plant, which must admit of change of technology and of services offered, always at a rate of investment which is commensurate with the rate of network growth. For two decades, technical innovation has been at a high level and has been pressing in the direction of a change of exchange technology from electromechanical to electronic, but without conspicuous success because of the economic limitations. The system described in Pts. 1 and 2 of this paper is believed to be a solution to both the technical and the economic problems.

It is not possible within the compass of two papers to describe all the features of a complete new system, nor is it suggested that the system described is the only solution to the problem. Its importance is in illustrating the general principles involved, the chief of which is that a telephone system comprises two sections, structure and control, which separately and together must be competitive with existing systems. The competitiveness of a system is enhanced by compatibility between the structure and the control, in the case of the system described, by both being based on synchronous t.d.m. operation.

The competitiveness of electronic switches in the structure is increased by their transmission[3] properties, which include amplification. In the control section, it is recognised that satisfactory solutions must be found between wholly wired-logic and wholly stored-program logic control, neither of which is able by itself to satisfy both the performance and the economic requirements, and that the bias due to the need for interworking with existing systems and extending existing systems, together with that due to integrated-circuit technology, is in the direction of minimising the amount of stored-program logic. The advantages, mainly flexibility, of stored-program logic apply at any one time to only a small part of the operation of an exchange, which enables the stored-program logic control to be minimised without significant loss of advantage.

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