Controller for a Remote Line Concentrator in a Time-Separation Switching Experiment

By W. A. MALTHANER and J. P. RUNYON

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Remote line concentration, time-separation switching and PCM transmission are combined in a communication system experiment called ESSEX (Experimental Solid State Exchange). Organization and design details of the concentrator controller used in the research model are presented and discussed.

I. INTRODUCTION

An earlier paper[1] has described the general organization of an experiment in time-separation switching. Two principal functional parts were incorporated into this experiment: a line concentrator, which might be remote from a central switching office, and a concentrator controller, which would be located within the central office. In this paper we will describe in greater detail the organization and design of the concentrator controller. A companion paper[2] presents details of the remote line concentrator. In both papers it will be assumed that the reader is generally familiar with Ref. 1.

The experimental equipment provides 24 time-division channels between the remote concentrator and the controller. Since the controller would be located at a central switching point, it would be more accessible for maintenance than the concentrator; therefore, whenever there was a choice between locating equipment in the concentrator or in the controller, the controller was chosen.

Of the 24 time-division channels, which will be referred to as *time slots*, the first 23, numbered 0 through 22, are used for pulse-code-modulated speech. Time slot 23 is reserved for scanning and control functions, which will be described in the body of this paper. Each time slot recurs at an 8-kc rate, and each contains eight binary digits; the first seven are pulse-code-modulated speech, and the eighth is reserved for control purposes. One cycle of time slots, 0 through 23, will be referred to as a *frame*. There are 8000 frames per second, 192,000 time slots per second, and 1.536×10^6 binary digits per second per repeatered transmission pair.

Each concentrator controller is interposed between its remote concentrator, the central-stage switch and a common control circuit that would serve a number of concentrators and trunkors.[1] The controller stores and delivers to the concentrator the information needed to control the gating of speech samples, delivers to the central-stage switch the information needed to gate PCM speech signals over the appropriate routes and maintains supervision of the subscribers' lines, which terminate in the concentrator. In performing this last duty, it scans each line every one-eighth second, and, upon two successive appearances of an "off-hook" signal from an idle line or an "on-hook" signal from a busy line, the controller sends an alerting signal to the common control. In the experimental arrangement, the common control is simulated by a manually operated console; hence, we will describe the steps taken in setting up and taking down connections in terms of the actions of an operator at the console.

II. SIGNALS TO AND FROM THE CONTROLLER

The environment of the controller is shown in Fig. 1. The concentrator and the switching center are connected by three repeatered pairs, one (shown as S), transmitting speech and line scan results toward the center, one (shown as R) transmitting speech and framing signals toward the concentrator and the third (shown as C) transmitting, toward the concentrator, control information identifying in real time the subscriber line that should next be sampled. The concentrator control also delivers, in real time, signals for the control of the gates in the central stage switch (see Section VII). The experiment employs a two-stage central switching network with a contemplated capacity of about 32 concentrators plus trunkors, whose S and R leads are interconnected by 32 junctors. In this case, five binary digits suffice to identify a junctor. Hence, the controller must deliver a five-binary-digit junctor gate number (JGN) per time slot to the network and an eight-binary-digit line gate number (LGN) per time slot to the C lead.

The gate numbers that are dispatched over lead C and toward the network are stored in the controller in circulating memories (see Section V). When a telephone connection is made or broken, gate numbers must be read into or erased from these memories. This information is not generated within the controller, but must be supplied from the manual control. Communication between the manual control and the concentrator control is provided by means of insert and dispatch circuits (see Sections VIII and IX).

The scanning of subscriber lines in the remote concentrator is carried out by the concentrator control with the assistance of an external scan number generator (see Section IV), which delivers subscriber line numbers to each concentrator controller. These line numbers are delivered serially, in cyclic order, and synchronously with the line numbers dispatched over the c lead. Each number is repeated once per time slot for four entire frames before the number generator advances to the next number. The signal delivered to the controller by the scan number generator is called the scan gate number (SGN).

Since there are eight bits per word, there are $2^8 = 256$ SGN numbers to be generated and, since the number generator advances every fourth frame, there is an interval of approximately one-eighth second between the periods during which a particular number is generated.

The use of a four-frame cycle for the scanning of a single line number

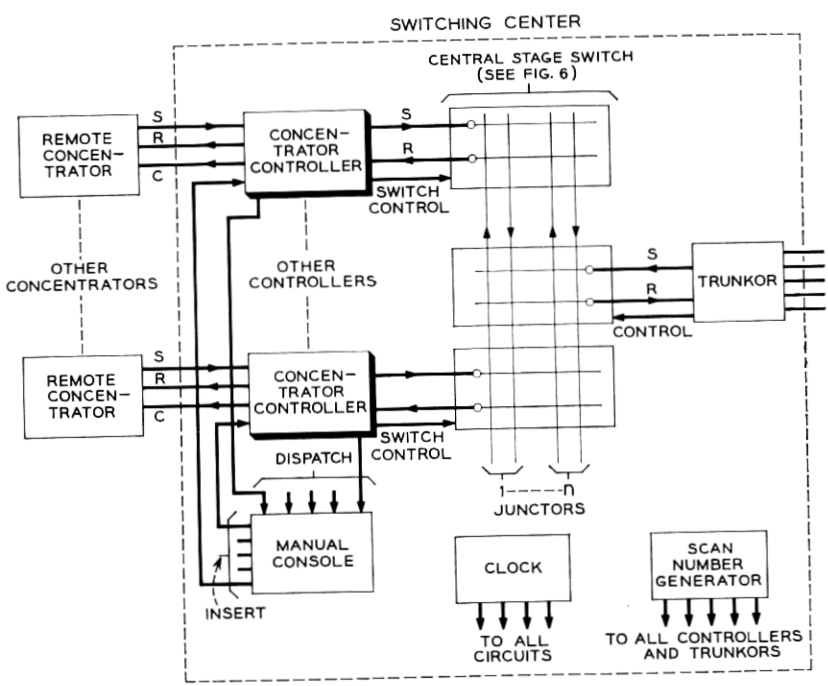

Fig. 1 — The environment of the controller.

gives rise to a natural numbering of frames when scanning is discussed. The scan number generator advances from one number to the next at the beginning of frame 0; delivers the same number throughout frames 0, 1, 2 and 3; and advances to the next number at the end of frame 3, which coincides with the beginning of frame 0 for the next scanning cycle.

We have now mentioned every category of signals that goes to or from the concentrator controller except one. The signals in this final category are timing signals that derive from a clock, used in common by all units at the switching center, which consists of a stable oscillator and attendant pulse counters (see Section XIII).

A list of the distinct signals that flow to or from the concentrator controller is given in Table I.

III. CALL PROGRESS WORDS

The signals listed in Table I describe the performance of the controller as seen from its terminals. The general arrangement of equipment that was chosen to meet these requirements is shown in Fig. 2. (Fig. 2 is a reproduction of Fig. 6 of Ref. 1.)

Digital operations within the controller are governed by the call progress memory, the call progress coder-decoder and the line scanning control. An understanding of the plan of operation of the controller is most easily obtained by considering the sequencing of call progress words in the call progress memory.

A *call progress word*[3] is a record of the state of a call to which a time slot has been assigned. The *call progress memory* is a circulating memory with a capacity of 192 binary digits, eight for each of the 24 time slots. In these locations are stored call progress words for the corresponding time slots.

Sequences of states through which a given call can progress, as reflected by the corresponding sequences of call progress words, are shown in Fig. 3. The call progress words themselves are indicated by the rectangular boxes of Fig. 3, the various admissible transitions from one call progress word to the next being indicated by the labeled arrows. Transitions that take place without the intervention of the operator are indicated by circles, and those that are caused by operator action by diamonds. Each automatic transition bears also a label made up of some or all of the letters H, M and D, with or without primes. These letter labels indicate, in a Boolean notation, the circumstances in which the transition occurs. The letter symbols stand for the following propositions:

H: "the scanner indicates off-hook";
M: "the SGN matches the LGN";
D: "the dispatch circuit is not occupied".

A prime indicates the negation of the proposition. Thus, the transfer from word P11 to P17, which is labeled $H'MD$, occurs when the scanner does not indicate off-hook, the SGN matches the LGN and the dispatch circuit is free.

Whenever the line scanner returns an "off-hook" indication for a hitherto idle line, the number of the line is entered in the line gate number memory in the first idle time slot encountered. This time slot is identified as idle by the appearance of P1 as its call progress word. At the time of entry of the line gate number, the call progress word is advanced to P2 ("suspect request for service"). No further action is taken until one-eighth second later, when the scan number generator next arrives at this line number. If a second "off-hook" is seen for this line at this time, the call progress word is advanced to P3, provided that the

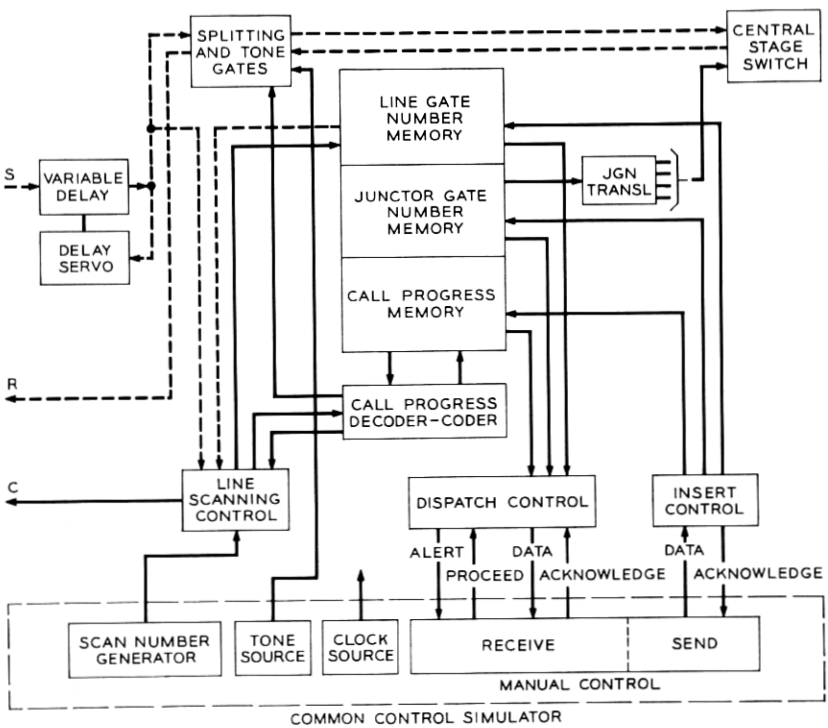

Fig. 2 — ESSEX concentrator controller.

TABLE I — SIGNALS THAT ENTER OR LEAVE THE CONCENTRATOR CONTROLLER

From or to	Name of signal	Sent via (See Fig. 3)	Time when sent or received by controller	Purpose
A. To concentrator	1. Line gate number (LGN)	C lead	Bits 0 through 7 of time slots 0 through 22 in every frame	Orders operation of line gate, thereby sampling
	2. Scan gate number (SGN)	C lead	Bits 0 through 7 of time slot 23 in frame 0	Scans idle lines to determine whether they are "off-hook"*
	3. PCM speech or tone	R lead	Bits 0 through 6 of time slots 0 through 22 in every frame	Delivers speech or tone signal to decoder
	4. Scan command	R lead	Bit 7 of time slots 0 through 22 in frame 0	Adds scan order to signal A1*
	5. Framing command	R lead	Bits 0 through 7 of time slot 23 in every frame	Orders reset of counters in slave clock
B. From concentrator	1. PCM speech	S lead	Bits 0 through 6 of time slots 0 through 22 in every frame	Transmits speech signal from encoder
	2. Scan result	S lead	Bit 7 of time slot 22 in frame 1 or 2	Indicates whether line scanned (A2 or A4) was "off-hook"
C. To central stage switch	1. PCM speech or tone	S lead	As in A3	Transmits speech or tone signal to other end of connection
	2. Junctor gate number (JGN)	Five parallel leads shown in Fig. 2	Bit 7 of time slots 23 through 21	Operates proper network gates for call in next-following time slot
D. To manual console	1. Request-for-service alert	Dispatch circuit	When dispatch circuit is free and two successive scans of an idle line have shown it to be "off-hook"	Informs operator that request for service has been detected and indicates time slot tentatively assigned the calling line

	2. Readout of controller memory data†	Dispatch circuit	After E1, memory contents in chosen time slot is read to manual console once per frame until receipt of E3	Informs operator of contents of controller memory in time slot interrogated
	3. Hang-up alert	Dispatch circuit	When dispatch circuit is free and two successive scans of a busy line have shown it to be "on-hook"	Informs operator that a hangup has occurred and indicates its time slot
	4. Acknowledge	Dispatch circuit	Response to E2	Informs operator that insert data was received with correct parity
E. From manual console	1. Proceed	Insert circuit	Under control of operator	Evokes D2; normally a response to D1 or D3
	2. Insert	Insert circuit	Time slot selected by operator	Permits operator to alter contents of controller memory
	3. Acknowledge	Insert circuit	Response to D2	Indicates D2 received with correct parity
F. Timing signals received regularly from clock and numbers for scan received regularly from scan number generator (see Sections IV and XIII).				

* Either A2 or A4 is used, not both (see Section IV).
† One time slot may be read out per interrogation; this signal is a response to E1.

dispatch circuit is free. Advance of the call progress word to P3 initiates signal D1 of Table I, informing the manual console of line action. Had the dispatch circuit not been free when the second "off-hook" was seen, the call progress word would have remained P2 until either the calling subscriber returned the telephone to its hook, (in which case the word would be restored to P1), or the dispatch circuit became free, (in which case the word would be advanced to P3).

Advance from P3 to P4 takes place as follows: entry to P3 causes the signal D1 (Table I) to be sent to the manual console, informing the operator that a request for service exists, and indicating the time slot in which this request is being handled. In response, the operator returns signal E1, requesting transmission of the memory content in the indicated time slot. Response D2 automatically follows the receipt of E1, and, if the information dispatched by D2 is received with correct parity at the console, acknowledgment E3 is automatically returned to the controller. The receipt of E3 advances the call progress word from P3 to P4. This frees the dispatch circuit and, if another time slot is at P2, it may now advance to P3.

When the call has reached P4, the operator knows the identity of the calling line and the time slot that has been tentatively assigned to it. The operator now must consult her records to see what sort of service this line receives. Let us suppose the operator discovers that the line is to be connected to an operator trunk.* By means which need not concern us here, the operator must locate an idle operator trunk and match a path through the network between the trunkor in which the operator trunk is located and the concentrator controller, in a time slot in which both trunkor and controller are idle. For this purpose, the operator may consider the tentatively chosen time slot in which P4 is stored be idle, but the operator may find it impossible to match through the network in that time slot. Let us suppose that a match is finally found that uses a different time slot.

As soon as it has been determined that a new time slot is to be used, the new slot should be reserved immediately in the controller memory by advancing its call progress word from P1 to P26, in order to prevent its seizure by suspected requests for service in the interim between matching and the inserting of line gate and junctor gate data from the console. In a practical system, the matching would be done by an automatic circuit, not described in this paper, which would cause the transfer from P1 to P26 by means of a signal that is not listed in Table I.

* In most cases, the line should be connected to a dial register. There is no point in detailing here the process of accumulating the called number and passing it to common control or to the console operator, which this introduces.

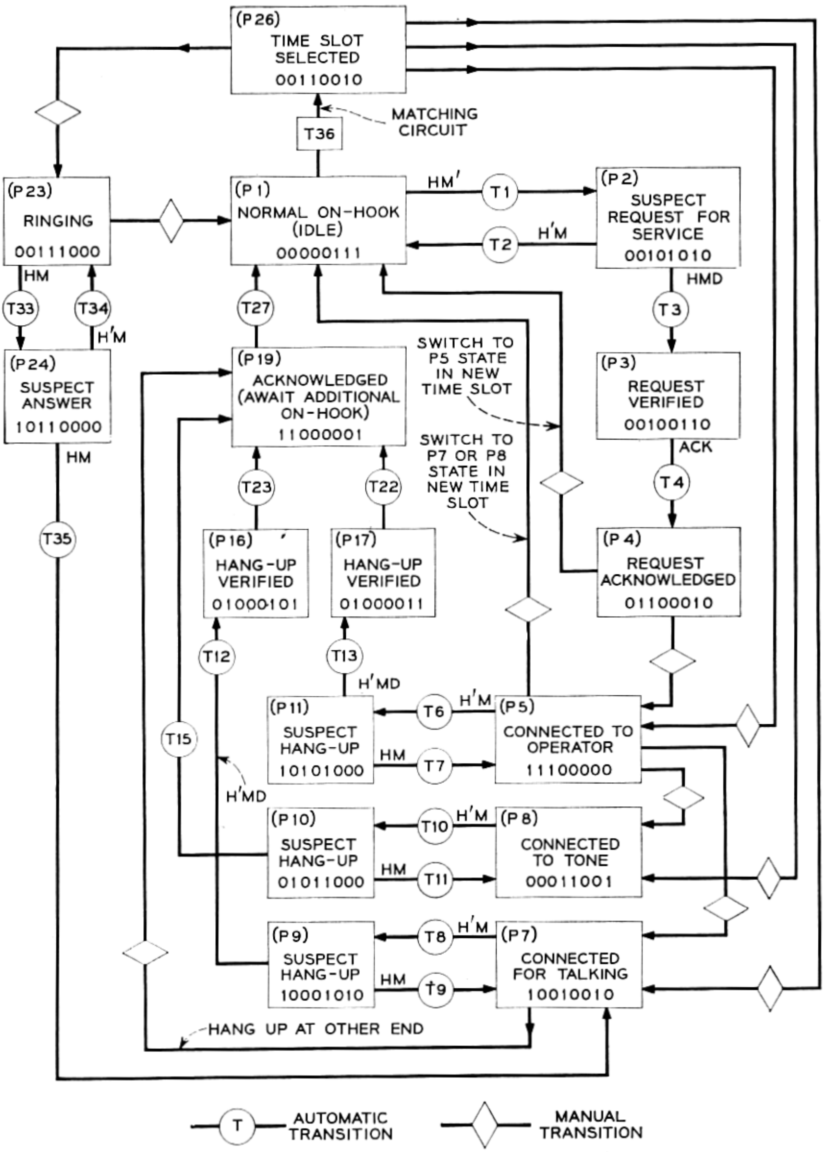

Fig. 3 — Call progress word state diagram.

To set up the connection, the operator first uses E2 to insert the line gate number, call progress word P5 and the junctor gate number yielded by the matching operation into the controller memory in the new time slot. This transmission is automatically checked for correct parity at the controller, and E4 acknowledges correct receipt (transition from P26 to P5). Signal E2 must then be used a second time to erase the information in the old time slot and restore its call progress word from P4 to P1.

From P3 and P4 there are no transitions that depend on the line scan information. If the calling subscriber should hang up while in P3 or P4, this fact would not be signaled to the operator until P5 was entered. This "filtering" of the scanner indications reduces the number of special sequences of events with which the common control must cope.

Once P5 has been reached, and the operator has made suitable entries in the trunkor memories to establish the other end of the connection, the subscriber is in voice communication with the operator. He may now indicate the number that he wishes to call. The operator now locates the concentrator in which the called line terminates and performs a busy test by means of 23 D2 interrogations, to determine whether the called line gate number appears in any one of the 23 working time slots of the terminating concentrator controller. If the called line is not thus found to be busy, the operator matches a path through the network in a time slot in which the two concentrator controllers are idle. Here again, the operator may consider the time slot in which she is connected to the calling subscriber to be idle; however, if the called concentrator is busy in this time slot, a new time slot may be chosen. If this is the case, the call progress word should be promptly advanced in both the originating and terminating controllers from P1 to P26 in the new time slot. The operator now inserts the line gate number and junctor gate number information in the chosen time slot in both controllers, inserting call progress word P7 in the originating controller and P23 in the terminating controller. Call progress word P23 causes operation of the splitting and tone gates (Fig. 3) in the terminating controller. These gates interrupt the S and R leads of the terminating concentrator in the chosen time slot and send a pulse-coded ringing signal on the R lead and a pulse-coded audible ringing tone on the S lead, which returns this tone through the network to the originating concentrator. If the called line is answered, the first "off-hook" signal from the scanning of that line causes transition from P23 to P24. In P24, the ringing signals continue. A second "off-hook" signal from the called line, one-eighth second later, causes advance of the call progress word to P7, which effects restoration of the splitting gates to the normal condition, removing the ringing tone and establishing a talking connection.

If the called line is located in the same concentrator as the calling line, the equipment is so arranged that two time slots are required for the conversation. Both calling and called subscribers must be connected through the network, in different time slots, to the same "unterminated" terminal of a trunkor. Here both sets of PCM signals are decoded to analog samples that are stored in and read from a capacitor. This capacitor replaces the customary line filter and permits interchange of the samples between the two time slots. This arrangement, although exceedingly simple, is wasteful of transmission capacity. In a working system where such "intraconcentrator" calls occurred frequently, changes would be made to permit such calls to be handled in a single time slot.

If the called line is not answered, the terminating concentrator will remain at state P23 and the originating concentrator will remain at state P7 until the calling subscriber tires of waiting and hangs up. The first "on-hook" scan result for the calling line will cause an advance to P9, and the second will cause an advance to P16, provided that the dispatch circuit is not occupied. Entry to P16 will initiate a "hang-up alert" signaling sequence between the controller and operator console, which corresponds exactly to the "request-for-service alert" sequence between P3 and P4. When the controller finally receives a "parity correct" acknowledgment from the console, the call progress word advances from P16 to P19. This causes immediate erasure of the JGN entry in the controller memory, and will cause erasure of the LGN entry and transition to P1 as soon as an additional "on-hook" signal has resulted from scanning the calling line.

The operator still must disconnect the line being rung. To do this, she consults the information sent to her during the signaling sequence between P16 and P19. She knows the time slot in which the hang-up occurred and the number of the junctor in use for the call. The operator now must locate the controller or trunkor whose memory stores the same junctor number in the same time slot. To do this, she may, for example, interrogate in turn the memory of each controller or trunkor, in the time slot in question, until she finds the location at which the sought-for junctor number is stored. The operator now erases the memory contents at the point she has just located, and restores the call progress word from P23 to P1, thus ending the ringing of the called line.

This typical history of the progress of a call is intended to acquaint the reader with the general scheme of operation of the controller, as

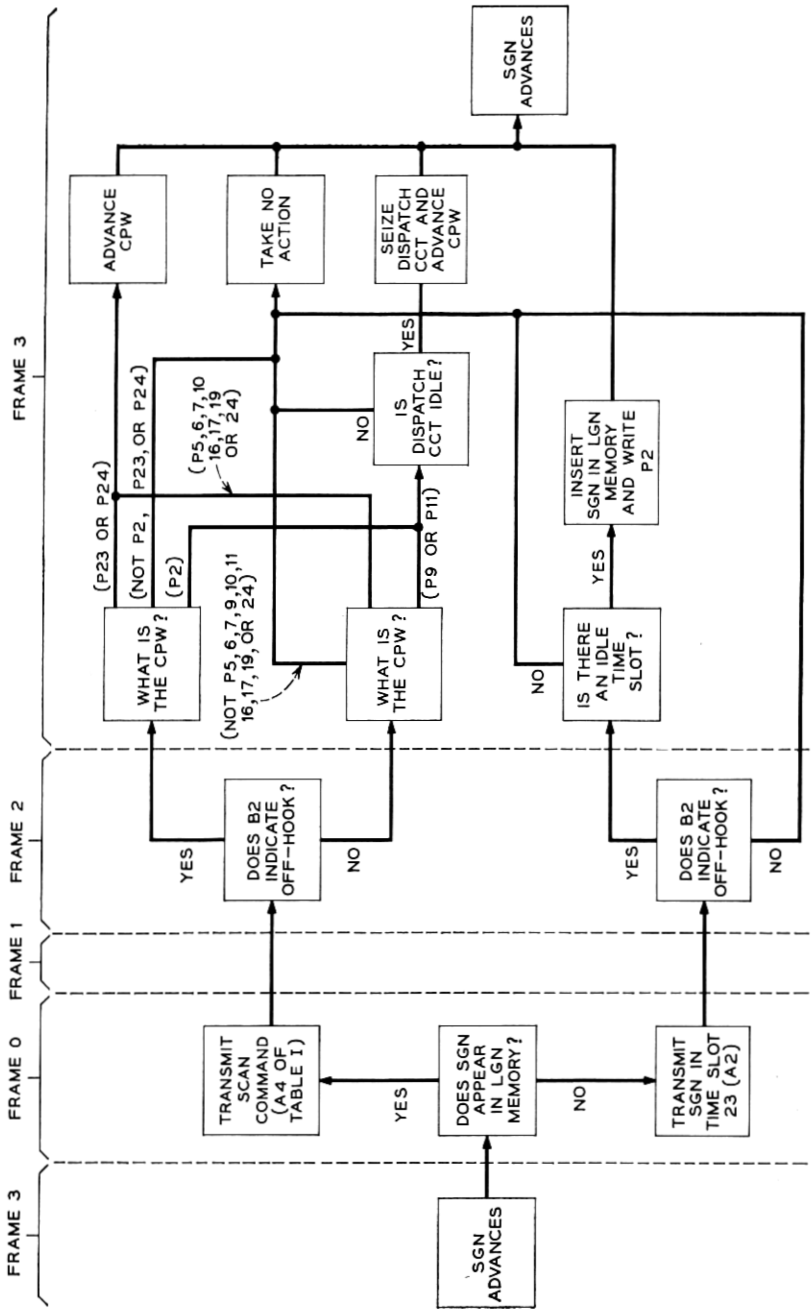

Fig. 4 — Sequence diagram of events and decisions in line scanning.

reflected in the sequence scheme of the call progress words and the manner in which they control the sequence of events in the system. From this description, a call progress word may be seen to be a sort of conditional "order," indicating the next operation that is to be performed as soon as the appropriate conditions have been established, rather than at some predetermined point in time.

We will leave to the reader the exercise of tracing out the call progress word sequences corresponding to other possible sequences of subscriber action, and will proceed to describe the circuits that have been provided in the experimental equipment.

IV. LINE SCANNING AND SUPERVISION

"Off-hook" and "on-hook" conditions at customer lines are detected by scanning sequentially all the lines at a remote concentrator. For each "off-hook" condition detected, a signal is transmitted to the concentrator central unit.

The scan number generator consists of an eight-bit shift register, called the SGN register, which is connected to recirculate its contents through an "add one" circuit. The number circulates through the SGN register every time slot (5.2 microseconds) and is available to the controllers for scanning and matching purposes. Each number circulates through the register without change 96 times, i.e., once each word time during four frames. After four frames, the "add one" circuit is enabled and the next higher binary number is entered into the SGN register. This four-frame scanning cycle allots one frame to a preliminary match of the scan gate number with the various line gate numbers in the concentrator memory, since the actions to be taken depend upon whether or not the line to be scanned was in an active state on the preceding scan. The round trip of the scan number from the concentrator controller to the concentrator and the return of the scan result may take one or two frames of the scanning cycle. The final frame is used for entering the line number into an idle time slot of the controller memory or for making any required alteration of the memory state if the line number was entered previously. Fig. 4 exhibits the various sequences of events encountered in line scanning.

The line scanning control circuit operates as follows. During frame 0 of the scanning cycle, the scan number is serially matched against the line numbers stored in time slots 0 through 22 in the controller memory. If no match is found, the line is idle and the scan number is transmitted on the C lead in the last time slot of this frame (time slot 23) to the concentrator (signal A2 of Table I). If the line is still on-hook, signal B2 is returned to the controller by the absence of a pulse, but if the line is "off-hook" B2 returns as a single pulse.

The "not-in-memory" and "off-hook" conditions are registered in flip-flops. Let us assume that B2 indicates "off-hook". During frame 3, the first idle time slot in the controller memory, as indicated by the call progress word memory, is assigned to the scanned line. The scanned number is gated from the scan number generator into the line gate number memory in this time slot and the call progress word is changed to indicate that an initial "off-hook" has been detected.

If the leakage of the remote line gates is not sufficiently low and an active line is gated to the scanner in time slot 23, and gated for speech in its assigned time slot, scanning noise in the form of "ticks of silence" may be introduced into the conversation. To prevent this, an active line is scanned in its assigned time slot.

If, during frame 0, the scan generator number is found to correspond to one of the line numbers in the controller memory, a "one" pulse (signal A4 of Table 1) is transmitted on the R lead in the eighth-bit position. To avoid interference with the framing operations (see Section XIV) at the concentrator the seventh, and least significant, speech bit in this and the next time slot are transmitted as "zero". The scan generator number in this case is not transmitted on the C lead in time slot 23. The presence of a pulse at bit 7 on the R lead causes the concentrator to scan the line in its assigned time slot. The signal indicating "off-hook", however, is still returned to the controller as bit 7 of time slot 22 of frame 3. During frame 3, the matching operation between the scan number and the line numbers in memory is repeated to identify the assigned time slot. The scan result is then gated into the call progress decoder-coder to alter as necessary the state of the scanned time slot.

By these processes, a line originating a call is identified, assigned to an available time slot and permitted, upon verification of the "off-hook", to alert the common control circuits of the office. In the same way, the answer of a called line is detected and the advance of the call from the ringing to the talking state is initiated. Similarly, the hang-up of a line at any time is detected, initiating the necessary disconnect operations, which may or may not require common control actions.

V. MEMORY STRUCTURE

The memory in each concentrator controller stores control orders for the remote and central switches. It also holds a record of the current status of each time slot. For each of the 24 time slots or channels, 24 bits of information are stored: eight bits for the remote line gate, five bits for the central stage switch, eight bits for the call progress words and three bits for checking. Three recirculating serial memory units are used in each controller. Each concentrator memory circulates 192 bits—that is, eight bits for each of 24 channels.

Binary-coded pulses are transmitted through a magnetostrictive delay line that holds 177 of the memory loop bits. This line is a 3-mil supermendur wire with a solenoid around one end as an input transducer and a similar solenoid at the other end as an output transducer. Binary-coded electrical impulses are impressed magnetostrictively on the line at the input transducer and travel along the line in acoustic form. The magnetostrictive effect is used at the output solenoid to convert back to electrical impulses; thus, an electrical delay and information store is produced that is dependent upon the distance between the delay line transducers (see Fig. 12 of Ref. 1.)

The output of the delay line connects to the first stage of a shift register, and the last stage of the shift register feeds pulses back into the magnetostrictive line to complete the loop. A diagram of one of these circulating loops is shown in Fig. 5. Information appears in the central stages of the shift register during the particular time slot with which it is associated, recurring, of course, every 125 microseconds. The infor-

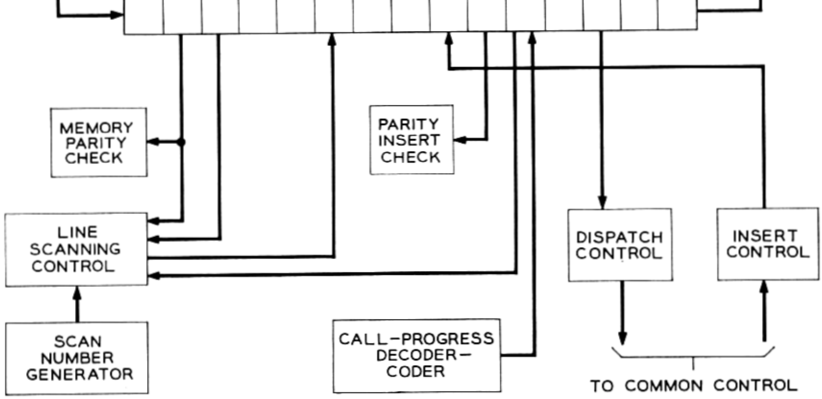

Fig. 5 — Line gate number memory unit.

mation may be examined and transmitted to external circuits in either serial or parallel form from the shift register. New information can be entered into the memory in serial or parallel form at the shift register at the half-bit time. A relative time shift in the information, causing it to lead or lag the occurrence of the master clock time slot with which it is associated, may be introduced during the design of any system function by operation at selected earlier or later stages of the shift register. This permits time coordination through the system without the use of auxiliary delay buffers or time-counting circuits.

In the model, line gate words are inserted serially from the line scanning circuit or common control and are transmitted serially to the line-scanning circuit, to the remote concentrator via the c lead and to common control. The junctor gate words are transmitted in parallel to the central stage switch selectors, transmitted serially to common control and inserted serially from common control. Call progress words are transmitted to and entered from common control serially, examined in parallel and altered in parallel by the call progress decoder-coder, as will be described in Section VI.

VI. MANIPULATION OF CALL PROGRESS WORDS

The call progress words are coded so that each word contains exactly three ones. There are 56 such words, but only about 30 of them are required in the model.

As each call progress word passes through the shift register of the memory loop, its eight bits are examined in parallel by a decoder-coder circuit, which consists principally of a diode matrix. The decoder energizes a single lead to indicate the state of the time slot, and actions such as the operation of ringing gates may result directly. Additional inputs from the line scan, dispatch or insert control circuits combine with certain indicated call progress states in the coder to produce a new call progress word. The word in the memory loop is immediately altered by parallel inputs to the shift register from the coder. The speed of the decoder-coder circuits is sufficiently fast that buffer storage between the shift register and the decoder is not required, and the word in the register can be altered by the coder before the occurrence of the next advance pulse. Certain control actions, such as the seizure of the dispatch control circuit, occur simultaneously with a coder alteration of the call progress word.

Call progress words are also examined serially for operations such as idle-time-slot selection during initial assignment of an originating call to a time slot, and for the path-matching operations of common control.

Call progress words may also be altered by serial transmission from common control via the insert control circuit to one of the later stages of the memory shift register.

VII. CENTRAL STAGE SWITCH

Each concentrator (or trunkor) connects to an associated section of central stage switching. The S and R leads of a concentrator are multipled to 32 concentrator-to-junctor gates, and the junctor outputs are multipled to the corresponding junctor outputs of all other concentrators (and trunkors) as shown in Fig. 6. Thus, each concentrator has access to the other concentrators and trunkors, and to junctors to other office modules[1] over a total of 32 space-separated paths in any of 23 time slots. For intramodule calls, the junctors are grouped in pairs. In a call between two concentrators the S lead of the first concentrator and the R lead of the second are connected to one junctor of the pair, while the R lead of the first concentrator and the S lead of the second are connected to the other junctor of the pair. The same time slot must be used in both concentrators.

The junctor gates are simple diode-and-transistor gates that pass binary signals unilaterally at low power. A five-bit transistor flip-flop register acts as a buffer between the circulating junctor gate memory of a concentrator and its junctor gate selector. The junctor gate selector is a two-stage diode AND matrix. Two of the input bits provide a one-out-of-four partial selection in one first stage, and the other three input bits provide a one-out-of-eight partial selection in a separate first stage. The one-out-of-four and one-out-of-eight partial selections are combined in the second selection stage to operate one of the 32 junctor gates, and the coded speech signals in both directions of a conversation pass each other simultaneously on the junctors.

VIII. DISPATCH CONTROL AND MANUAL CONSOLE

Each concentrator controller contains a dispatch control circuit through which it sends orders and data to common control. This communication is necessary at various stages in the progress of a call, such as on the detection of a request for service, answer, or hang-up condition at a customer's line. Common control correlates the information from the particular concentrator with information as to the rest of the office, and advances the call as required. In the experimental model, the dispatch circuit connects to the receiving circuit of a manual console. Information is displayed at the console to an operator who, with the

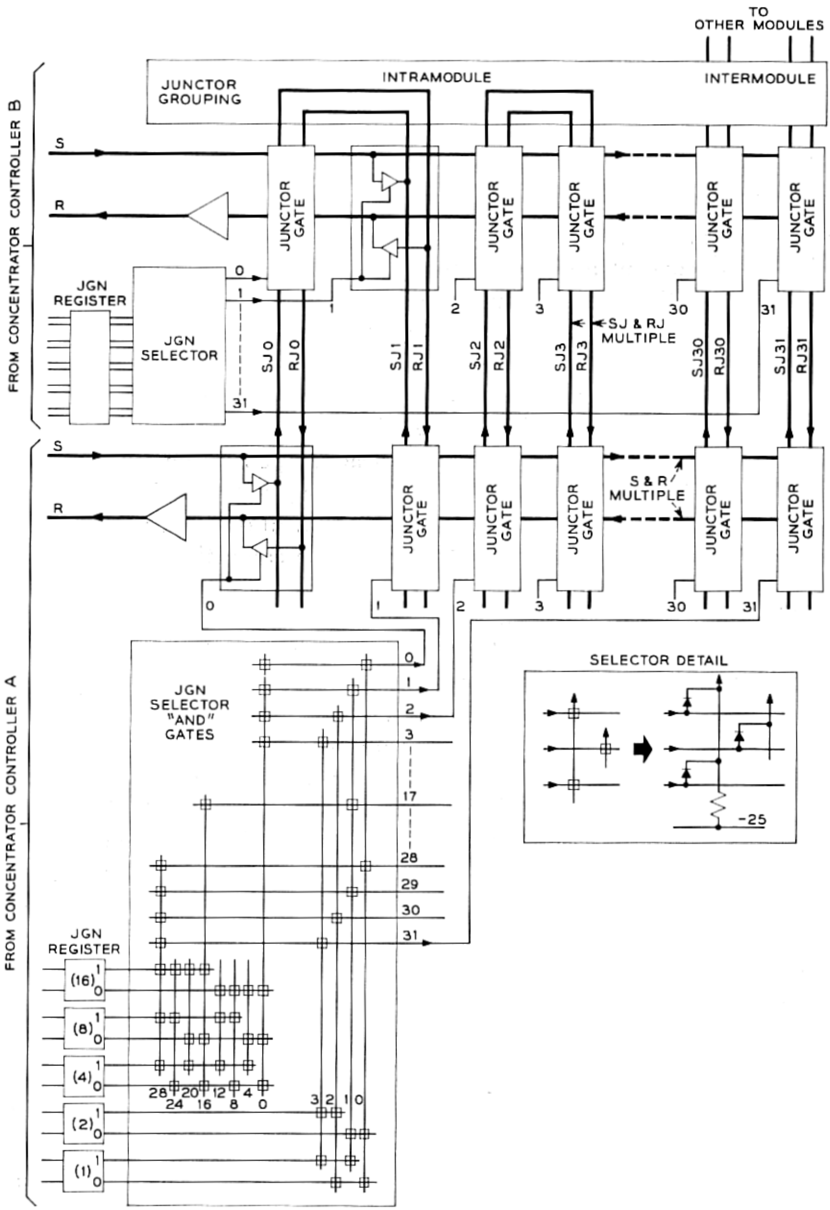

Fig. 6 — Central stage switch and selector.

assistance of manual aids to memory, makes the decisions and initiates the actions that would be performed automatically by common control in a fully developed system.

Functional relationships between the concentrator controller, its dispatch circuit and the receiving circuit of the manual console are outlined in Fig. 7. When the call progress word in a concentrator controller reaches a transition into a state that requires the use of the logic and memory functions of common control, the transition is made only if the dispatcher is idle, and the dispatcher is seized on the transition. This provides lockout between the various time slots of a concentrator in their access to the dispatcher. Lockout is required since the dispatcher may be used from any time slot and is held for a few frames on each usage. An alert register in the dispatch control is set from the call progress word decoder-coder upon seizure. The setting is identical to some of the bits in the new call progress word that the decoder-coder simultaneously writes in the associated time slot memory. An alert indicator in the console informs the operator that the particular concentrator requires attention and gives information as to the priority of the action required. The dispatch control on all subsequent frames indicates which time slot is in the dispatch state by means of a serial match between the alert register setting and the pertinent bits of each word in the call progress memory loop.

The console operator elects to serve the concentrator with the highest priority alert indication by setting the C/T selector switch to the corresponding position. To identify the alerting time slot, the setting of the console time-slot selector switch is varied until its output pulses coincide with pulses from the serial match detector. Readout keys enable the receiving sequence circuit, which in turn controls the dispatch sequence circuit, so that data from the alerting time slot of the concentrator memories are transmitted serially through dispatch data gates to data shift registers in the receiving circuit. The junctor gate number and line gate number information are read to the receiving registers consecutively in the frame following the operation of a readout key. If the order information in the alert indication is not sufficiently explicit, the complete call progress word may be transmitted, by operation of an alternate readout key, to a receiving shift register in the frame following the line and junctor number transmission. For maintenance purposes, provision has also been made for transmitting information from the memory loops to the data registers in nonalerting time slots by operation of special readout keys.

Each block of data transmitted to the receiving circuit is preceded

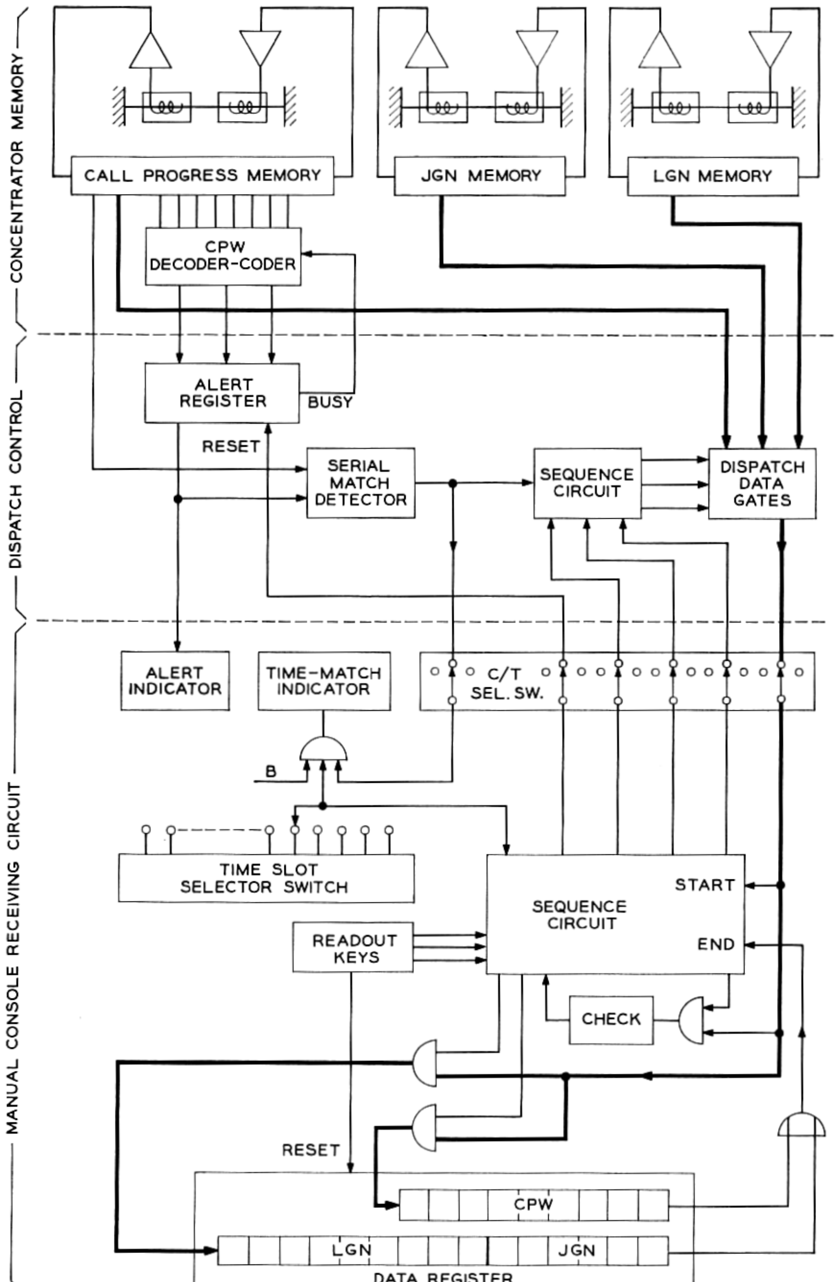

Fig. 7 — Diagram of dispatch control operations.

by a start bit. This causes the receiving sequence circuit to provide advance pulses to the receiving shift registers and enablement to an associated data-check circuit. The emergence of the start bit from the far end of a receiving shift register informs the sequence circuit that the block of data has been completely received. Advance pulses to the shift register are discontinued, the state of the check circuit is examined and the sequence circuit is primed for a second trial or its next function. The data registers are equipped with indicators for visual readout of the data to the operator, who resets them manually when the data are no longer needed.

IX. INSERT CONTROL AND MANUAL CONSOLE

Each concentrator controller contains an insert control circuit through which information from common control may be passed for storage in the controller memory. This communication is necessary at the various stages in the progress of a call in which common control actions for path selection, path tracing, billing, etc., are performed. In the experimental model, the logic and large-scale memory functions of common control were not implemented. Instead, a manual control console with visual display of current common control data was provided. An operator can select the concentrator or trunkor and the time slot into which information is to be inserted, preset the insert order and data items, and initiate the insert actions.

The relationship between the concentrator controller, its insert control circuit and the sending circuit of the console is outlined in Fig. 8. The operator selects the particular concentrator or trunkor memory to be altered by setting the C/T selector switch accordingly. The time slot selector switch also is set to the proper position, and the operator manually selects an insert order word, call progress word and, if necessary, line gate number and junctor gate number. Every insert operation includes at least an order word and a call progress word. The selected order and data words are registered in parallel in the data shift register stages by operation of a manual set key, which advances the sequence control circuit. The register setting is displayed to the operator for verification. Operation of a spill key enables the sequence circuit, so that advance pulses are applied to the data shift registers, and the send gates are operated in proper anticipation of the occurrence of the selected time slot at the concentrator memory input positions. A start bit in the order word, which precedes all other transmission, is detected by the sequence circuit of the insert control. The order word itself is then stored in an order word shift register under control of advance pulses from the sequence circuit. Arrival of the start bit at the far end of the order word register advances the sequence circuit, so that the data-in gates to the concentrator memory are opened as required and in the proper sequence. Data flow directly into the shift registers of the memory loop serially in real time, so that no buffer storage is re-

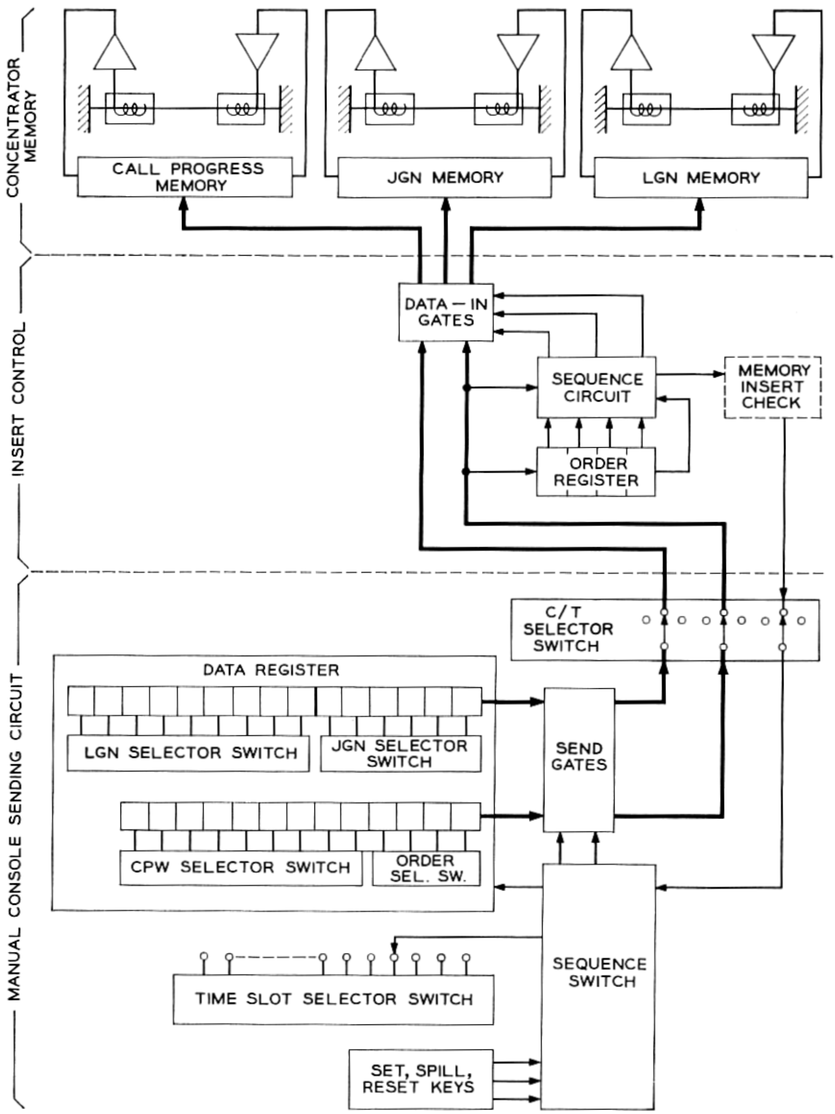

Fig. 8 — Diagram of insert control operations.

quired in the insert control. The sequence circuit in insert control also enables, in the proper time sequence, a memory-insert check circuit, which monitors the new data immediately after its insertion into the memory loop registers. Second trial and release signals are sent from this check circuit to the sending circuit of the console.

X. DELAY-STABILIZING SERVO

A delay pad is provided in the s lead, so that the round trip delay, from the switching center out to the remote concentrator and back to the switching center, is exactly equal to an integral multiple of 125 microseconds. This delay is required so that, for each conversation, the pulses representing speech in one direction may pass through the central stage switch at the same time as the pulses representing the other direction of the same conversation. The delay is provided by a magnetostrictive wire delay line of the same construction as the lines for the memory loops (Section V). The binary-coded electrical impulses of the s lead are impressed magnetostrictively on the line at the input transducer, and they travel along the line in acoustic form. The magnetostrictive effect is used at the output solenoid to convert back to electrical impulses; thus, an electrical delay is produced that is dependent upon the distance between the delay line transducers.

The delay can be set initially to the required value by manual positioning of the transducers. However, because the delay in transmission through cables varies with temperature, it is necessary to vary the delay of the pad in a compensating manner. This is done by a servo unit, shown in Fig. 9, that changes the physical position of the input solenoid.

Each information pulse from the delay line is transmitted to an integrating network through a "phase slicer" controlled by phase-timing pulses from the master clock. The portion of the information pulse that precedes the leading edge of the timing pulse drives the integrating network with one voltage polarity, and the portion of the information pulse that occurs after the leading edge of the timing pulse drives the integrating network with the opposite voltage polarity. An error voltage is developed unless the delay is such that the information pulses are centered about the leading edge of the timing pulses. If the error voltage exceeds a threshold value, a servo motor moves the input transducer along the delay line in the correcting direction. The reference phase-timing pulses are also used to regenerate the delay line output, so that standard-timed information is delivered to the central stage switch despite small variations in the delay line setting.

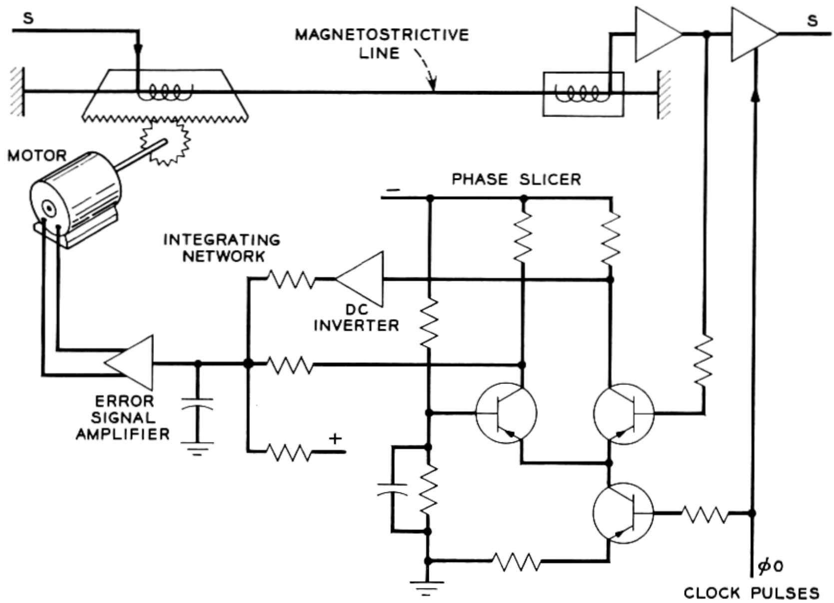

Fig. 9 — Delay pad and servo circuit.

XI. SPLITTING AND TONE GATES

The splitting and tone gate circuit, shown in Fig. 10, is inserted in the path between a remote concentrator and its appearance on the central stage switch connections. At this point, the normal send and receive paths may be opened and special coded signals may be connected to either lead under control of call progress words. Since the S and R lead signals are in pulse-code-modulated form, the signals inserted at these splitting gates must be in the same form. Time-varying signals for ringing, ringing tone and busy tone are generated in a circuit common to the office, as described in Section XII. Other special signals (see Table I), such as the framing command, the scan command and the zero-level speech code, may be obtained directly from the master clock. Simple diode and transistor gates, similar to those that make up the crosspoints of the central stage switch, are controlled from the call progress decoder-coder to connect these signals to the S and R leads as required. A buffer flip-flop register extends the call progress decoder order for the duration of each time slot.

This circuit provides full access to the concentrator speech paths, so that no blocking can occur in connecting these special signals, and reduced traffic load is placed on the junctor paths of the central state switch. In addition, some operations in the common control are avoided, since transitions in the concentrator controller, such as from the ringing to the talking state upon the answer of the called customer or from the busy tone to the idle state upon hang-up of the customer hearing the tone, are now made locally within the controller.

XII. DIGITAL TONES

In order to pass through the speech transmission and gate circuits of an electronic system, ringing is accomplished in the voice frequency band and at the power levels satisfactory for speech. In addition, since the voice-frequency signals in the central office are in pulse-code-modulated form, the special tones must also be in this digital form.

The PCM codes to be generated include the maximum amplitude positive speech-sample code and the maximum amplitude negative

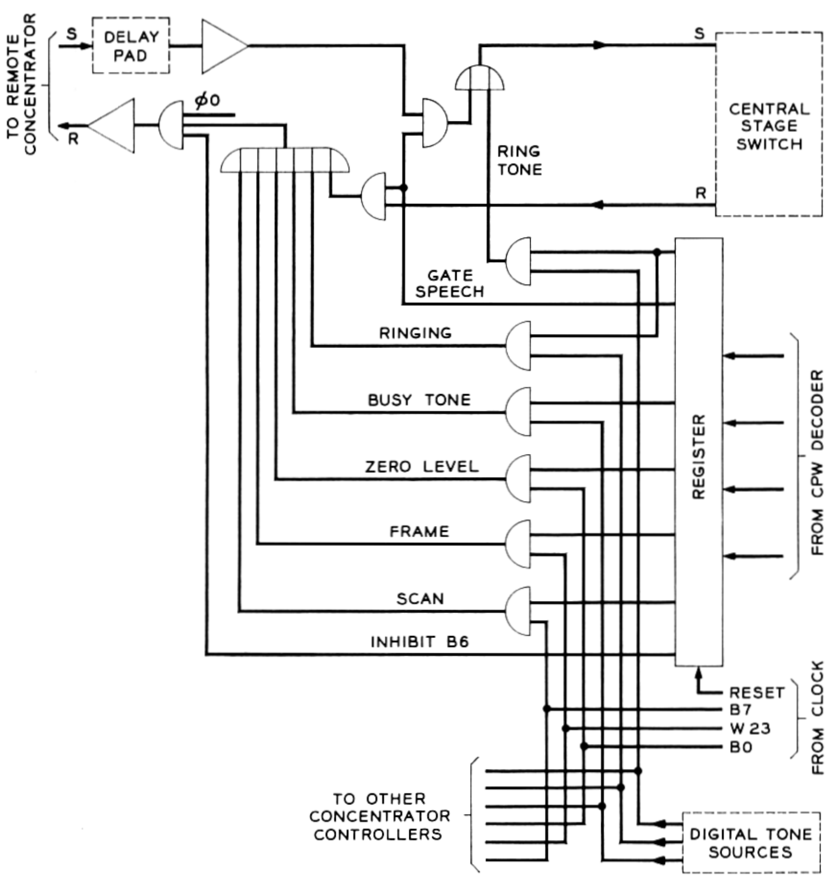

Fig. 10 — Splitting and tone gate circuit.

speech-sample code for ringing, the half-maximum amplitude codes for ring tone and busy tone, and the "zero level" speech-sample code for the silent intervals of the interruptions. These must be logically combined at the proper frequency and interruption rates.

The PCM tone signals generated are:

i. *ring*, which is a 1000 cps signal of maximum amplitude interrupted at both a 7.8 and 0.245 cps rate;

ii. *ring tone*, which is similar to ring but of lower amplitude;

iii. *busy*, which is a 250 cps signal of the same amplitude as the ring tone interrupted at both a 7.8 and 0.98 cps rate.

XIII. CLOCK

Timing of operations in the model is under the control of a central source of pulses, Fig. 11. A crystal oscillator operating at the basic bit rate of 1.536 mc acts as the master clock. Blocking oscillators driven through buffer and phase-shifting stages provide negative-going power pulses of 0.1-microsecond duration at the bit rate. These pulses are provided in two-phases, with the pulses of the second phase, ϕ_2, occurring midway in the interval between pulses of the first phase, ϕ_0. All shift registers in the system are advanced with ϕ_2 and may have their contents modified at ϕ_0 time. The phase pulses drive an eight position commutating circuit to provide eight-bit pulses, each of 0.65-microsecond duration and each spaced by 5.2 microseconds, the width of a time slot. In a similar manner, one of the bit pulses drives a commutator to form 24 "word" or time slot pulses, each 5.2 microseconds wide and repeated every 125 microseconds, which is the basic "frame" time of the system. In turn, one of the word pulses drives a commutator to furnish four frame pulses, each of which is 125 microseconds wide and is repeated every 500 microseconds.

Each commutating circuit is a shift-register, 8, 24 or 4 stages long, operated as a re-entrant ring with a single active stage. Each of the various time pulses occurs for the time interval in which the corresponding stage in its ring is active. These basic signals and logical combinations of them are distributed by power amplifiers to all units in the office as required. Similar pulses at the basic bit and time slot rate are generated at the remote units by timing recovery circuits dependent upon a received train of data bits.

XIV. FRAMING

Although the remote concentrator can recover the basic system bit rate from the PCM signals transmitted to it and can reconstruct pulses of time slot duration, it must be provided with a phase reference signal in order to associate a time slot pulse with the proper group of bit pulses.

This is the function of a framing command signal transmitted on the R lead. In time slots 0 to 22, this lead carries a seven-bit PCM speech code and an eighth bit that is normally a "zero". In time slot 23, eight "one" bits are transmitted, forming the unique framing signal. This signal originates in the splitting and tone gate circuit, Fig. 10. Occasionally, as described in Section IV on supervision, an eighth-bit "one" is inserted in one of the time slots 0 to 22 as a scan command, and speech code bits are suppressed to maintain the unique status of the framing code.

XV. SAFEGUARDS AND CHECKS

In an experimental model such as this, all of the checks, redundancy and automatic standby circuits necessary to guarantee continuity of service are seldom provided. However, some provision for their eventual incorporation must be contemplated. In this model, safeguards were included principally through the use of odd-parity coding for the line

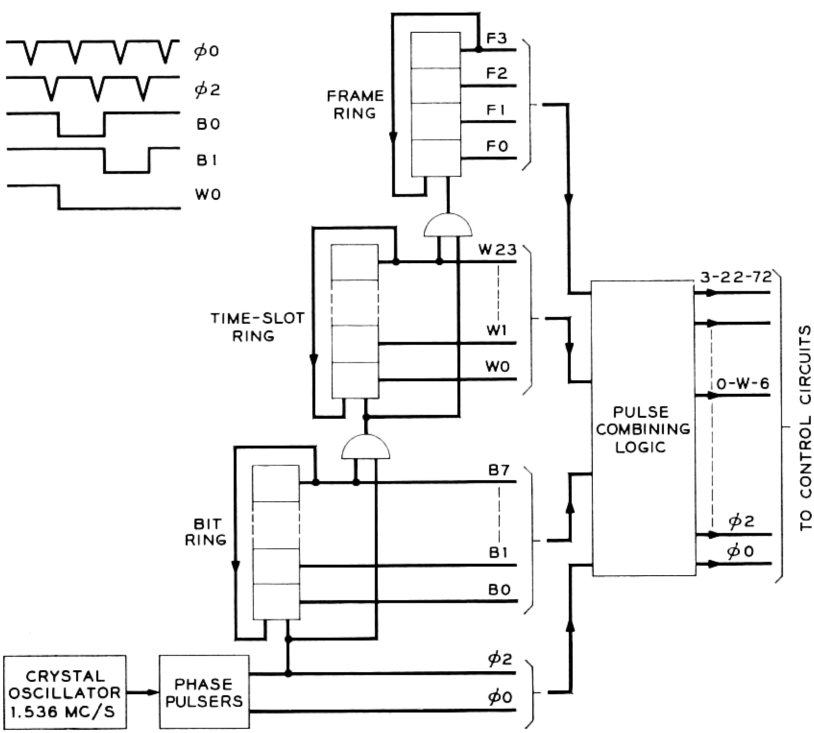

Fig. 11 — Clock structure.

and junctor numbers and the call progress words. The call progress words are chosen from the three-out-of-eight code group. A sixth bit is added to the five-bit junctor number and a ninth bit to the eight-bit line number, so that these complete binary number groups are converted to odd-parity groups. In the memory of the concentrator controller, the parity bit for a line number is stored in one of the spare bit positions of the junctor number memory. Parity check circuits associated with the controller memory continuously monitor the stored information as it circulates. A detected failure disables the actions of the call progress decoder-coder in the associated time slot to prevent compounding of the error, and an alarm indication is produced. The parity of information received by the insert circuit and transmitted to the console receive circuit is also checked, and automatic second trial is provided on the insert and dispatch operations. Failure on second trial results in an alarm indication.

XVI. CONCLUSIONS

Although this equipment is experimental, we have tried to assume realistic constraints as the basis for design. Thus, signaling between controller and common control has been kept to a reasonable minimum. Flexibility has been obtained by the use of call progress words, so that the particular sequences of control operations carried out within the controller can be altered, to accommodate changes in system requirements, by replacing a plug-in diode matrix in the call progress word decoder-coder. The use of call progress words to control the application and removal of tone signals within the controller reduces the usage of the common control and guarantees that tone connections can always be made when needed. The use of such tone connections also reduces traffic through the switching network and removes the necessity for tone trunks. Advantage has been taken, as in the control of line scanning, of the presence within the controller memory of stored information which specifies the state of the switching system.

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