New Time Division Switch Units for No. 101 ESS

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The No. 101 ESS provides centrex service utilizing stored program common control located in the central office and time-division switching units located on the customer's premises. The 2A and 3A switch units serve a wide range of customers (up to 820 lines) using a PAM time-division switching network with lossless through switching, high return loss, and high crosstalk attenuation. System operation, time-division transmission, logic and control, maintenance features, and physical characteristics of the switch units are described.

I. INTRODUCTION

The initial development of the No. 101 Electronic Switching System to provide commercial private branch exchange (PBX) service was completed in November 1963.[1] This system utilizes a stored program common control located in the central office and time-division switching units located on customers premises, connected to the common control by data links and trunks. This initial system design included a time-division switch unit, which served customers having a maximum of 200 extensions and 40 trunks.[2] Although this line capacity meets the requirements of a large percentage of the PBX customers of the Bell System, there are a significant number of customers who require service for more than 200 lines. These customers may now be served by No. 101 ESS through the use of the 2A (364 lines), 3A (820 lines), and 4A[3] (800 to 4000* lines) switch units in concert with the control unit. This paper describes the 2A and 3A switch units; the 4A is described in a separate article in this issue.

* The 4A switch unit capacity is 2000 lines. Expansion to a 4000 line capacity is under development.

II. SYSTEM DESCRIPTION OF NO. 101 ESS

2.1 *System Plan*

The control unit, by means of a stored program, provides the logic and memory required for call processing and for system maintenance. The switch units, by means of wired logic and memory, provide the switching paths between subscribers, supervisory scanning of subscriber lines, and ringing and signaling sources for alerting subscribers and attendants. In addition, maintenance circuits in the switch units, in conjunction with a maintenance program operating in the control unit, provide for rapid detection of equipment malfunction. Component and circuit redundancy is included in both the control unit and the switch units to minimize service degradations which would otherwise result from equipment failures.

Information transfer between the control unit and switch units is accomplished by a voiceband data facility and a set of trunks for carrying dialed digits. Each switch unit has its own data channels connecting it to the control unit.

In addition to controlling the switch units connected to it, the control unit, by means of direct association with a central office switching system, provides an interface between No. 101 ESS switch units and the Bell System switching network. The No. 101 ESS provides the entire range of centrex services and memory features available to PBX customers.

2.2 *Basic System Operation*

In the interest of economy of program storage, each switch unit served by a control unit is handled in the same way. Thus, for call processing and maintenance, one basic program is contained in the control unit. Administrative variables provide information needed for processing calls according to the requirements of each customer. The switch units being served by the same control units are independent of each other and therefore, from the point of view of switch unit operation, the system may be accurately discussed in terms of a single switch unit operating with a control unit.

Connections to lines and trunks are provided on a time-division basis at the switch units. The identities of the parties being connected are held in successive words of a sequential memory. The period of the memory operation establishes the period of the sampling process. In the 2A switch unit, a maximum of 60 simultaneous connections can be established. The 3A switch unit may provide a maximum of 240 simultaneous connections.

Figure 1 is a block diagram of the switch unit. Time-division connecting paths are shown as heavy lines. To illustrate, let us describe a typical intra-PBX call. When the calling party goes off-hook, the supervisory state of the associated line circuit is interrogated by the scanner and registered in the scanner logic via the scanner bus. The last-look state, or supervisory state when last interrogated, is extracted from memory and compared with the present state. Noting a change in state, the scanner ceases to interrogate other circuits and formulates a message which the switch control sends to the control unit. The control unit recognizes this message as an origination service request and sends a message to the switch unit to establish a dial tone connection. A *Touch-Tone®* telephone subset will be assumed as the calling party's instrument. The *Touch-Tone* dialing signals by the station user are transmitted through the switch unit on a time-division basis, then by conventional transmission to the control unit.

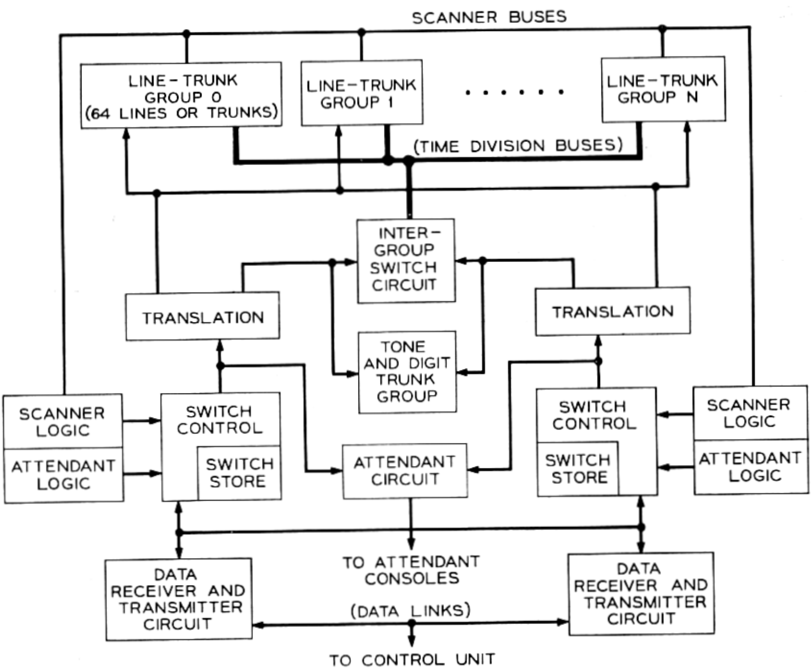

Fig. 1 — 2A and 3A switch unit block diagram.

At the completion of dialing, the control unit establishes a ringing connection in the switch unit between the calling and called parties. When the called party answers, the change of state is noted and the off-hook message is sent to the control unit. The control unit then sends a message to change the ringing connection to a normal talking connection. When the call is terminated, the on-hook state of either party is detected and the message is sent to the control unit. A disconnect message is then sent to the switch unit, removing the connection.

In the Section III, we describe in detail the manner in which these various functions are implemented in the 2A and 3A switch units. The basic system design is the same for both switch units, but differences do exist in the particular realizations of the design. We describe some of these in Sections IV and V. As a direct result of the similarities in the switch units, a high degree of component and circuit package compatibility between the two has been achieved, leading to long-term savings in manufacturing costs and ease of maintenance. In Section VI we discuss the equipment aspects of the systems.

III. ORGANIZATION AND DESCRIPTION

3.1 *Time-Division Transmission*

The essence of time-division transmission is that properly spaced periodic samples of a band limited information signal (for example, speech) completely define the signal. Sampling switches and suitable filters establish a bilateral transmission path as shown in Fig. 2. A connection is established by synchronously operating the selected switches for a time τ every T seconds. During τ, charges on the low pass filter capacitors C are efficiently interchanged by resonant transfer.[4] The high frequency sampling components are suppressed by the low pass filters resulting in a bilateral transmission of baseband signals.

By making τ a small fraction of T, a common bus can be shared by many connections. It is necessary to provide a "guard" interval between adjacent connection time intervals. A connection or "talking" interval and a "guard" interval is termed a time slot. During the guard interval, residual energies left on the bus at the end of the talking interval are dissipated by a resistance in series with a bus clamp to ground. In the 2A and 3A switch units, the timing values

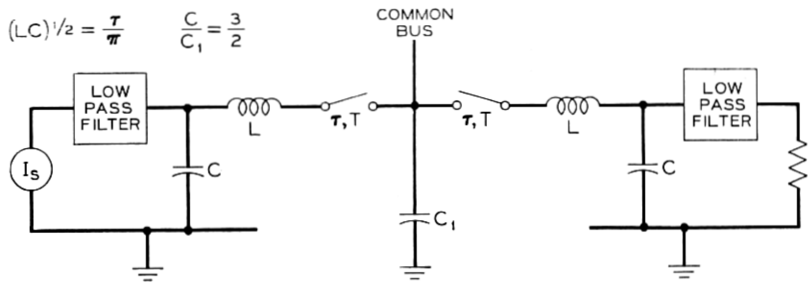

Fig. 2 — Time-division transmission path.

are 0.8 μsec for talking interval (τ), 0.432 μsec for the guard interval, and 85 μsec for the sampling period (T).

The low pass filter and filter response are shown in Fig. 3. The filter design provided by Thomas is modified to include an antiresonant circuit at the sampling frequency.[6] Without this, the normal filter attenuation of about 40 dB will not adequately suppress signals at the sampling frequency. With it, greater than 42 dB of suppression of the first lower sideband is realized. The 8.1 KHz attenuation peak is a result of the M-derived terminating section ($M = 0.7$), and is required to suppress the half sampling rate frequency components present during a ringing connection.

Negative impedance converters are used in two areas of the transmission network. A common negative impedance converter is connected to each time division bus to reduce the shunt losses from other transmission components. Improved system return loss results and a small amount (0.2 dB) of insertion gain is realized. In order to pro-

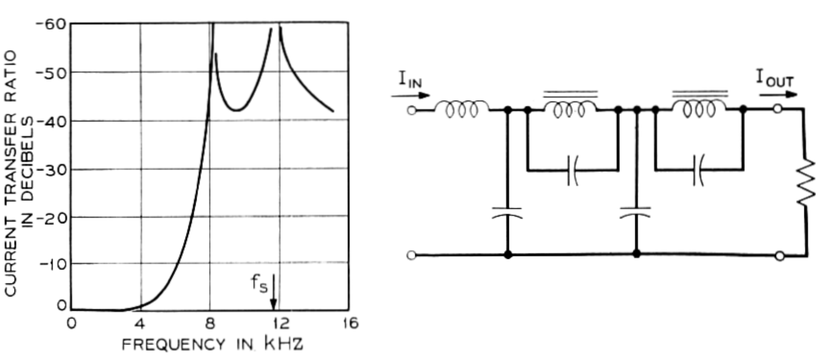

Fig. 3 — Low-pass filter and response.

vide a lossless through-switched connection (trunk to trunk), a switchable negative impedance converter gain circuit is provided with each tie trunk circuit (see Fig. 4). As required, control signals switch in the trunk negative impedance converter to reduce the 2.0 dB system insertion loss to near zero. Table I lists the typical transmission performance characteristics of the switch units.

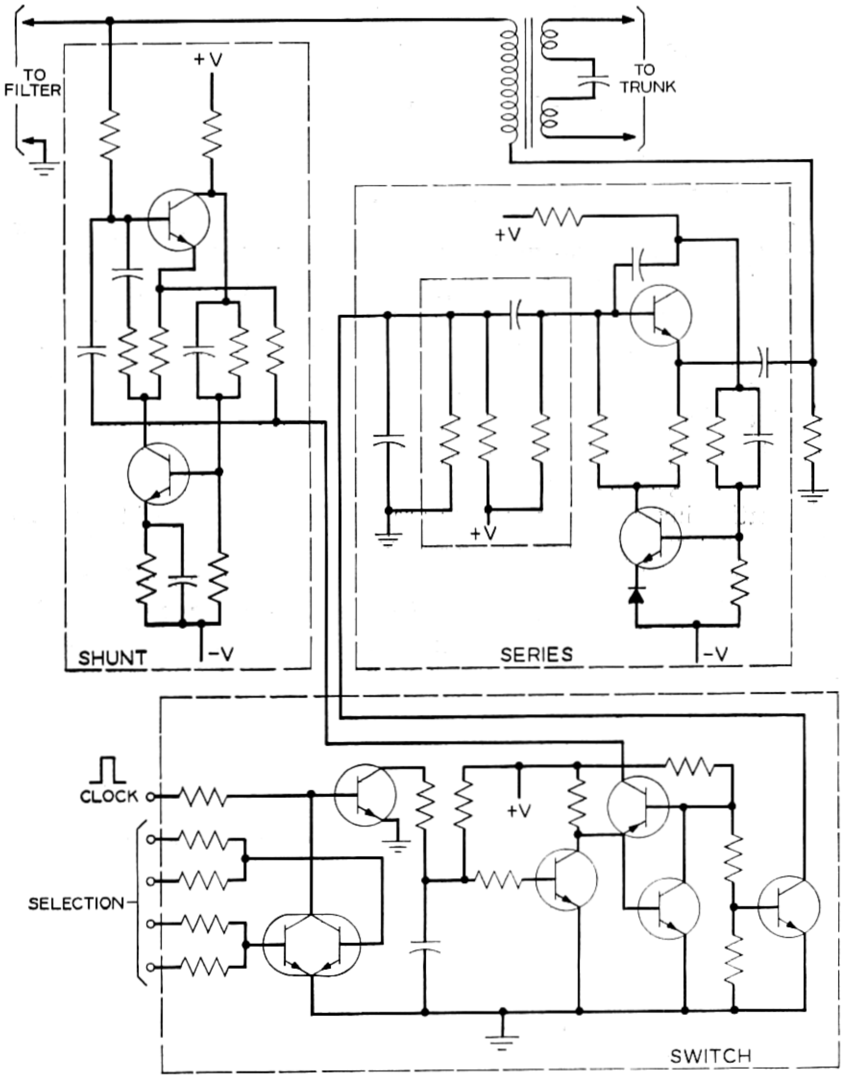

Fig. 4 — Switched-gain negative resistance amplifier circuit.

TABLE I—2A AND 3A SWITCH UNIT TYPICAL TRANSMISSION PERFORMANCE

Insertion loss (dB)	
Trunk to trunk	0.35
Trunk to line	2.0
Line to line	2.2
Echo return loss (dB)	30
Crosstalk (dB)	−90
Noise (dBrnc)	18
Signal overload	
6 dBm	no compression
9 dBm	1.8 dB compression
12 dBm	2.6 dB compression

In the 2A and 3A switch units, the time slots provide talking connections and data functions, such as scanning of the supervisory states of line, trunk, attendant, and maintenance circuits; sending and receiving data messages; and lighting the attendant console lamps.

3.2 *Line and Trunk Arrangement*

In a time-division switching system, a few common buses are being time shared by a relatively large number of lines and trunks. Therefore, the design must take into account the possibility of at least single component failures, and try to eliminate the possibility of the loss of a bus resulting from a single line or trunk component failure. Also, since the actual number of lines and trunks served by a switch unit in a given installation is variable, the parasitic loading of the buses is also variable. This loading and variations in it have a significant effect on the transmission performance of a time division system.

In the 2A and 3A switch units, control of system failure modes and control of parasitic bus loading is achieved by segregating the lines and trunks into groups of 64 as shown in Fig. 1. In each group, lines and trunks occupy positions in an 8-by-8 matrix; this provides for efficient use of access circuitry which is duplicated to preclude a total group failure. To further control parasitics, there are two time-division buses for each group, each serving 32 lines or trunks. A duplicated intergroup switch provides time-division connections between these group buses, such that during any time slot, any group can be connected to any other group. Since there are no restrictions on the time slots in which lines or trunks may be selected, any line or trunk may be connected to any other line or trunk during any time slot.

An additional benefit of line and trunk groups is that a switch unit may be installed with fewer groups equipped than will be ultimately required by the customer. As his needs grow, additional lines and trunks may be plugged in without disturbing the transmission performance of the system.

3.3 *Logic and Control*

3.3.1 *Store Control*

The switch store operation is cyclic in nature, providing the rate of sampling for talking connections and the rate of scanning. During talking time slots and some data time slots, information is read and written back into the memory in the same form. In the execution of some of the system control functions, the information read from the store is written back in the same word, but shifted one bit position. Repetitive operation in this mode involving a particular word of storage makes that word a shift register. This technique is used during the data time slots for scanning, sending messages to the control unit, and processing messages received from the control unit.

3.3.2 *Scanning*

The first two data time slots are used for scanning (see Fig. 5): the first for interrogating the scan points to determine their present state and the second for reading their past state from memory. Since

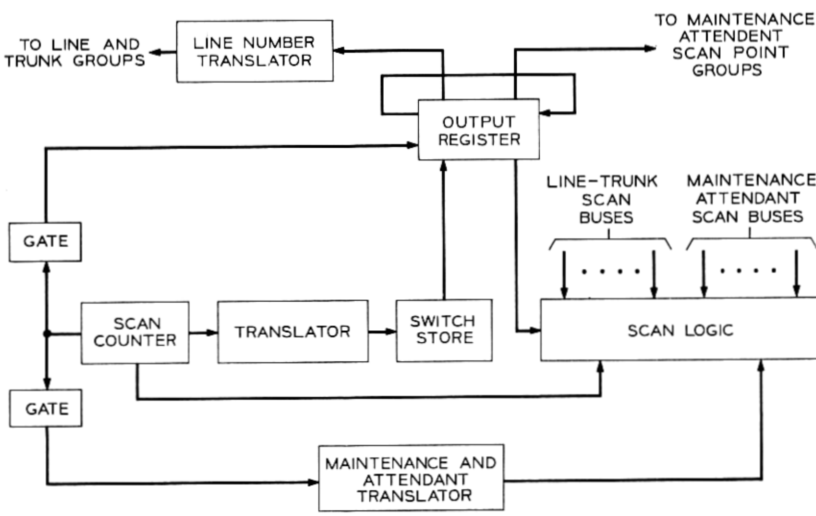

Fig. 5 — Scanner block diagram.

no talking signals are sampled during these time slots, the same line number translation circuitry is used to interrogate scan points as is used to operate time division switches. A separate translator provides access to the maintenance and attendant scan points.

3.3.2.1 *Line and Trunk Scanning*

The scan counter generates the address of each line and trunk circuit sequentially. To interrogate a line or trunk scan point, the address in the scan counter is gated into the output register bits normally used for the called party address in a talking time slot. As shown in Fig. 5, these bits are then translated by the line number translator to select the line or trunk circuits. The supervisory state is interrogated by pulsing the time-division switch driver, which in turn drives the scan point circuitry. The time-division switch current is inhibited during this scan time slot to eliminate false sampling of the talking signal. If the line is off-hook, a pulse is generated by the supervisory circuit and gated to a scanner logic flip-flop via the scan bus. During the second scan time slot, the past state of the scan point is obtained from the switch store and gated to the scanner logic where it is compared with the present state bit previously stored. If no difference is recognized, scanning continues by incrementing the scan counter and repeating the sequence. If a difference between present and past states is detected and does persist for a time interval sufficient to discriminate against line noise, the scan point change is assumed valid; a message is formulated in the switch store and the past state bit is updated. The switch control then sends the message to the control unit.

3.3.2.2 *Maintenance and Attendant Scanning*

Requests for service by an attendant or operation of maintenance circuits cause their assigned scan point circuits to change state. Scanning of these circuits differs from line and trunk scanning; for each scan point, a binary address is assigned, which also identifies a last-look bit in the switch store. The scan address is gated to a translator that selects a group of 16 scan points. The particular scan point in the group is interrogated by a ring counter consisting of a single "one" circulating in a word of the switch store. The position of the one is determined by the scan counter. The last-look bit is extracted from memory in the same manner as the line and trunk scanning. When a change in state occurs, a message is formulated for transmission to the control unit.

3.3.3 *Message Transmission*

When a message is to be sent to the control unit, the scanner is stopped and the message sending circuitry is activated (see Fig. 6). The word in the switch store which was used to contain the address of the interrogated scan point is also used to outpulse the data message. This message contains a start bit, the address of the circuit interrogated, a present state bit, and a parity bit. Each bit duration is timed by a crystal oscillator and a counter in the data receiver. The message is gated one bit at a time to the data transmitter. After each bit, the contents of the message word and counter word are shifted one position and, if the bit was a one, the parity counter is advanced. After 13 bits have been transmitted, the position of the counter bit is recognized, and the proper parity bit is transmitted. The scanner is then signaled to begin its normal scanning sequence.

3.3.4 *Incoming Message Control*

Communication between the control unit and the switch unit is accomplished with a voice-frequency signaling system using serially-generated frequency-shift signals. The data transmiter and receiver circuit provide the conversion into dc levels as well as the timing signals for bit identification. As each bit is received, it is gated into bit

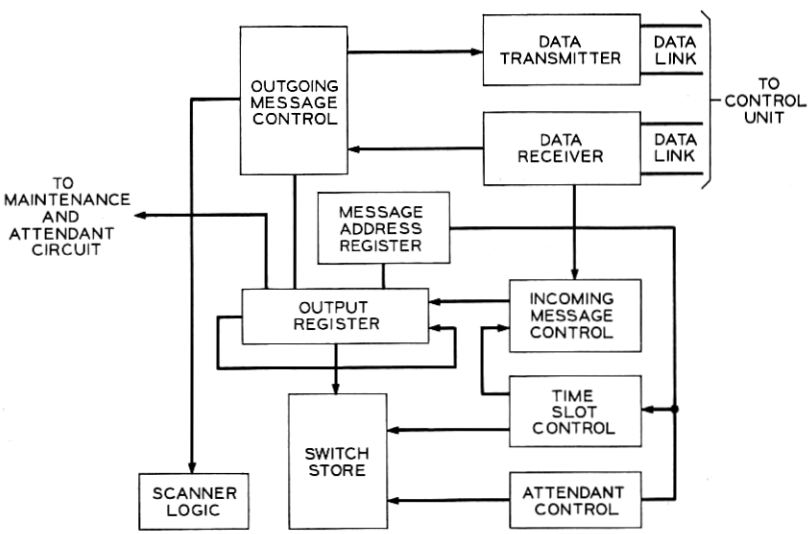

Fig. 6 — Switch unit message control.

1 of both stores during the message-loading time slot. On the next store cycle, this bit is shifted one position, thereby preparing bit 1 for the next message bit to be received. In this way, the message is loaded into both stores as it is received.

3.3.5 *Connection Message Loading*

Since the incoming message length exceeds the store word length, the loading sequence uses two store words. The first word is sequentially loaded with a start code and the message address. When the start code is recognized, the message address is gated to the message address register for interpretation, and succeeding message bits are loaded into the second word, which was reserved for this purpose. When the correct number of these bits have been loaded, the remaining bits of the message are then loaded into the remainder of the first word.

If parity is incorrect, the message is discarded and a parity-failure message is sent to the control unit. If parity is correct, relocation of the information in the second word is begun by reading this word out of the store into the output register. Information in the first data word is cleared. The contents of the message address register are gated to the store address circuitry to cause the corresponding word to be the next one read from the store. This new information is written into the memory.

Control of the store address circuitry is returned to the time slot counter, thereby completing the relocation sequence. In this process, the first data word is cleared, leaving it available for processing the next message received.

3.3.6 *Attendant Lamp Message Loading*

The attendant lamp message is loaded into the incoming words in the same manner as the connection message. In this case both data words contain information to be relocated to the attendant lamp memory words. The message address is recognized as an attendant message and a supplementary attendant address contained in the message is gated to the message address register.

The first data word is relocated as follows. During the incoming message time slot, the message address register contents are gated to the attendant store address counter, which causes the addressed attendant word to be read out. The information read out is inhibited from reaching the output register, thereby clearing the word. On the write cycle, the new lamp information is written from the output register into the store. The cycle is repeated for the second data word during the next occurrence of this data time slot.

3.3.7 *Maintenance Message Loading*

The maintenance message, identified by a special message address, is loaded into the incoming message words in the same maner as the connection message; the contents of the second data word are gated directly to the maintenance circuit rather than into the store word associated with a time slot. The first data word is cleared and made ready for the reception of a new message.

3.3.8 *Line Number Translation*

The translation of the calling or called party addresses from the binary form in the switch store to select the desired line or trunk circuit is accomplished in three stages (see Fig. 7). The first stage is associated with each switch store and is called the group pretranslator circuit. It converts the most significant bits of the address from binary to one-out-of-n signals to select the corresponding group of 64 lines or trunks. The group pretranslator circuit either translates the least significant six bits into two sets of one-out-of-eight signals (2A switch unit) or gates them directly to the group control circuit (3A switch unit). The second stage of translation at the group lines or trunks combines and translates information from the group pretranslator circuits as follows.

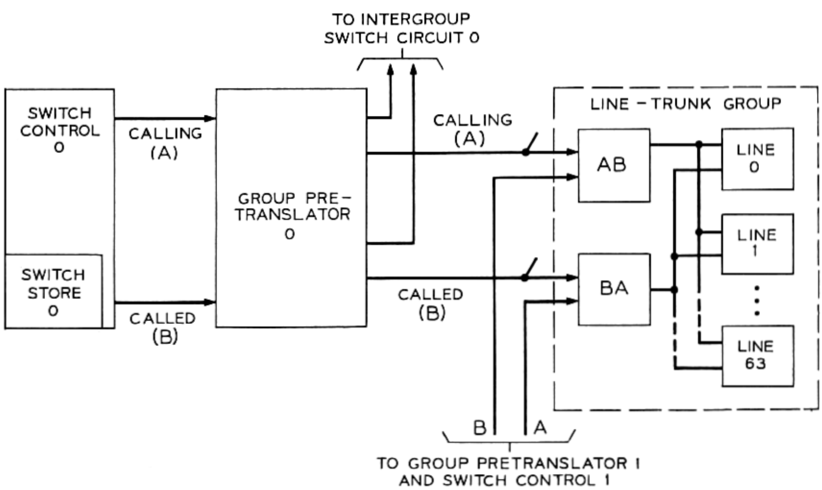

Fig. 7 — Line number translation.

The "calling" (A) party information from the group pretranslator of store 0 is ORed with the "called" (B) party information from the group pretranslator of store 1 (the AB translator). The "called" (B) party information from the group pretranslator of store 0 is ORed with the "calling" (A) party information from the group pretranslator of store 1 (the BA translator). Both the AB and BA translators have access to all 64 lines or trunks in the group.

This combining of translated information permits both incoming and outgoing intragroup calls to be completed in case of a translator failure. This kind of failure can be detected by the maintenance program which will cause the call program to select a time slot from the proper store to avoid using the failed circuitry. This combining of information which originated in the two stores places requirements on the logic and timing control circuits and on the call program in order to maintain the integrity of calls. In the 2A switch unit, the timing of the two stores is synchronized so that only one store is delivering an output at a given time. As a result, the combining of the information as described above is a time-sharing of the group translation circuitry between the two stores.

In order to obtain a greater number of time slots in the 3A switch unit, all stores deliver outputs at the same time. Therefore, information from one store is gated into only those groups which are selected by that store in that time slot. It is a requirement on the call program that the groups specified in a call in one time slot of one store be different from those specified in the same time slot of the other stores.

The third stage of the line number translator is provided on a per-line basis. Logic gates combine the matrix output information with a resonant transfer timing signal to complete the translation and operate the time-division gate.

The line number translator, in selecting and closing the line circuit time-division switch, connects the line to the group time-division bus. To complete the connection to another group, it is also necessary to select the proper time-division switch in the intergroup switch circuit. Figure 8 illustrates the time-division network. Each group of 64 lines has two time-division group buses; alternate circuit packs of 4 lines each are connected to each bus. The group buses are connected to each intergroup bus by an associated time-division switch. To complete an intergroup call, it is necessary to select two line circuit switches and two intergroup circuit switches. This selection is initiated by the group pretranslator which transmits the necessary group select and group bus information to the intergroup switch circuit.

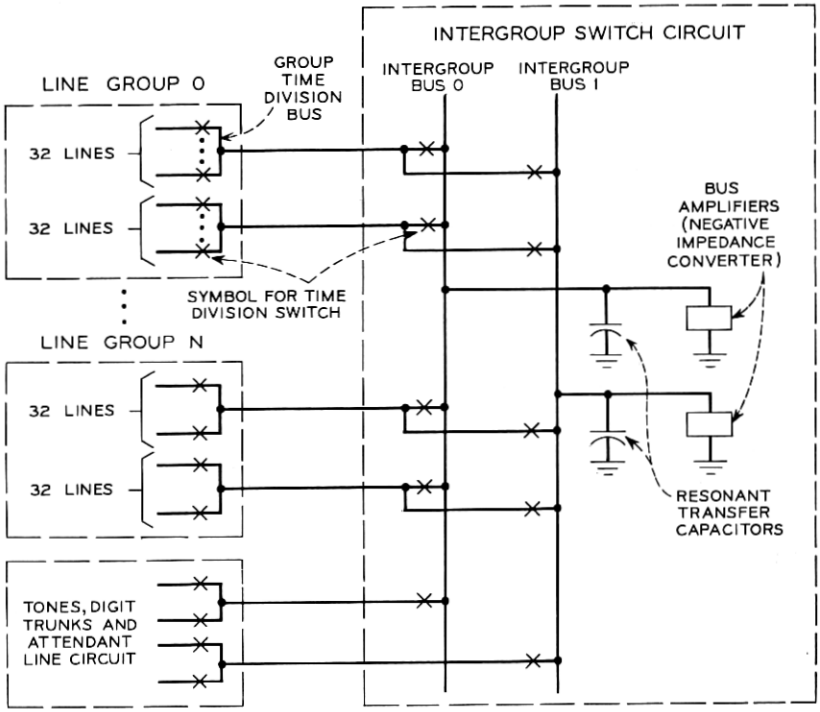

Fig. 8 — Switch unit time-division network.

This information, together with the resonant transfer timing signal, operates the intergroup time-division switches.

Intragroup calls using the same group bus are connected to the intergroup bus so that the common bus amplifier and the resonant transfer bus capacitor are included in the connection.

3.3.9 *Dialing Connection*

Dialing information is transmitted through the time-division system using two methods, one for *Touch-Tone* dialing and the second for rotary dialing.

3.3.9.1 ***Touch-Tone*** *Dialing*

A normal talking connection is first established between the calling party and the digit trunk circuit. The line transformer provides a voice path between the subset and the time-division network. For *Touch-Tone* dialing, the tones generated at the subset are transmitted directly through the time-division path to the digit trunk and then to the digit receiver at the control unit via the digit trunk pair.

3.3.9.2 *Rotary Dialing*

An additional path must be established to transmit rotary dial pulses to the digit trunk circuit. This path is established using the same scan bus that the scanner uses to obtain the present supervisory state of the line or trunk circuit during the scan data time slot. The scanner interrogates the selected line or trunk circuit by pulsing the time-division switch driver; when the time-division switch is selected to sample the talking signal, the supervisory state of the line is also interrogated. This automatically places the supervisory state of the line on the scan bus at each time-division switch closure (approximately every 85 μsec). The off-hook and on-hook conditions caused by rotary dial pulses are present on the scan bus in the form of a series of pulses during the off-hook interval and no pulses during the on-hook interval. Logic in the group pretranslator circuit recognizes the digit trunk address and gates the scan bus to that digit trunk each time the connection information is read from the store. The digit trunk then filters the pulses to reconstruct the rotary dial information and transmits a 50-msec tone burst to the control unit digit receiver to represent a rotary dial pulse.

During the time a line or trunk is connected to a digit trunk, normal scanning is inhibited to prevent the scanner from interpreting the on-hook interval of a rotary dial pulse as a disconnect signal. Instead, the digit trunk provides supervisory information about a dialing line to the scanner.

3.3.10 *Conference Connection*

Two types of conferencing are used in the 2A and 3A switch units. The first is an add-on or bridging conference for three parties, one of which may be a trunk. The second is a gain-type conference which is set up by the attendant and provides for six conferees (two may be trunks) and the attendant.

The bridging conference is established in a dedicated time-slot pair which may also be used for normal 2-party connections. When used for a conference connection, a conference bit must be loaded into both time slots. Associated with each conference time-slot pair is a time-division switch which connects a capacitor onto the intergroup bus during the resonant transfer interval of both time slots.

The capacitor provides the temporary storage necessary to connect both time slots on a bridging basis.

The gain-type conference may be set up using any available time slots. Each conferee line number is inserted in a time slot with the assigned conference port address. Up to six conferees may be connected in this manner. The conference circuitry provides gains at each port, reducing the normal bridging loss.

3.3.11 *Ringing and Tones*

The ringing generator used in the switch units is a 90-volt rms, 20-hertz source. Since this exceeds the signal-handling ability of the time-division network, ringing voltage is connected to the lines by means of a per-line miniature wire spring relay which is operated by a dc signal transmitted through the time-division network to the selected line. The system tones are transmitted from common sources through the time-division network to the selected line or trunk circuit.

A line-to-line ringing connection is established when the time slot is loaded with the calling and called parties and a ring code of two bits. An immediate ring feature is provided which connects ringing to the line as soon as the calling party completes dialing. The control unit provides for changing to interrupted ringing after 1 second. The interrupted ring has a 1-second ring interval and a 3-second silent interval.

3.3.12 *Attendant Lamp Control*

Attendant features are provided in the No. 101 ESS using universal telephone consoles of the cordless type shown in Fig. 9. Each attendant has six loops which may be switched to any line or trunk in the system, one loop at a time. Signaling is accomplished when the attendant operates keys on the console to alert the system, or when lamps on the console operate to alert the attendant. For example, the system alerts the attendant to an incoming call on one of the loops by a flashing light associated with that loop. The attendant accepts the call by operating a key associated with that loop. This is detected by the switch unit scan logic, and a message is sent to the control unit. The system responds by establishing a time-division connection between the attendant and the calling party, and changing the illuminated state of the lamp associated with the loop from flashing to a steady "on."

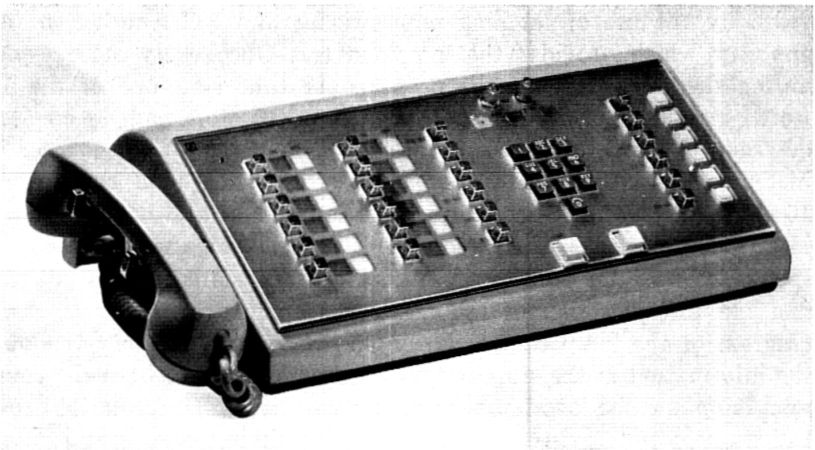

Fig. 9 — Universal telephone console.

Lamps on the attendant consoles are controlled by the control unit in a fashion similar in principle to the way that time-division switching is controlled: the new state of a lamp or set of lamps is determined by the control unit and a coded message containing this information is sent to the switch unit. This information is stored in the switch unit memory and remains unchanged until another message is sent. There are three lamps associated with each of the loops on the console. Additional lamps may be associated with any loop (for example, RDY, EXC DEST),* while other lamps are loop independent (for example, POS BUSY, CW, NS)†. Some of these lamps may be illuminated either steadily or at various flashing rates. The total number of bits required for each console is contained in four words of storage per console. Three of the four words are used to store the states of the lamps associated with the six loops, each word containing the information for two of the loops. The fourth word for each console contains the information for all of the common (or loop-independent) lamps.

The readout of the memory and lighting of the lamps is carried out on a time-division basis in which much of the common decoding circuitry and flashing rate control circuitry is time-shared among all of the lamps and all of the consoles. The smoothing required is pro-

* These are READY and EXCLUDE DESTINATION, respectively.
† These are POSITION BUSY, CALL WAITING, and NIGHT SERVICE, respectively.

vided by the use of latching pnpn triodes and RC filtering in the circuitry which provides the lamp current. Once every store cycle, during the occurrence of the proper data time slot, one of the 16 words of lamp memory is read. The attendent store-address counter determines which word it is, and after each readout, this counter is incremented, resulting in a particular word being read once every 16 store cycles, or 1.36 msec. Since the contents of each word must be interpreted in terms of the console it pertains to, there is a correspondence between the state of the attendant store address counter and the interpretation of the memory readout. Fig. 10 is a block diagram of the lamp control logic. On every lamp memory readout, the information in the store output register is gated to both the common lamp and the loop lamp logic. In these circuits, information from the store output register is combined with timing signals and gated to the appropriate lamp drivers as determined by the address of the word. The timing provides for two lamp lighting phases, during each of which only half of the information read from the store is actually used. During each phase, half of the lamp drivers are pulsed, causing the appropriate pnpn triodes to convert the single time-slot pulses to 50 percent duty factor millisecond pulses. An RC circuit then provides sufficient filtering to maintain a continuous current to the lamp.

3.4 *Memory*

The switch stores are involved in the execution of every one of the switch unit control functions. In these operations, the stores are used as shift registers, ring counters, and as conventional memory. Because each of the system control functions has a different operating cycle, the store is a random access store. The memory module consists of ferrite cores in a 2-wire, linear select array. Each word is defined by a word line linking one core for each bit in the word. Bit lines, one for each bit in a word, link all words in the store, so that in processing a word, all the bit lines operate in unison.

In this memory organization, the readout signal detection problem is complicated by the use of a single bit line for both writing and sensing. Although writing and sensing are separated in time, the input signal to the sense amplifiers during these two operations may differ by at least an order of magnitude. Thus, the sense amplifier is time-strobed. The gain of the amplifier is low during the write time,

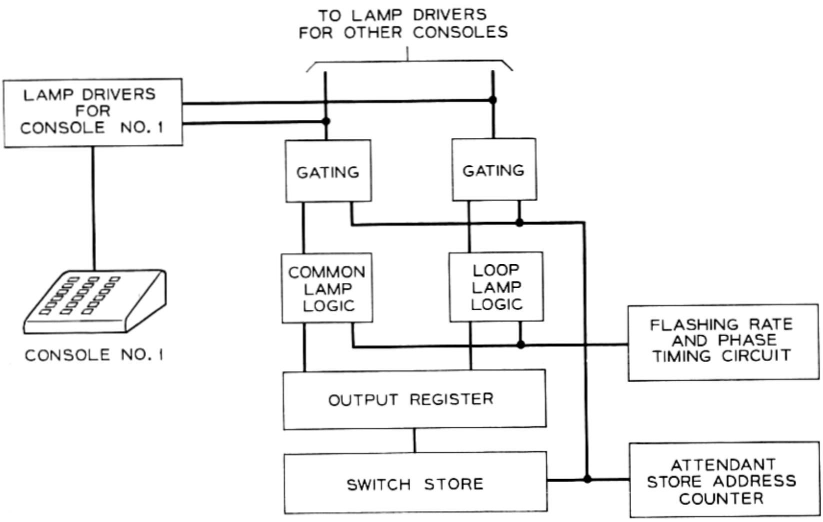

Fig. 10 — Lamp control logic block diagram.

and, during the readout interval, the gain is raised to the required level. This gain control is introduced into the sense amplifier in a manner which prevents the write noise from disturbing the bias point and dynamic range of the amplifier during the following readout interval.

3.5 *Logic*

Little is said in the description of the various logic functions performed in the switch units about the speeds required and the circuits used to carry out these functions. At an early stage in the development it was determined that a building block logic circuit approach held greatest promise for long-term economy of manufacture. A gate having no more than a 70 nanosecond worst-case delay and a 35 nanosecond nominal delay was required; the choice was a high-speed version of the transistor-resistor logic gate. The basic forms of this gate are shown in Fig. 11. To realize this gate design, two silicon planar epitaxial switching transistors were developed. These two transistors are virtually identical in operating characteristics except that the one is a double transistor in a single encapsulation as shown. Table II summarizes their characteristics.

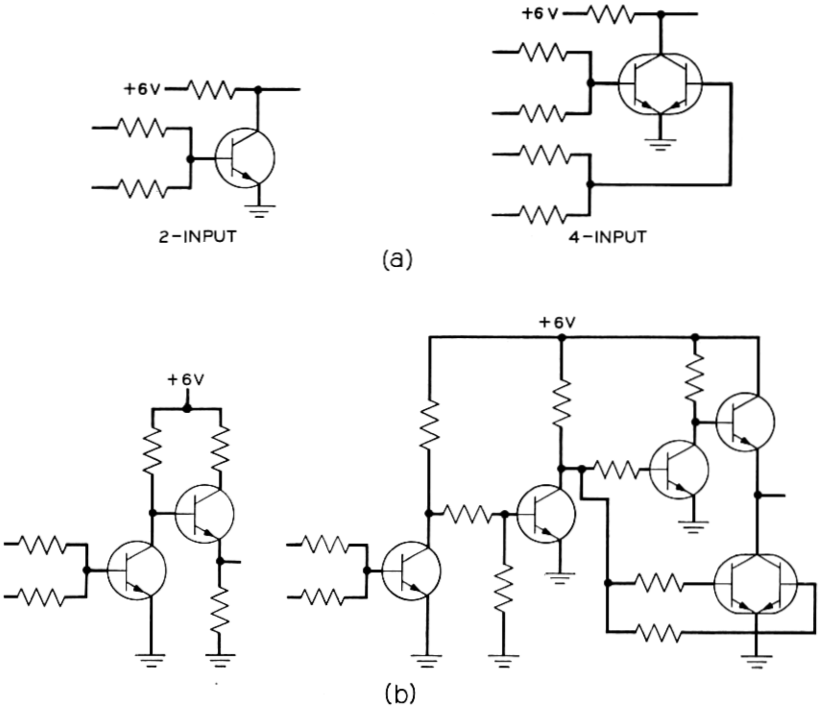

Fig. 11 — Transistor-resistor logic circuits: (a) low fan-out (fan-out ≦3), (b) intermediate fan-out (≦10), (c) high fan-out (≦44).

3.6 *Power*

Three potentials are used in the circuitry of the 2A and 3A switch units:

Potential	*Uses*
+6 volts	Logic circuitry
+24 volts	Talking battery (line circuits) Time-division switch drive circuitry Maintenance relay circuitry
−24 volts	Memory circuits Time-division switch bias Trunk and extended range line talking battery

These dc potentials are obtained from solid-state diode rectifiers supplied with alternating current from a single-core, multiwinding, ferroresonant transformer, connected to commercial 60-hertz single-phase power. Ringing power for the system is provided by a 20-

hertz subharmonic oscillator operating directly on commercial ac power.

In order to maintain telephone service in the event of either a commercial power failure or an equipment failure, a reserve power arrangement has been developed to provide backup for the 3A switch unit ferroresonant supply. By monitoring the commercial alternating current, the system will survive a failure of commercial power by automatically switching to the reserve arrangement. The reserve system delivers +24 volt power directly from the batteries to the switch unit. However, converters are required to convert the battery voltage to −24 volts, +6 volts, and the ringing voltage. The battery and charging rectifiers are engineered to provide as much busy-hour reserve capacity and as short a recharge time as the customer desires. The equipment design of this power system is such as to permit deletion of the reserve components if the customer so desires. In this case, in the event of commercial power failure, selected PBX lines are transferred to central office battery feed and become standard central office lines.

3.7 *Maintenance Features*

3.7.1 *Redundancy Plan*

In order to minimize service degradations resulting from equipment failures, much redundancy is included in the switch unit design. Thus, Fig. 1 shows that virtually all of the control logic is duplicated, so that a single failure affects only half of the system. When both halves of the logic and control portion are operative, some of the control functions are actually enabled in only one half;

TABLE II—CHARACTERISTICS OF LOGIC TRANSISTORS

Unity gain frequency f_t > 400 mHz	
	(at $V_{CE} = 10$ Vdc, $I_c = 10$ mA)
Capacitance	
	$C_{ob}(I_E = 0, V_{CB} = 5\text{Vdc}) < 3.5$ pf
Storage time constant *ts* < 16 nsec	
	$(I_{B1} = I_{B2} = I_c = 5$ mA)
Saturation voltages	
	$I_c = 10$ mAdc, $I_B = 0.5$ mAdc V_{CE} sat < 0.25 Vdc
	$I_c = 10$ mAdc, $I_B = 1.0$ mAdc V_{BE} sat ≤ 0.80 Vdc

the circuitry in the other is on stand-by. This is the case with scanning and attendant lamp control, so that both of these functions are unaffected by a half-system failure. However, time-division switching control is shared between the two halves, so that only half of the talking time slots reside in each store. The full traffic capacity of the switch unit is realized only when both halves are operative; therefore, a failure of one half causes a reduction in the switch unit traffic capacity and leaves all essential services intact.

Reliability is achieved in the time-division switching network by path diversity and component redundancy (see Fig. 1). Within each 64-line group of lines and trunks, the lines or trunks are separated into two groups of 32 lines, each group having its own time-division bus. A single failure which disables a bus can therefore affect at most a set of 32 lines or trunks.

3.7.2 *Failure Detection and Diagnosis*

When failures do occur, they must be expeditiously discovered, diagnosed, and repaired in order to minimize inconvenience to the customer. In the absence of any trouble conditions, both halves of the switch unit control logic are operative; scanning and attendant lamp control reside in one half or the other (though not necessarily both in the same half). Failure detection circuitry maintains a continuous check on power supply voltages (input and outputs), fuses, and the ringing power source. A continuous sequence of test calls, established by the maintenance program in the control unit, periodically checks the operation of all lines, trunks, digit trunks, tone sources, conference circuits, and time-division control logic in the switch unit. When switch unit failures are detected, the maintenance program attempts to establish a working mode in the switch unit with full traffic capacity and with the failed equipment either switched to stand-by status or at least made busy to future traffic. Failing this, a half system may be disabled. If an operating mode cannot be found, the maintenance program enables all switch unit equipment and ceases further testing until reinitiated by maintenance personnel. When failures are detected or when maintenance actions are executed, maintenance personnel at the control unit are alerted by alarms and by teletypewriter. By interpretation of teletypewriter printouts, the testing sequence may be reconstructed and the trouble condition diagnosed.

IV. 2A SWITCH UNIT

4.1 *Line and Trunk Capacity*

As shown in Fig. 1, lines and trunks in both 2A and 3A switch units are arranged in groups of 64. In the 2A switch unit, there are seven such groups; any line or trunk in any group can be connected to any other line or trunk in the same or any other group in any time slot under control of either store. With tone sources, digit trunks, and test lines excluded, the total number of lines and trunks combined is 420, which can be arranged optionally in a given installation as either 80 trunks and 340 lines or 56 trunks and 364 lines. The total busy-hour traffic capacity of the switch unit, assuming 70 percent time slot occupancy, is 1510 ccs.

For customers with fewer lines, an equipment option is available in which only four groups are provided. The switch unit provides service for 156 lines and 80 trunks or, optionally, 180 lines and 56 trunks. As indicated in Section VI, the conversion of a 180-line switch unit to a 364-line switch unit is accomplished by plugging in; no installation wiring is required. Irrespective of line size, the 2A switch unit can accommodate three attendants and seven digit trunks; the actual number used depends on the traffic requirements of the customer being served. These circuits, along with the switch unit tone sources, are equipped in a separate group in which a nonmatrix type of translation is used to control time-division switching. This arrangement precludes the possibility of a single component failure causing the loss of several of these common facilities. Time-division control of these circuits can be established from either store, so that a half-system failure does not restrict use of these facilities.

4.2 *Time Slot Arangement*

The 60 talking time slots of the 2A switch unit are divided between the two halves of the switch unit; 30 talking time slots are associated with each store. Data time slots occur in both halves because each half must be able to carry out control functions independently. As already indicated, each time slot consists of an energy transfer interval and a guard interval. Fig. 12 illustrates how the time slots in the two halves of the 2A switch unit are related. The energy transfer interval of the time slots in one half is made time-coincident with the guard interval of the time slots in the other half. Crosstalk coupling between adjacent time slots in the two stores is greatly reduced,

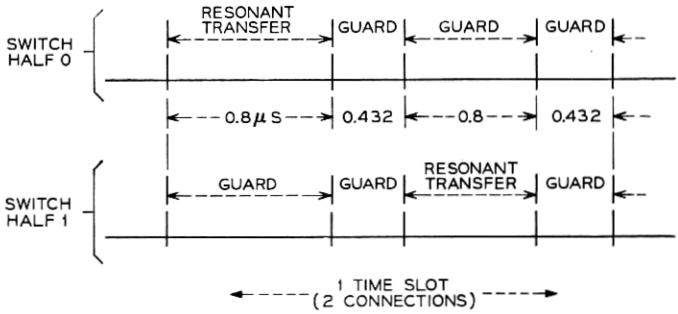

Fig. 12 — 2A switch unit half-system time slot relationship.

permitting the use of relatively inexpensive wiring for the time-division buses. Since only one time-division connection is actually established at a time, the circuitry used in the line and trunk groups is time shared between the two halves with no loss of traffic capacity resulting from mating time-slot blocking.

In addition to this "slip" between time slots in the two stores, Fig. 13 illustrates that one half has five data time slots where the other half has four. Since both halves must receive messages from the control unit at the same time and either can be controlling attendant console lamps, the last two of the data time slots, which are used for implementing these functions, are always present in both stores. However, the scanning function resides in only one half at a time and is essentially disabled in one half by the deletion of the time slot used for reading the last-look memory. Thus, in one half there are 30 talk-

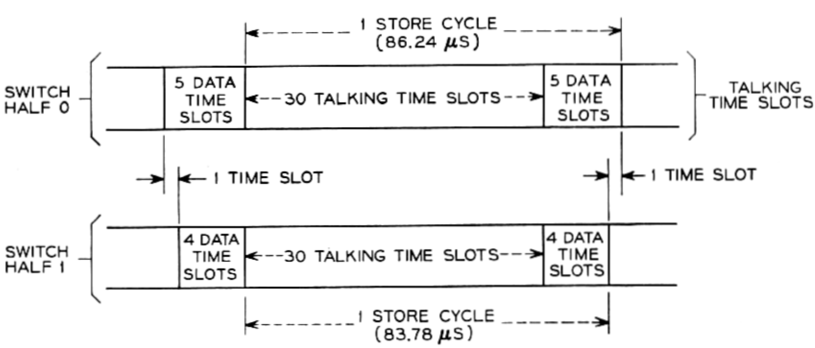

Fig. 13 — 2A switch unit half-system store cycle relationship.

ing time slots and 4 data time slots, while in the other half there are 30 talking time slots and 5 data time slots.

Irrespective of stores, the duration of each time slot is 2.464 microseconds, and therefore the cycle time of the store with 35 time slots is 86.24 microseconds; for the store with 34 time slots it is 83.7 microseconds. Thus, calls established in one store have a sampling rate of 11.9 kHz, and calls established in the other store are sampled at a 11.6 kHz rate. As a result of this rate difference, there is a periodic motion of the time slots in one store relative to the time slots in the other store. This motion of the time slots has a period of approximately 2.93 milliseconds and constitutes a process in which a given time slot in one store samples the crosstalk from a time slot in the other store at a 341 cycle per second rate. Since the baseband signal spectrum is from 0 to 6 kHz, this sampling process will cause severe fold-over distortion of the crosstalk signal energy, resulting in unintelligible noise only.

When scanning control is transferred from one half of the switch unit to the other, the number of time slots in the two halves is reversed. Thus, the store in which scanning control resides always has 35 time slots, and the other store always has 34 time slots.

V. 3A SWITCH UNIT

Figure 1 illustrates the switch unit block diagram for 120 talking time slots, each half of the system providing 60 talking time slots (as composed to the 30 provided by the 2A switch unit). Associated with the control circuitry of each half is an intergroup bus, to which all line or trunk group buses may be time-division connected. Any line or trunk has access to both intergroup buses and may be time-division connected to any other line or trunk using any time slot.

The control circuitry associated with an intergroup bus, which provides the necessary translation, storage, scanning, and message control functions is called a time-division control (TDC). Each TDC contains a switch store, with a capacity of 60 talking time slots and 5 data time slots which are normally synchronized from the switch control circuitry of TDC 0 resulting in a simultaneous time-division connection in each TDC. These mating connections are established by the call processing program in such a manner that the same line or trunk group is not selected in more than one TDC. Time-division samples do occur at the same time, requiring a high degree of isolation provided in the time-division bus cables.

Isolation between adjacent time slots is accomplished by dividing the 65 time slots into groups of 32 and 33. By alternating between these two groups, individual time slots move with respect to each other, resulting in an adjacency every 2.75 msec. Any crosstalk between adjacent time slots is therefore sampled at so low a rate as to be nonintelligible. The cycle time of the group with 32 time slots is 83.5 μsec or a sampling rate of 11.9 kHz, while the group with 33 time slots is 86 μsec or a sampling rate of 11.6 kHz.

Connections to the tones, digit trunks, and attendant line circuits are not mating time-slot restricted as are line and trunk circuits. Each TDC has a tone and digit trunk group which connects all tones, the attendant lines, and six digit trunks to the associated intergroup bus. The 3A switch unit may be equipped with a minimum of 120 time slots having a traffic capacity of 3240 ccs* and line and trunk frames for 436 lines and 112 trunks. An additional frame containing six line groups may be added to increase the maximum number of lines to 820. Two line groups may be equipped optionally as trunks to provide either 756 lines and 168 trunks or 696 lines and 220 trunks.

In the event additional traffic capacity is required, additional time slots may be provided in blocks of 60 talking time slots. In this case, a logic and control frame is added and equipped to bring the total number of time slots to 180 or 240, with a capacity of 4730 and 6130 ccs*, respectively.

When the switch unit is equipped for 180 or 240 time slots, an additional data link is required to meet the increase in data messages. This data link receives all messages associated with the added time slots. To provide for a more uniform traffic level, switch unit to control unit messages are sent alternately over both data links.

VI. EQUIPMENT FOR 2A AND 3A SWITCH UNITS

The circuits of the 2A and 3A switch units consist of gate subassemblies and loose components assembled on circuit packs which plug into equipment units which in turn are wired into two-bay frames. The wired and factory-tested frames are interconnected at the time of installation by plug-in cables. These plug-in design features minimize the time spent on the subscriber's premises for installation and maintenance.

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* Without call transfer.

6.1 *Thin-Film Gates*

Tantalum nitride thin-film resistor networks deposited on a ceramic substrate are used for the logic gates and time-division transmission gates. Up to five TO-18 transistors mount on a single 0.55 by 1.8 inch substrate to form a multiple logic gate subassembly which is given a functional test before assembly onto a circuit pack. Figure 14 shows two views of a typical thin-film logic gate. A larger 1.6 by 2 inch substrate supports the transistors and pulse transformer of the time-division transmission gate, which receives a similar preassembly test. Both logic and transmission gates have wire terminals to provide both mechanical and electrical connection to an etched wiring board.

6.2 *Plug-in Circuit Pack Physical Characteristics*

Two types of circuit packs are used in the 2A and 3A switch units. Logic circuits are built on 4.6 inch high by 6 inch deep circuit packs; line and trunk circuits are built on 5.6 inch high by 11 inch deep packs.

The logic packs have space for flat mounting of ten logic gate substrates, giving an upper bound on packing density of 50 transistors per pack. The height of the substrate plus transistor permits pack center-to-center spacing as little as 0.4 inch. Circuits other than pure logic (for example, clock oscillator and store packs) are built of conventional discrete components mounted directly on the board. The overall average density for the logic circuit packs is 20 transistors per pack.

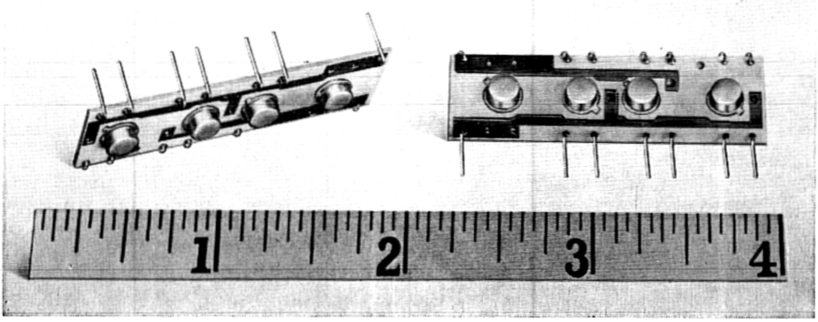

Fig. 14 — Thin film logic gate.

A 38-terminal board-end connector with plastic body and bifurcated gold-plated contacts is soldered onto one end of the double-sided etched copper-clad phenolic wiring board. A plastic faceplate with holes forming sockets around etched test point paths is riveted onto the opposite end of the pack; holes are also provided for a pack extractor tool. The width of the faceplate varies from 0.4 inches in increments of 0.2 inch to 1.4 inches as required by the highest component on the pack. Connections between paths on the two sides of the pack are made using a special highly reliable through-connection first used in the No. 101 ESS.

The line and trunk packs contain four complete line or trunk circuits or related circuits and are provided with a 46-terminal connector. A die-cast frame 2 inches wide supports the epoxy-glass composition etched wiring board upon which are mounted the relatively heavy line transformers and filter networks. To conserve space, the ceramic substrates of the time-division transmission gates are mounted perpendicular to the board; furthermore, some of the other per-line circuits are packaged on 1.6 by 2 inch "daughter boards" (etched wiring boards with discrete components), which are also attached perpendicularly. Figure 15 shows these features of the line and trunk packs.

6.3 *Circuit Pack Electrical Designs*

Although there are differences in the control circuits of the 2A and 3A switch units, circuit pack and circuit designs have been formulated to minimize the number of packs required for both the 2A

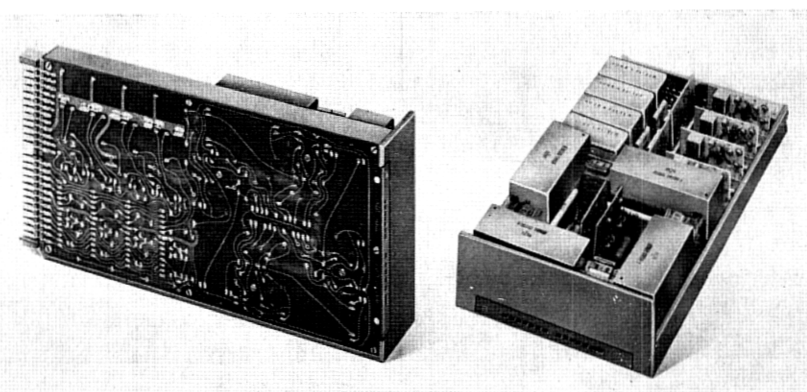

Fig. 15 — Circuit pack containing four line circuits.

and 3A switch units. A constraint of maximizing packing density to reduce the overall size of the switch unit has dictated the need for special-purpose logic packs containing many etched interconnections. General-purpose packs suffer from low-packing density because of terminal limitations, whereas special purpose packs tend to be space limited by the area of the etched wiring board but are limited in application by their specialized function.

Eighty-seven different logic packs are used in the 2A and 3A switch units. Fifteen percent of the pack types form the general-purpose core of the 2A and 3A equipment; these contain gates, flip-flops, counters, and amplifiers with a minimum of interconnections. Seventy percent of the pack types have specialized logic functions, and fifteen percent perform nonlogic functions such as store control, data transmitter-receiver, and attendant lamp driver. Despite the high proportion of special-purpose packs, 60 percent of the total logic pack types are common to both switch units.

The line and trunk circuits are identical in the 2A and 3A switch units; there are slight differences in the line group control packs and attendant line circuits. More than half of the 31 line and trunk type packs are used in common. The line and trunk circuit packs have compatible terminal assignments among themselves so that changes in line and trunk type (and in the 3A, changes from a line group to a truck group) can be accomplished by plugging in, with no wiring changes required.

6.4 *Apparatus Mountings*

The logic packs plug into die-cast aluminum apparatus mountings consisting of one, two, or three 12-inch-wide trays illustrated in Fig. 16. The card guide castings on the top and bottom of the tray have slots on 0.2 inch centers to accept any combination of circuit pack widths. Knock-out nose pieces on the front of the casting prevent accidental insertion of a pack in an unused position. A female connector snaps into slots at the rear of the casting to mate with the circuit pack connector. This connector is arranged for up to three levels of wire wrapping and the twist-lock fork terminals may be individually replaced in the field without removing the connector body and wiring on adjacent terminals. A ground strip with terminals on 0.2-inch centers is mounted under the connectors at the bottom of each tray to provide a short path from the circuit packs to the low-inductance frame ground.

Apparatus mountings for the line and trunk packs have similar

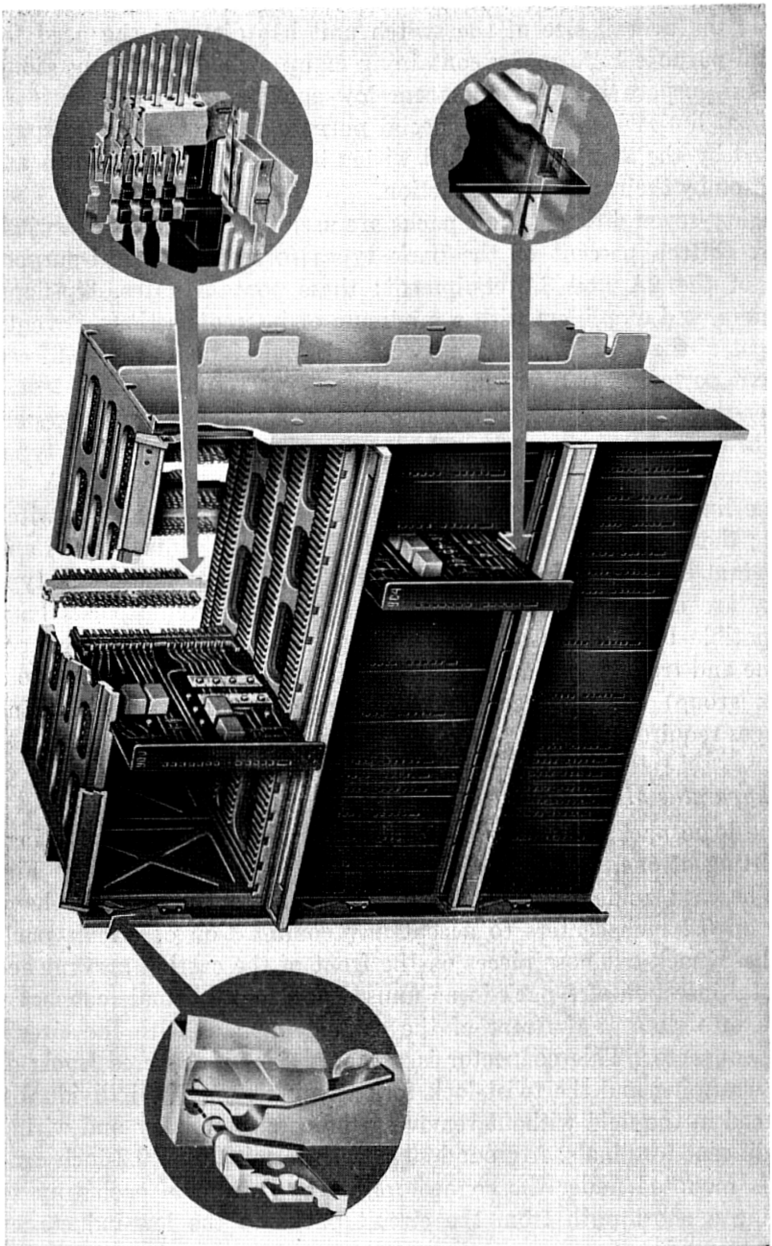

Fig. 16 — 2A and 3A switch unit apparatus mounting.

features, except they are 6 inches high and have card-guide slots on 1 inch centers with width to accommodate the cast frame of the packs. A mechanical interlock is provided to prevent certain circuit packs from being inserted into package locations where electrical damage may result.

6.5 *Wiring and Cabling*

The equipment within each cabinet is factory wired and tested before shipment to the field. The various equipment features and options available are implemented in three ways: first, by inserting or removing a circuit pack; second, by moving a circuit pack from one prewired connector position to another, and third, by replacing one circuit pack code by another in the same position. These methods eliminate any wiring by the installer in the switch unit itself and permit factory testing of all features and options.

Connections between frames are made using 64-terminal connectors. Single-ended connector cables are used, with the other end preformed and wired into the frame. This "umbilical cabling" technique results in smaller space requirements for connectors and higher reliability over a double-ended connecting cable, since only one pressure contact is in series with each interframe lead. Signal leads are distributed among the connectors so that the accidental removal of one connector will not disable the entire switch unit.

Logic and fused power connections between the frames are accomplished with six connectors in the 180-line 2A switch unit; three more connectors complete the signal and power interconnections to the auxiliary line frame, increasing the switch unit capacity to 364 lines. A similar expanded cabling scheme interconnects the three, four, or five frames of the 3A switch unit. In addition, the intergroup time-division buses of the 3A switch unit, which are constructed of shielded twisted-pair cable, are plugged together between the transmission frames via coaxial connectors.

External connections for lines and trunks are made using a 32-pair cable with a 64-terminal connector which plugs directly into the line and trunk group units. Four connectors are provided per group: one for the 32 tip and ring pairs per half group, one for attendant direct station selection (ADSS) control leads per half group, and two corresponding tip and ring and ADSS connectors for the other half of the group. Attendant console leads, digit trunks, and data links also leave the switch unit through 32-pair cables.

Terminal assignments in the 2A and 3A switch units are made so that existing cross-connection wiring need not change when a 2A installation grows to the point where it is replaced by a 3A switch unit. Additional external leads are required by the 3A, but changeover involves only repositioning the 2A cables in the appropriate 3A connectors. Digit trunks, data links, and the first three attendant consoles can be replaced one-for-one, and the line and trunk group numbering plan is such that there is compatibility among the first seven groups.

Planned wiring is used to make intraunit connections in each apparatus mounting (this is bench wired before the unit is installed in the frame). Loose wiring interconnects the units in the frame, and local cables and formed switchboard cabling compose the interframe "connectorized" wiring. To alleviate wiring congestion, some of the cabled wiring is run as "air lift" cabling, that is, the wires are behind the plane of the wire-wrap terminals and come into the wiring field only at connection points.

6.6 *Cabinet Features*

The cabinets for the 2A and 3A switch units are constructed of aluminum extrusions and formed sheet aluminum parts welded together to form a basic framework into which the apparatus mountings are fastened. The frames are 34.5 inches wide by 19.5 inches deep to accommodate two bays of equipment while remaining small enough to be easily moved.

The minimum 2A control and line circuits for 180 lines and 56 trunks occupy two frames; the minimum 3A control and line circuits for 436 lines and 112 trunks occupy three frames, additional frames house added lines, control circuits, distribution (cross-connection) fields, and auxiliary equipment to give a uniform appearance to the installation.

The 2A frames are 62.5 inches high; the 3A frames are 84 inches high with the top 4.25 inches forming a removable cable rack which is installed after low elevators and doorways have been negotiated.

Bolt-on side panels and lift-off front and rear doors completely enclose the frames but allow quick access to equipment for maintenance. The decor of the cabinets is designed to blend with modern office furniture so that installation may be made in the general office area on the subscriber's premises. The frames are finished in dark covert gray textured vinyl paint; the lift-off doors are light olive gray (see Figs. 17 and 18).

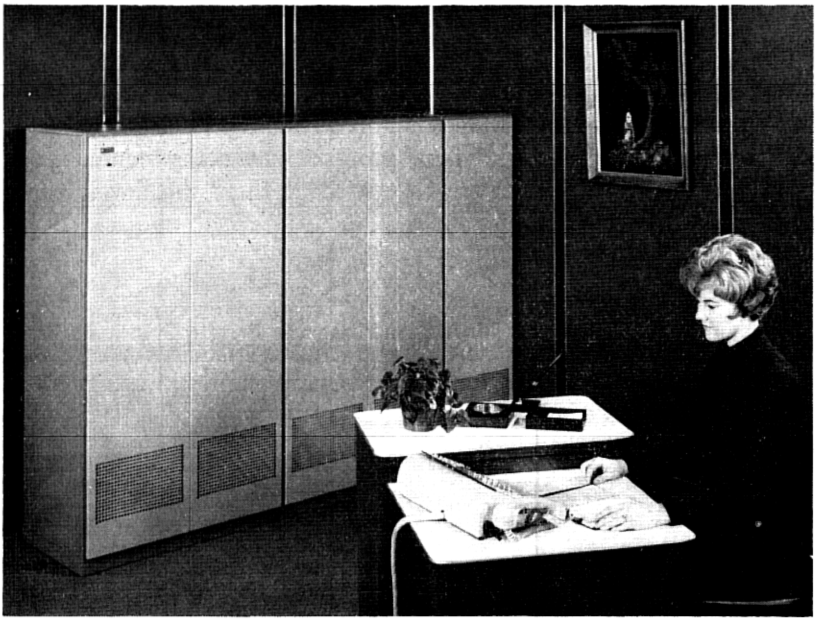

Fig. 17 — 340 line 2A switch unit.

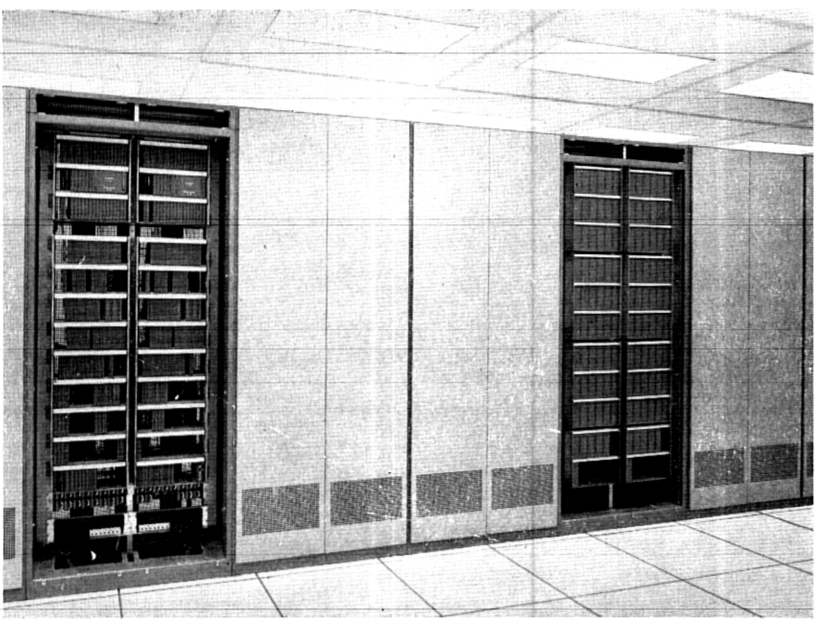

Fig. 18 — 820 line 3A switch unit.

VII. ACKNOWLEGMENTS

The design of the 2A and 3A switch units has involved a large number of people. In particular Messrs. W. B. Gaunt and R. O. Soffel have greatly contributed to the time-division circuit design. It is not possible to acknowledge individually all of the many contributors, but the authors are well aware that without them the development could not have been a success.

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