GTE LENKURT

DEMODULATOR

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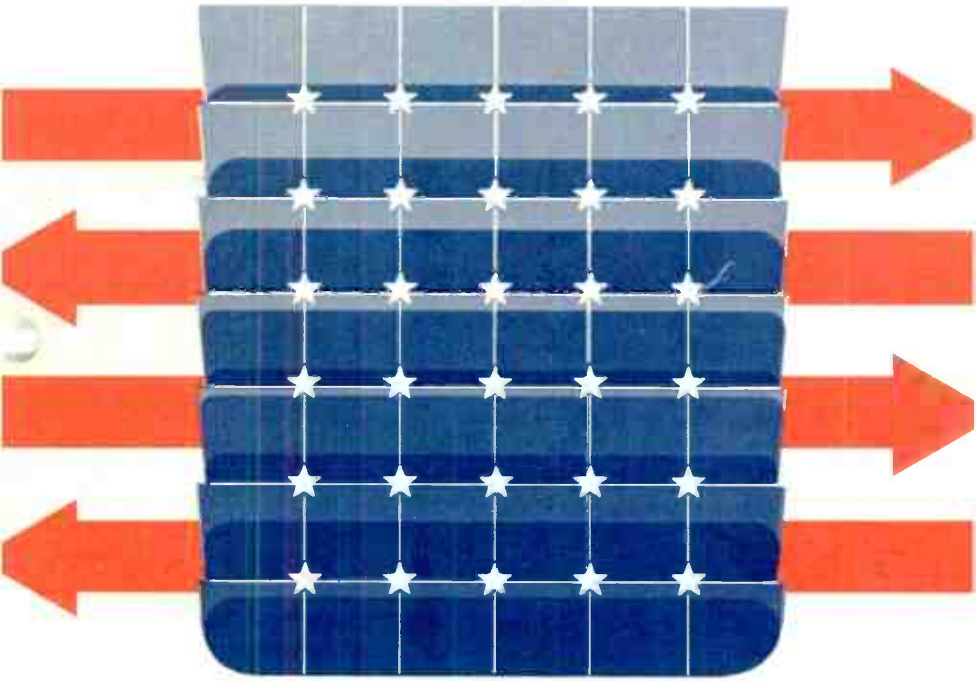
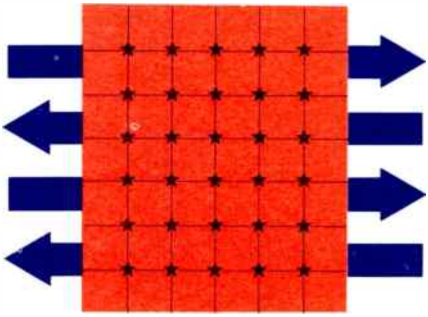


SWITCHING AND PCM SYSTEM INTERFACES

PARTS 1 AND 2



Technological advances have greatly increased the speed and versatility of the switching process in the telecommunications industry. The development of new and more sophisticated switching circuits is one of the ways in which the industry has sought to improve service to its customers.

SWITCHING AND PCM SYSTEM INTERFACES
PART 1

One of the ultimate goals of the telephone industry is a system in which any subscriber in the world can reach any other subscriber without the assistance of an operator, and have the best possible communication channel over which to conduct business, whether voice conversation or data transmission. Achievement of this two-fold goal requires advances in both the switching and transmission fields.

Transmission systems using pulse code modulation (PCM) techniques have some inherent advantages over systems using frequency division multiplex (FDM) and other analog techniques that make them very attractive for all types of telephone applications; among these advantages are relative insensitivity to fluctuations in the transmission medium and to high levels of line noise and crosstalk. Likewise, electronic switching centers afford switching speed, size and power advantages over electromechanical facilities, and allow a much wider range of services to be provided. Together, these technologies promise to bring the industry's goal another step closer.

Switching Concepts

Switching within the telephone industry is, basically, the process by which a communication channel is established and maintained. When a subscriber places a call, for example, an originating switching equipment network connects the caller's line to a transmission facility, or "trunk," leading to a terminating switching equipment network serving the called subscriber. Central offices typically contain both originating and terminating networks, which together are considered to comprise a switching system. "Intraoffice" trunks usually join the networks within one office, while networks in different offices are connected by "interoffice" trunks. Some switching systems, however, have both the origination and termination functions integrated into a single network and do not use intraoffice trunking.

The number of trunks to which a switching system has access determines

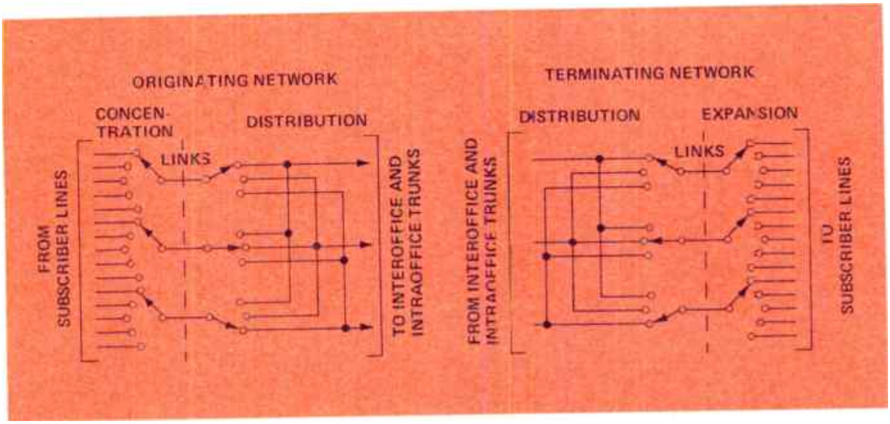


Figure 1. Concentration, distribution and expansion stages in a switching system allow a limited number of trunks to serve a larger number of subscribers.

its call-handling capability. Studies have shown that a significant portion of an office's subscriber lines are idle at any given time, so the number of trunks accessible is always made smaller than the maximum number of subscribers. Because of this, a switching system typically includes concentration and expansion stages in which various interconnection methods provide an interface between subscriber lines and a limited number of trunks (see Figure 1).

Concentration allows many originating subscriber lines to compete for a smaller number of links to a distribution stage. This stage selects an idle trunk that connects the calling line with the terminating network serving the desired subscriber. In the terminating network, a distribution stage provides access to an expansion process, which links a small number of incoming trunks to a larger group of subscriber lines.

In placing a telephone call, a subscriber transmits to the switching system a directory number identifying the location of, and the subscriber station associated with, the desired terminating network. The basic task of the system is to interpret this information and make the proper connection. The simplest way to do this is to have all lines and trunks terminate at a jack panel, and have a human operator manually connect subscribers with patch cords.

Although such manual switchboards have been around since the earliest days of telephony, and will most likely still be necessary in some applications for many years, their reliance on relatively slow manual procedures and the limitations of human operators restrict their usefulness in high-density areas. A more efficient means of providing subscriber interconnections is through the use of fully automated switching systems, in which switching devices take the place of cords, and control circuitry performs the operator's functions.

Control circuitry in general falls into two broad categories: progressive and common control. In a progressive control system, switching devices are arranged in stages, each of which has multiple output branchings, or links, to other stages. A path through such a system is established one step at a time, with the condition of the next stage unknown. A common control system, on the other hand, first identi-

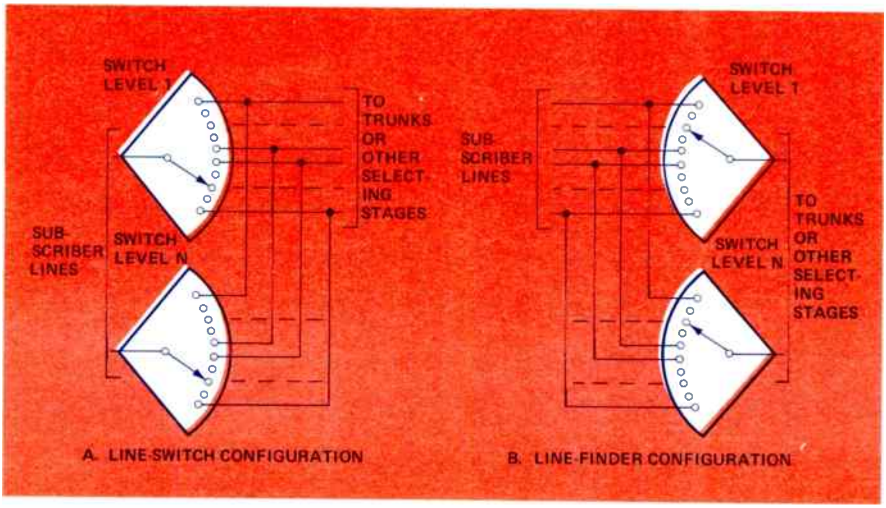


Figure 2. Concentration stages are typically of the line-switch or line-finder variety.

fies the originating and terminating points and then seeks a path through the system to connect them. In almost all cases, the switching devices in such a system are arranged in a grid-type matrix.

The major subdivisions of these broad categories are: direct and register progressive, register marker, and stored-program common control.

Direct Progressive Control

As the name implies, a direct progressive control network responds directly to digits dialed on a subscriber's subset. This type of control is limited to networks composed of large-motion electromechanical switches or relays and is primarily associated with step-by-step (SXS), or Strowger switch, systems.

A SXS switch consists of a shaft-mounted wiper, a contact bank – typically containing ten levels, with ten contacts on each level – which allows an input to be connected with one of several outlets, and control circuitry composed of relays and electromagnets. A series of switches is arranged in stages to provide selection from among several alternate path routes. Dialing a digit on a subscriber's telephone, or "subset," generates a series of electrical pulses, to which the control circuitry responds either by driving the wiper vertically (or rotating it if the vertical motion has already occurred), or by driving the wiper to the proper level and allowing it to hunt – rotate according to pulses generated within the switch itself – to find an idle contact. In practice, these techniques are combined so that the majority of the stages have hunting capability, while the final stage, which connects directly to the called subscriber line, is fully controlled by the dialed number.

Access to the switching stages is through a concentration stage using either a line-switch or a line-finder technique. In the simplest (line-switch) SXS system, every subscriber line connects directly to the wiper of a different switch or switch level (see Figure 2A). The contacts of the switches are interconnected (multipled) to allow access to all of the available trunks, or to links to subsequent selecting stages. In this line-switch configuration, a given input switch is idle unless a call is being made. To alleviate such inefficiency, the subscriber lines can be multipled to appear on the contacts while the wiper provides connection to the succeeding stages (see Figure 2B). This line-finder technique employs a certain amount of common control, in that a small group of line-finders is shared by a larger group of lines, and control of these switches is exercised by a common circuit. The selection process, however, is still controlled directly by the subscriber.

A simplified line-finder-type direct progessive system might appear as shown in Figure 3. When a subscriber lifts his handset, an "attending function," or "line," circuit — which is essentially a circuit that continuously monitors the condition of the subscriber lines — senses it and notifies a line-finder group circuit. This drives the wiper of an idle line-finder switch to the contact associated with that subscriber line; each line-finder is also connected to a switch that supplies dial tone to the originating subscriber. The first digit dialed then drives the wiper of the originating selector switch to the appropriate level, where it hunts for an idle trunk going to the correct terminating network. The second digit dialed drives the intermediate selector stage wiper to the proper level, where it in turn hunts for a link to the final selector, or connector. When the third digit is dialed, it causes the connector wiper to rise to the desired level, and the fourth digit rotates the wiper to the contact associated with the called subscriber, thus completing the connection.

While direct progessive systems are relatively simple, efficient and economical in small telephone exchange applications, they have disadvantages making them unsuitable for serving large numbers of subscribers. Chief among these are the inflexibility inherent in having to make trunk and line assignments in accordance with a rigid office number code, and the many switching stages necessary to accommodate large groups of subscribers. Additionally, all of the control circuitry associated with a switch is tied up as long as a connection lasts, even though its function is fulfilled in, at most, a matter of a few seconds; this represents a very inefficient utilization of control capability. A much more flexible and efficient system configuration can be achieved by introducing a greater degree of common control and divorcing the subscriber from direct participation in the overall switching process.

Register Progressive Control

Common control can be introduced into a progressive system through a register, wherein dial pulses are stored for a short time before being used to control the switch functions. The register is basically a circuit, or group of circuits, which receives information signals, translates them into a form more readily usable by the network — some system types, for example, convert dc dial pulses to multi-frequency tones — and generates control signals to establish the desired connection.

Generally, a register is placed between the concentration and first selecting stages so as to accept information only from that line having access to the network. The actual time required to process subscriber input data and establish a connection is very short compared to the total holding time per call, so a small group of registers can serve a large number of subscribers, significantly reducing the amount of control circuitry needed. A further reduction can be realized by divorcing the translating portion of the register from the information reception, storage and control signal generation circuits; this is possible because,

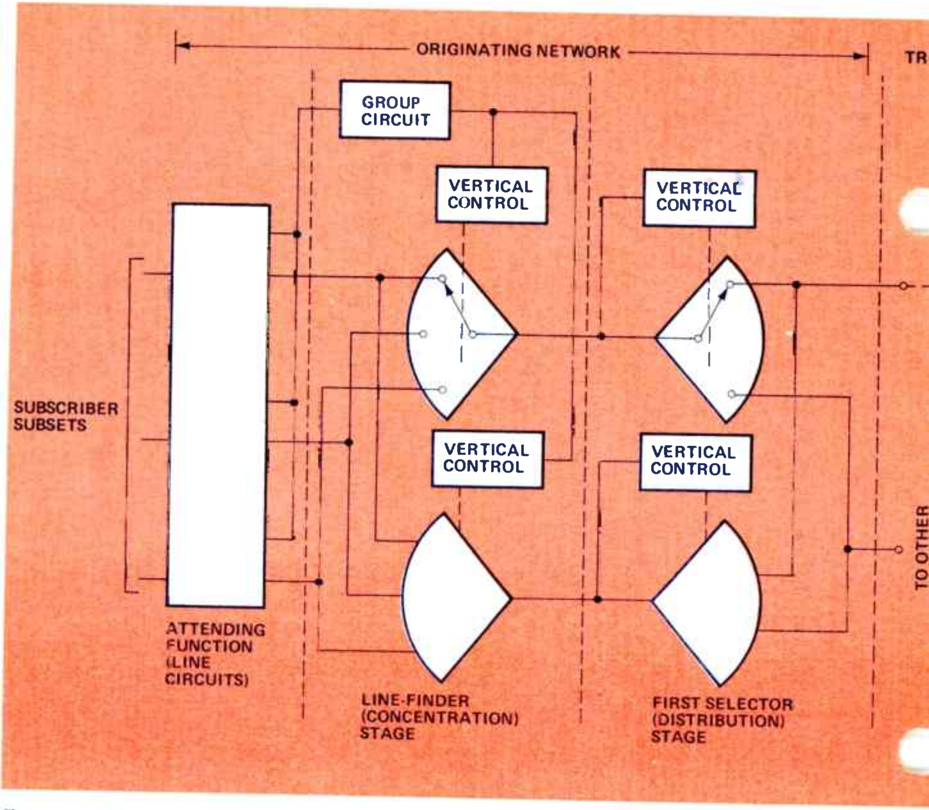
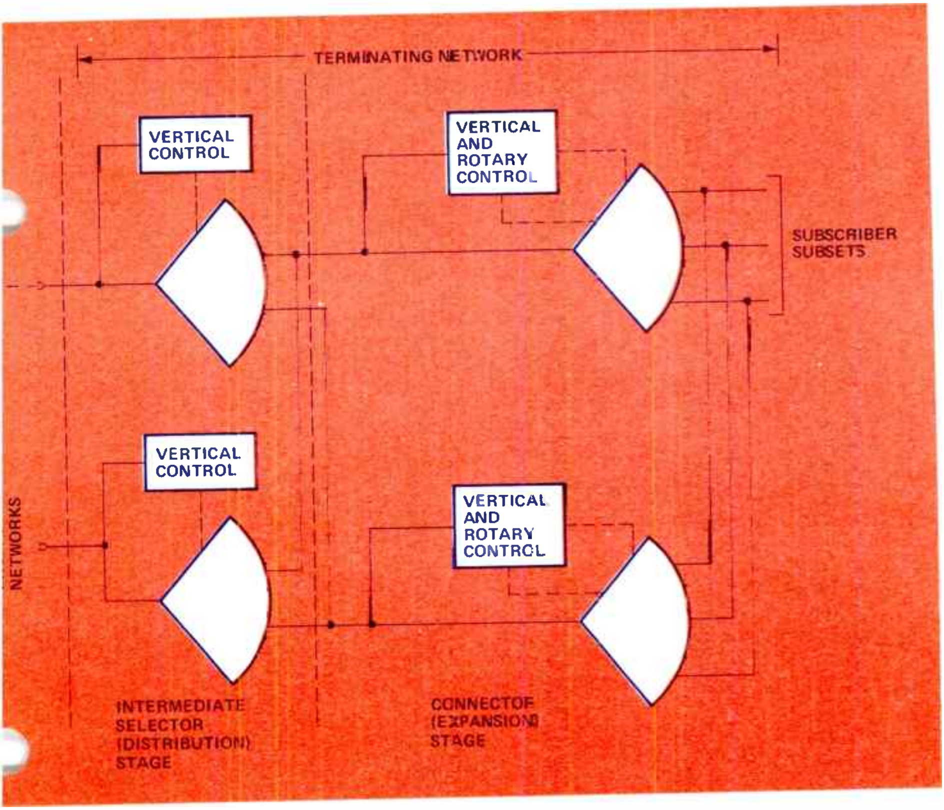


Figure 3. In a direct progressive system, electrical pulses generated by a subscriber subset directly control the switching action.

once again, the process occupies only a small part of the total circuit operation time, and can thus be shared by several registers. A register is commonly thought of in terms of two units: the "control register," which receives and stores information, and the "translator," which interprets the information. Because it not only receives and stores data but also transmits control signals to the switching stages, the control register in a progressive system is frequently referred to as a "sender," or "register-sender."

When a subscriber lifts his handset, the concentrator connects his line to an intra-stage link served by a register (see Figure 4). In a typical application, dial pulses then set relays in the control register, thus storing, or "writing in," the digits. These digits, identifying both the location of the desired terminating switch network and the called line served by that network, necessitate two translations. To speed service, translation and selection of a trunk usually occur as soon as those digits are registered, while the line code is still being received. With a telephone directory number of the form 345-6789, for example, the first three digits indicate the terminating network serving the desired subscriber and, once they are registered, the translator commands the control register to generate the signals necessary to connect the originating line to a trunk going to that network. The other four



digits contain information as to what subscriber is being called.

The trunks to which a network has access, and the switch groups providing that access, are assigned unique location, or equipment, numbers that are related to directory numbers within the translator. The first digit of the office code digits 345, for example, might be associated with the bank of contacts on the second level of a SXS switch; when this digit is dialed, the necessary translation is performed and control signals are produced to drive the switch wiper.

With the line-to-trunk connection made, the line code digits are read out of the register, driving switches in the terminating network to the contact associated with the called subscriber line. Once the path has been established, the register is removed from the circuit and is free to accept another call. Since information regarding the desired subscriber line is retained in the register until completion of the connection, the network can try an alternate route should the most direct path be blocked. Hunting time is thus not limited to the time between dialed digits, as it is in direct progressive systems.

As shown in this simplified explanation, register progressive control isolates the dialing process from the actual control process, thus increasing the flexibility of the system. By their very nature, however, register progressive systems are slower than direct progressive systems, requiring as much as several seconds to search for a path, drive a series of switches, and complete a connection. Additionally, utilization of alternate routing is restricted

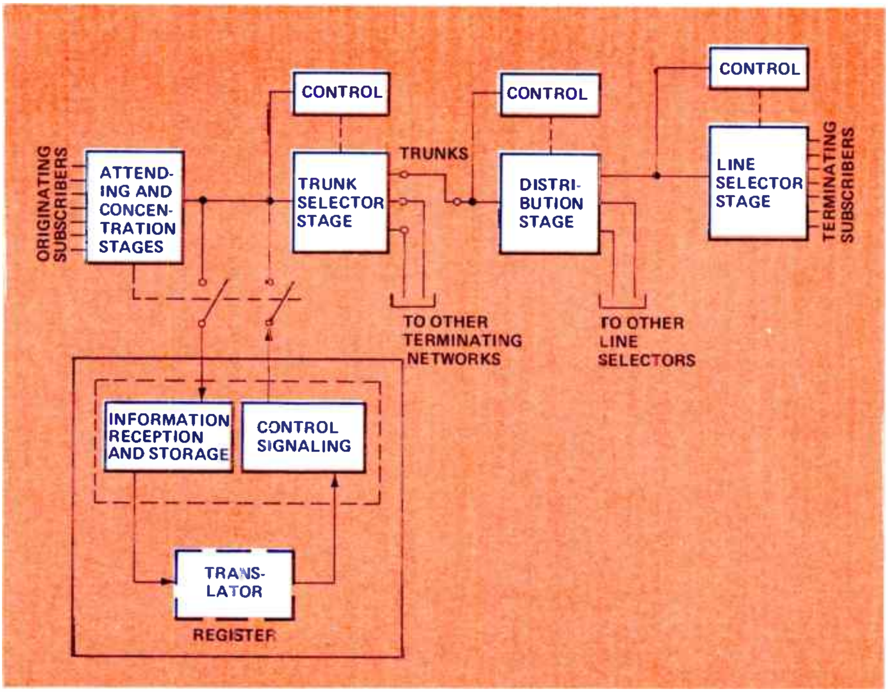


Figure 4. In a register progressive system, the subscriber is isolated from the control function by a register, in which dial pulses are translated into a form more compatible with electromechanical switch operation.

because the number of interconnections possible with an economically feasible group of switches is limited.

These shortcomings in progressive-control switching systems are mainly due to the limited number of outlets per switch as they sequentially hunt for idle trunks and links. For example, the wiper of a SXS trunk selector might hunt for one idle trunk in a group leading to the desired terminating network. Until the subscriber line-to-trunk connection is made, however, the control circuitry does not know if the terminating network switch has access to idle links to the line selector. If no access is available, the call is blocked and selection must begin again on an alternate route. The situation is aggravated by the structure of the large-motion switches involved, which hunt in one direction over one contact bank only. Because of this unidirectional uni-bank motion, any switch in a progressive-type system is able to examine only a very small portion of the potentially usable outlets. To improve upon this situation, it is advantageous to eliminate the stage-by-stage process and use a technique which finds an idle trunk as soon as the subscriber demands one, and then performs the line-to-trunk connection. This is the principle behind register marker common control systems.

Register Marker Common Control

Although register marker control has occasionally been applied to progressive-type networks, it is most effective when used with switches arranged in a grid, or matrix, form.

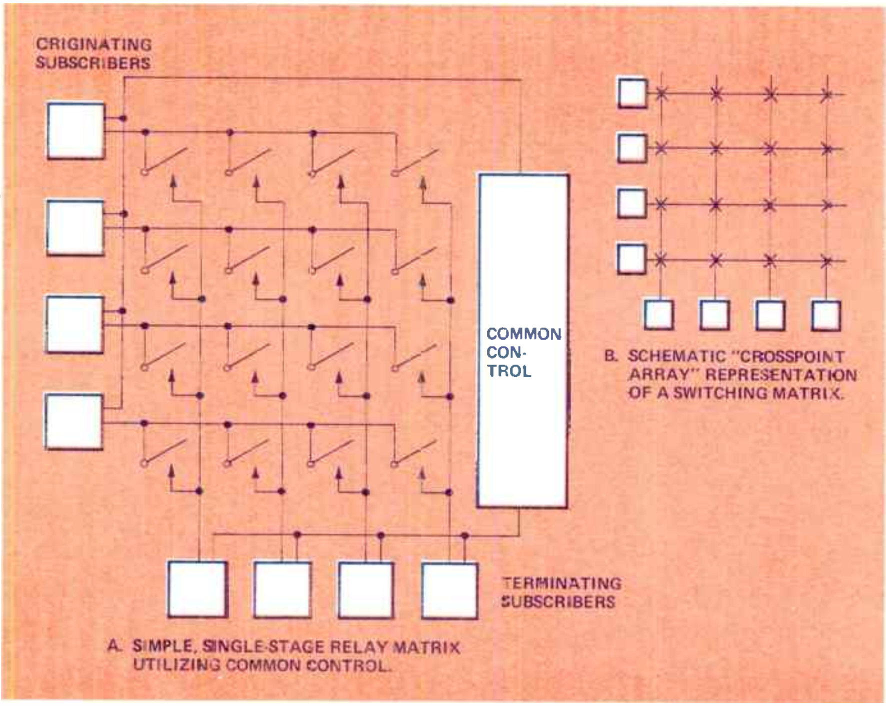


Figure 5. A switching matrix, or crosspoint array, provides connection between subscribers, and is the basic element in non-progressive networks.

Essentially, a matrix can be defined as an orderly array of switching devices. Large-motion switches such as those found in progressive control systems do not readily lend themselves to this type of arrangement, and are therefore rarely used. Instead, small-motion devices such as relays, crossbar switches and reed switches are used. Figure 5 is an example of a simple, single-stage relay matrix; the common control circuitry responds to information transmitted by an originating subscriber by determining what terminating subscriber is desired, and energizing the relay necessary to complete the connection. In practical terms, several matrices are usually interconnected in a "grid network" to provide more than one switching stage and thus expand the system's capabilities. In this case, the individual matrices are commonly referred to as "primary," "secondary," "tertiary," and so forth, depending upon their relationships within the grid network.

Common control is exercised in systems using such networks by "marker" circuits whose basic purpose is path establishment. To accomplish this, the marker surveys all of the available network output lines, "marks" one that is idle, and activates the appropriate switching devices. Marking usually entails placing either a ground or some voltage on a control line associated with the selected trunk or link; the opposite potential is placed on the input control line, and the common control circuitry attempts to find a path between the two.

This marking process requires that groups of digits be stored to allow

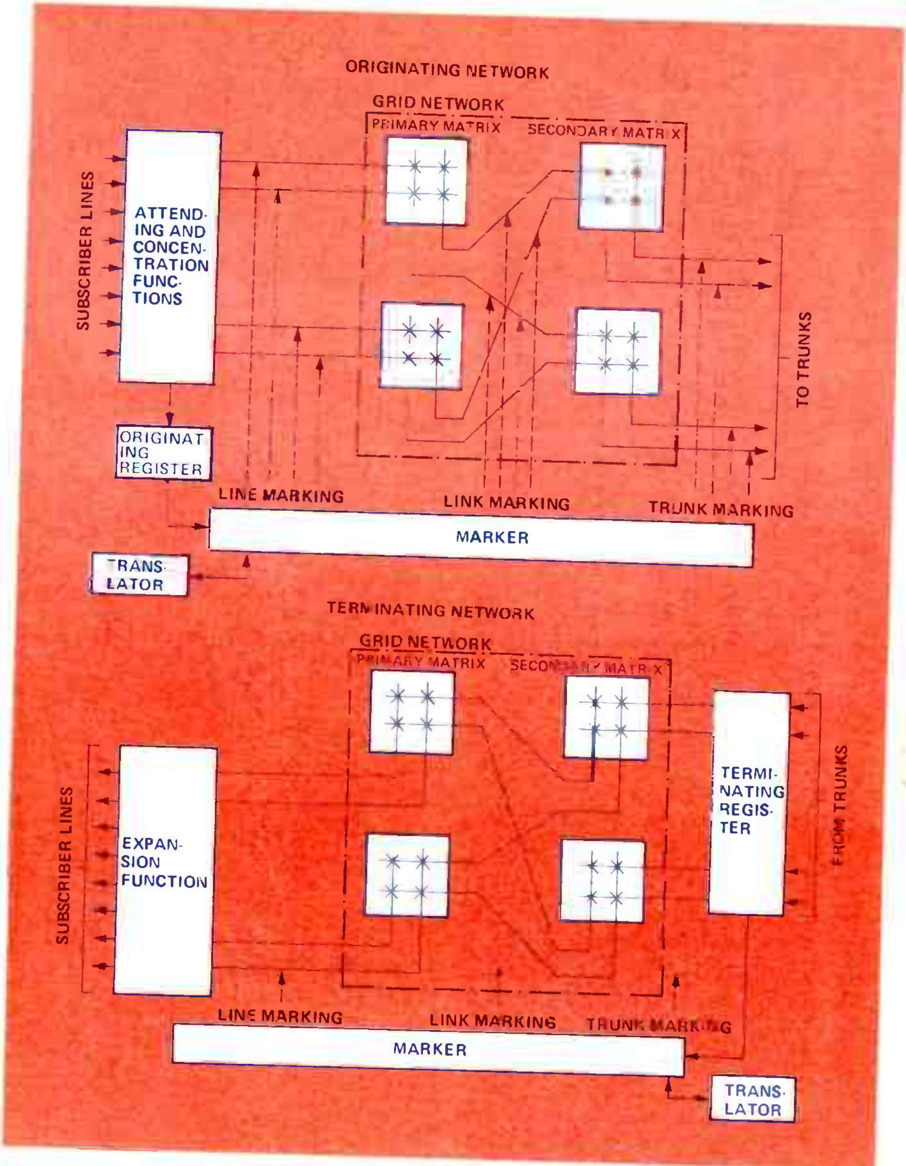


Figure 6. A simplified two-stage register-marker system in which origination and termination are accomplished in separate networks.

identification of the desired terminating network location, so systems using markers must also contain registers. Unlike those found in progressive systems, however, these registers are only required to serve as information stores: translation — essentially the same directory code number-to-equipment number conversion as occurs in progressive systems — is typically handled by a translator common to several markers, and control signal generation occurs within the marker itself.

Common control techniques afford considerably more flexibility in system organization than do progressive control techniques. While progressive systems are limited to sequential arrangement of switching stages, systems using common control can assume many forms. The originating and terminating functions may, for example, be performed by completely separate networks (see Figure 6), as are progressive systems. In such a configuration, information from an originating subscriber is received by an originating register. The office code portion of the directory number held in the register is sent to a marker, which translates it, locates an idle trunk, and establishes a path through the network. An intermediate link-marking process is used to find and select an idle link between matrices within the grid network. The terminating network accepts the line number code in its own register and locates the desired subscriber line. In any system using separate networks, every subscriber line must appear at both the input (origination) and output (termination) sides of the system.

Another configuration made possible by common control techniques takes advantage of the bidirectional characteristics of matrix arrays by combining concentration and expansion in one stage. Origination and termination are still separate, but the multiple appearance of subscriber lines at both input and output is eliminated, and more efficient use is made of the system.

A third system combines not only the concentration and expansion operations, but the originating and terminating networks as well (see Figure 7). Unlike the other systems, which require register-marker circuits for each function, this plan makes possible the utilization of one marker; corresponding to the No. 5 Crossbar System, this configuration makes fuller use of com-

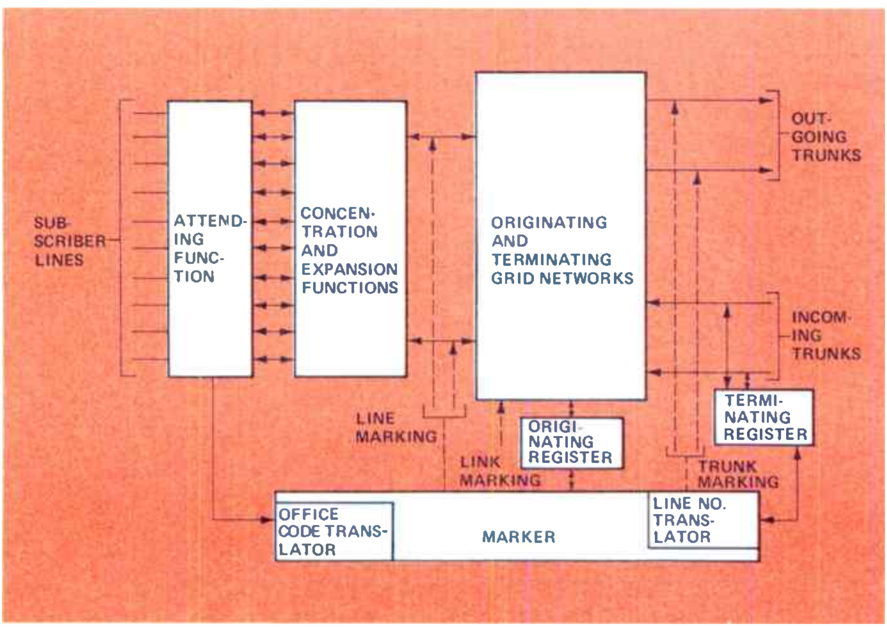


Figure 7. Combining functions in bidirectional networks allows common control techniques to be utilized in the most efficient manner.

mon control than any other electromechanical system.

When a subscriber begins a call, access from his line to the marker's office code translator is provided through the attending function. The dialed office code is translated and an originating register selected. This register is connected to the subscriber line and the marker released to serve another line. The register receives and stores the dialed line number. When the subscriber has finished dialing, the register regains access to the marker and supplies it with both the location of the calling line and the called number. The marker selects an appropriate trunk and establishes a path. Called line numbers received on incoming trunks are stored in a terminating register; the marker uses this information to establish a trunk-to-line path.

In systems composed entirely of electromechanical devices, switching functions are carried out by mechanical elements. Even such control circuitry as registers, translators, and markers depends upon groups of switches and relays. Although these devices have been considerably reduced in size and increased in speed since the earliest days of telephony, their capabilities are still limited by the time required to open and close a considerable number of contacts (some crossbar markers contain as many as 1500 relays) in storing, translating and generating control signals. Developments in centralized control techniques have allowed systems to be produced that replace electromechanical devices with electronic stored-program control and thus increase processing speed.

Electronic Stored-Program Control

Switching systems using stored-program common control (SPCC) are more generally referred to as electronic switching facilities, although, except for the latest generation, they are combinations of electronic and electromechanical techniques. In the most widely used electronic switch systems, such as Western Electric's No. 1 ESS and GTE Automatic Electric's No. 1 EAX, the switching matrices are arrays of reed switches — called "ferreeds" by Western Electric and "correeds" by GTE Automatic Electric — which are, in fact, a special type of relay whose contacts, or reeds, are part of both the magnetic and electrical circuits. That is, the contact points serve as the core of the electromagnet energizing them, and at the same time complete the circuit in which they are placed. These devices are considerably smaller than conventional relays and switches, and their speed of operation is correspondingly more rapid.

Control of the reed-switch matrices is exercised through a computer-like centralized facility, the "processor," which is composed basically of a call store, a program store, and a central control unit (see Figure 8). Using read-write (alterable) and read-only (permanent) electronic memories, and solid-state logic circuitry, the processor keeps track of all line, trunk and equipment states and assignments within the system, ascertains what actions must be taken to complete a call, causes those actions to occur, and even provides billing information to the telephone company.

The call store is a temporary, read-write-type of memory facility; that is, information can readily be programmed into and recalled from it. In some systems, a "network map" in the call store records the idle and busy state of all the central office links, and of all the subscriber lines and trunks served. The call store also registers dialed digits and converts them into a computer-language format.

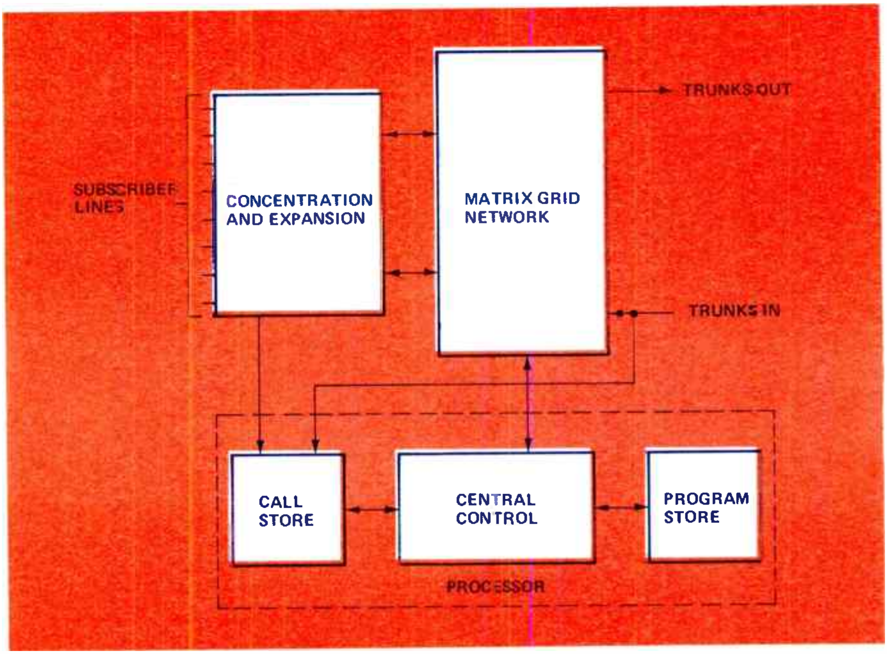


Figure 8. In electronic stored-program switching systems, control is exercised by a computer-like processor.

The program store contains all of the rarely changed, office-dependent data necessary to identify the lines, trunks and equipment that must be involved in the completion of a given telephone call. This memory is permanent in the sense that a physical change — such as replacement of a magnetic tape — is required to modify the stored information. In addition to such data as line and trunk assignments, equipment locations and subscriber class of service, the program store contains the operating instructions that control the performance of the switching system. These instructions can be divided into five functional groups: input and output programs, subroutines, operational programs, and executive control programs. Each of the first four functional groups controls a particular phase of call processing, under the overall direction of the executive control program. The input programs, for example, provide such information as line and trunk states to the call store, where the operational program examines it and decides upon the necessary action. The subroutines permit translation of dialed digits, trunk and link availability, and equipment locations into a form readily usable by the output program, which orders the opening and closing of paths through the network.

The central control unit serves as an interface between the call and program stores. It receives instructions from the program store and draws upon the data in the call store to perform the actual circuit actions that result, ultimately, in connection of a calling subscriber to a transmission path.

In one system, an input scanning program (part of the input program group) causes the central control unit to scan each subscriber line at least one time every 200 milliseconds (ms).

The "present" condition of a line – whether on- or off-hook – is compared to its "last" condition, as recorded in the call store. If an originating subscriber has lifted his handset, this status change is noted by the scanning program, which temporarily halts the scanning process and allows the number of the calling line to be registered in the call store. To ensure that all of the dialed digits are properly received, the program then directs the central control unit to scan the line at 10-ms intervals; it also directs that dial tone be supplied to the caller.

After all of the dialed pulses have been received by the call store, the operational program examines them and informs the central control unit of the type of call (interoffice, intraoffice, etc.) that is being made, and directs it to refer to the network map memory for idle links and trunks. When a path has been found, the central control unit is commanded to generate signals to make the proper connections within the grid network. There is thus a constant exchange of information and commands among the processor components, occurring at such a rapid rate that, in No. 1 EAX and ESS systems, as many as 65,000 subscriber lines can be served, compared to the 10,000 normally accommodated by all-electromechanical No. crossbar systems.

All of the systems thus far considered have been based on space-division switching. That is, the individual speech or message paths established through the network – regardless of control mechanism – are physically separated. The latest generation of switching systems, such as GTE Automatic Electric's No. 3 EAX and Western Electric's No. 4 ESS, totally do away with electromechanical devices and utilize what are essentially time-division-multiplex (TDM) networks under processor control.

TDM Switching

Perhaps the most notable difference between space-divison and time-division switching is that, in the former, the calling and called lines are joined by a permanent, unique path which exists as long as the call lasts, while subscribers served by the latter are actually connected only intermittently, although at such a rapid rate that they are unaware of it.

Before entering a TDM switching system, the intelligence to be switched must be in a digital form. When the intelligence within a given voice-frequency (vf) channel is already in such a form – as in a PCM transmission system – it can be applied directly to the TDM system. When the intelligence is analog, however, – the electrical signal representing an individual voice conversation, for example – it goes through a conversion process in which it is sampled at intervals to determine its general characteristics. This rate is high enough (usually 8000 times per second) so that no important information is lost. Each amplitude sample is encoded as a group of eight electrical pulses, or "bits," that constitute a binary "word" giving its value. These binary words are then presented to the input of the switching system.

Within the TDM system, each input and output channel is sequentially sampled by a processor. The sample time, or "time slot," allotted to each channel is sufficient to accommodate one binary word (see Figure 9). A word appearing in a channel is thus associated with a particular time slot, and the switching process involves moving this word into the slot associated with the desired output channel.

Transfer of information through the system is accomplished by "opening" semiconductor "gates" (causing diodes or other solid-state devices to conduct) that are associated with the

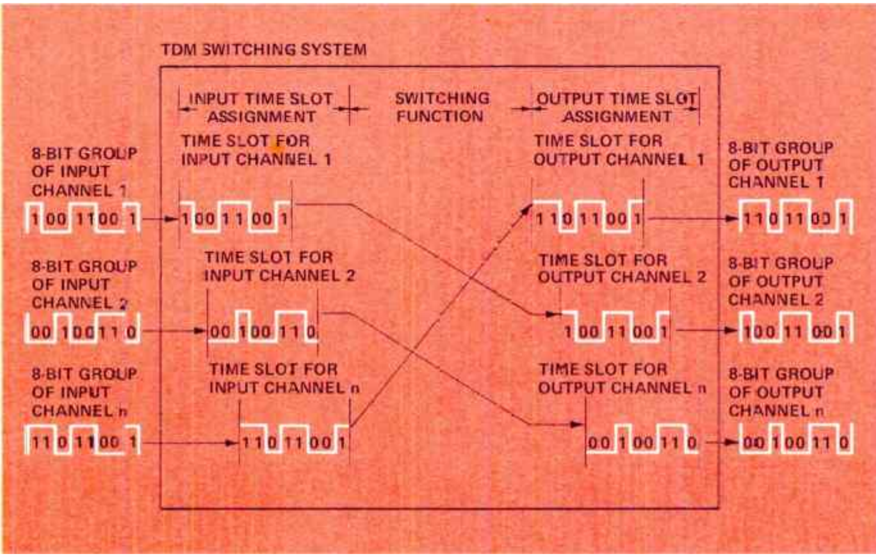


Figure 9. In TDM switching, input and output channels are associated with unique time slots. The switching process involves transferring the contents of one slot into the desired output channel slot.

input and output channels. The processor controls the opening and closing of gates so that the bit groups of a particular input channel are directed to the proper output channel, where conversion to analog form can occur if necessary.

Even the new, all-solid-state electronic switching systems require a physical conductor for transmission of voice and signaling information, so some type of space-division facility is provided in most of the larger systems. There are currently two basic ways to integrate this element into a TDM system: time-space-time and space-time-space configurations. The former is utilized in Western Electric's No. 4 ESS, and the latter in GTE Automatic Electric's No. 3 EAX.

Time-Space-Time Switching

In the No. 4 ESS time-space-time configuration (see Figure 10), a unit called the time slot interchange (TSI) provides time-division switching. A time-multiplexed switch matrix composed of solid-state devices serves as a space-division facility that is shared by a number of TSI's.

The input to a TSI is a stream of bits representing 120 vf channels. When it is necessary to interface with analog voice circuits, a voice interface unit (VIU) encodes the transmitted intelligence of 120 channels and interleaves, or "multiplexes," the resultant bit groups into a single stream. When the interface is with a 24-channel PCM transmission system, a special digital group, or "digroup," terminal combines five 24-channel signals into the requisite 120-channel input.

Routing information — the number of the called subscriber. for example — is read into a call store memory and is used by a trunk hunt program to find an unoccupied channel that is assigned to a trunk going to the called line. A path hunt program then finds a path through the switch matrix, and stores the information in a time slot memo-

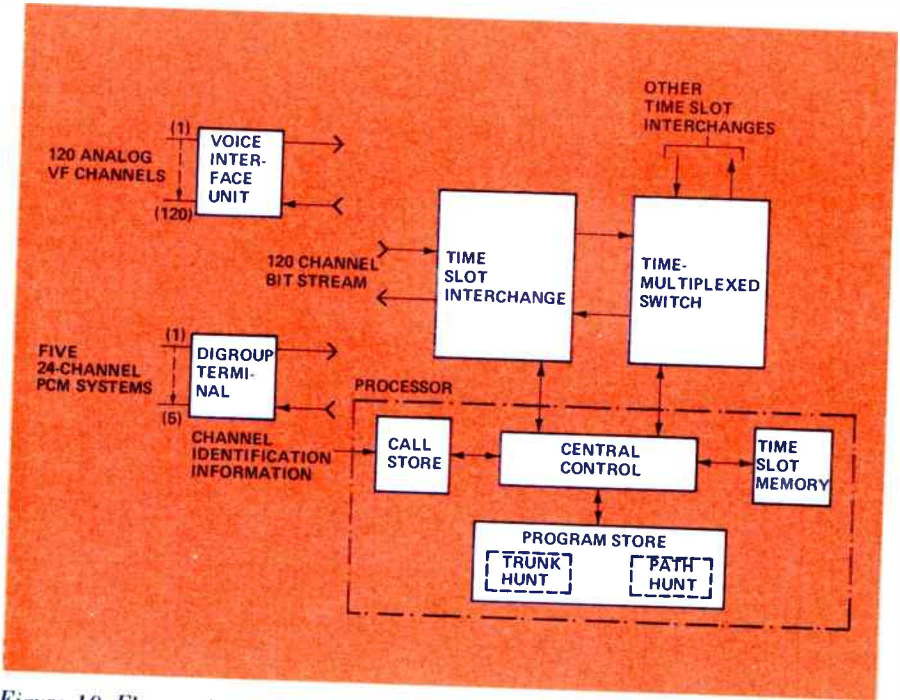


Figure 10. Electronic switching using a time-space-time configuration.

ry. This information is read out once every 125 microseconds (μs) to connect the input and output channels; during this connection period, which is slightly less than one microsecond in duration, one binary word is transferred through the system.

As each binary word in the bit stream appears at the input of the time slot interchange, it is written into an input buffer memory cell (see Figure 11) so that the word of channel one is stored in cell 1 during time slot 1, the word of cell two is stored in cell 2 during slot 2, and so on to the word of channel 120, after which channel one's next word appears. At the TSI's output, buffer memory cells are read out in the same manner (cell 1 into channel one during slot 1, etc.) to reconstruct the single 120-channel bit stream. Between the input and output buffer memories, the processor can arbitrarily assign time slots.

For example, the trunk hunt program might direct that channels 2 and 4 be connected. The path hunt program would find the appropriate crosspoint (A1, in this case) and locate an idle time slot; it might determine that slot 120 is idle and assign it to the call. This data is stored in the time slot memory. During time slot 2, a binary word from channel two would be written into input memory cell 2; as previously described, any word in output memory cell 2 would be read out at that time to become part of the bit stream. Similarly, during slot 120, one word would be written into input cell 120 and another read out of output cell 120. At the same time, however, the processor directs that the word in cell 2 be transferred through crosspoint A1 into output cell 4. When slot 4 appears, this word is read out into the bit stream. The entire process occurs 8000 times per second, and the

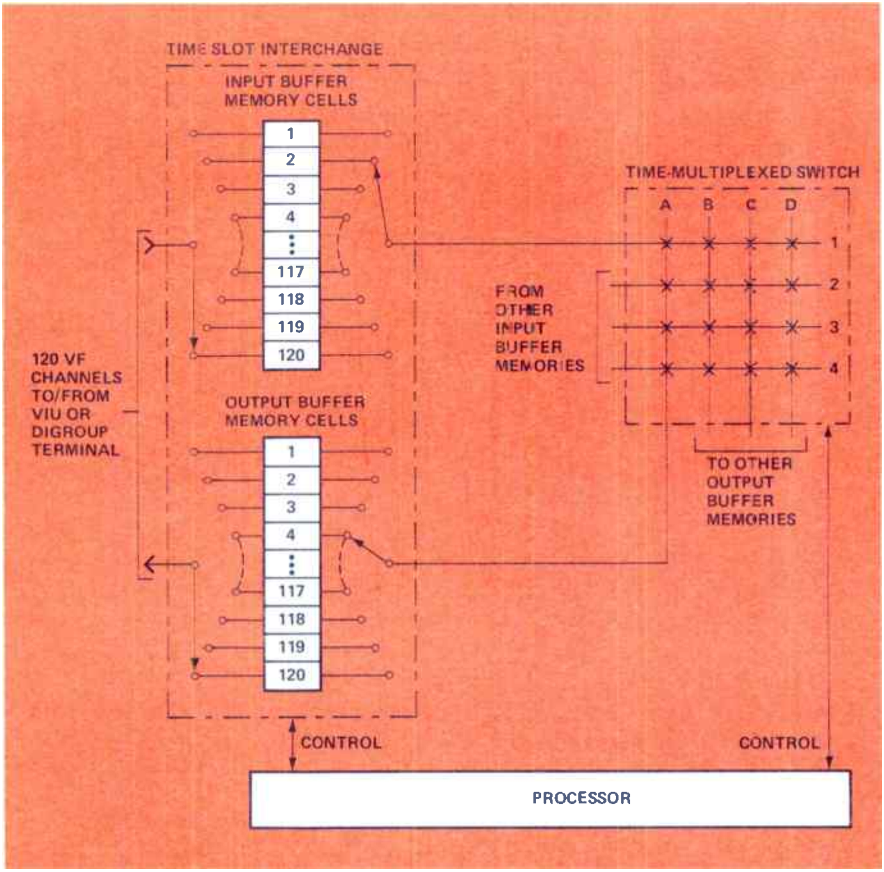


Figure 11. In a time-space-time switching configuration, input memory cells are read into output memory cells through a solid-state matrix under the direction of a computer-like processor. The process is carried out by rearranging binary words in time and space; the rotary switch symbol is used only for the sake of convenience.

subscriber is never aware that he is only intermittently connected.

Space-Time-Space Switching

As with time-space-time switching, a space-time-space configuration requires that its inputs be in a digital form. In the case of GTE Automatic Electric's No. 3 EAX, an interface with analog voice circuits is provided by a PCM channel bank, which performs an analog-to-digital conversion prior to actual entry into the switching system (see Figure 12). For interfacing with PCM transmission systems, an office terminating shelf is provided to terminate the PCM line for monitoring purposes, and for final regeneration of the signal. The space-time-space system itself consists of three major subdivisions: peripheral equipment, switching network, and control and memory complex (CMC).

The peripheral equipment consists of line equipment, group equipment, and a complex of service circuits that

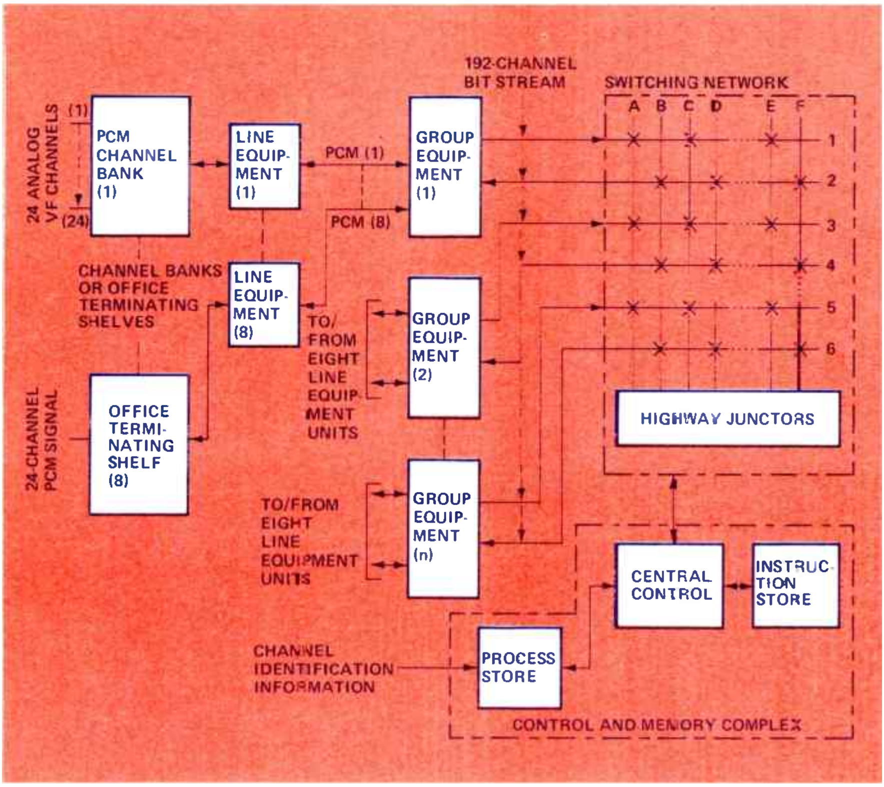


Figure 12. An electronic switching system in a space-time-space configuration.

are concerned with signaling and other supervisory functions. The line equipment interfaces with the input signals, and provides an essential synchronization function that ensures that all channels into the network have the same relationship in time. One line equipment unit has circuitry to terminate a single 24-channel PCM signal. Eight line equipment outputs are multiplexed by a group equipment unit to produce a 192-channel bit stream that is applied to the switching network.

The control and memory complex contains the central control processor and the memory facilities required to oversee operation of the system. The instruction memory contains instructions and data to be used repeatedly by the processor; it is, in other words, a type of program store. The process store, which is essentially a call store, is the repository of transient information relating to particular calls and of such other data as the idle and busy states of all lines and trunks served by the system. The central control unit actually carries out the instructions provided through the programs.

The switching network is divided into a space-division section consisting of a matrix of integrated circuit elements, and a time-division section, or "highway junctor," that accepts binary word inputs from one channel and switches them to an outgoing channel.

The group equipment accepts, in sequence, one binary word from each of 192 input channels and assigns them to time slots so that the word from channel one appears in slot 1, etc. The resultant 192-channel bit stream is applied to the switching network. A group equipment unit also accepts the output bit stream and demultiplexes it into eight 24-channel PCM signals.

Using such information as the number dialed by a subscriber, the CMC determines the channels that are to be connected and ascertains what crosspoints have to be activated. As each binary word enters the matrix, it is transferred into a data transfer memory (DTM) within the highway junctor. When the correct time slot appears in the output bit stream, the stored word is transferred through the appropriate crosspoint into it.

For example, the CMC might demand that group equipment 1, channel 4, be connected to group equipment 2, channel 175. In this case, the channel 4 word might be transferred through crosspoint C1 into an idle DTM in the highway junctor. At the appearance of time slot 175 in the group equipment 2 output bit stream, the CMC would activate a crosspoint – D4, for example – and insert the word into the slot. Group equipment 2 would demultiplex the 192-channel bit stream and route the word to the output processing equipment (channel bank or office terminating shelf, depending upon input interface). This process would be repeated 8000 times a second, joining the subscribers at that rate.

The August *Demodulator* will discuss the ways in which PCM transmission systems interface with the various switching systems.

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SWITCHING AND PCM SYSTEM INTERFACES PART 2

The growing use of PCM transmission systems within the telecommunications industry has solved many of the problems encountered at the various switching system interfaces.

The July *Demodulator* outlined the operation of several of the major switching system types. This issue will consider the problems encountered when they must interface with one another and with the PCM systems that are in wide use today for multi-channel telephone transmission.

PCM Transmission Systems

Basically, pulse code modulation (PCM) is a process which converts a continuous-wave analog signal into a pulse-type digital signal. To accomplish this, samples of an analog signal's amplitude are taken at regular intervals. Each sample is then encoded as a series of electrical pulse/no pulse conditions, or bits (binary digits), which represent, in binary form, the amplitude. These bits can then be transmitted over a communication facility. At the receiving end, the bits are decoded and a very close approximation of the original signal constructed.

Most PCM transmission systems in use today have an 8-kHz sample rate, encode the samples as eight-bit binary words, and combine the bits representing 24 analog signals, or voice-frequency (vf) channels, into a single, continuous stream. With an 8-kHz rate, there is a 125-microsecond (μs) interval between successive samples of any given channel (see Figure 1A); the binary word representing the sample amplitude is allotted a 5.2-μs time slot. Between the binary words for one channel, then, the words for 23 other channels can appear (see Figure 1B). Such a block of 24 eight-bit words is referred to as a "frame," during which all of the channels served by the system are sampled and encoded in sequence.

Besides the voice conversation data, signaling information must also be transmitted. Signaling in general is the process by which an originating subscriber notifies the switching system that a message is to be communicated. Since it is of a much lower frequency than a voice transmission, signaling information can be sampled and transmitted at a slower rate. For five consecutive frames, therefore, eight-bit voice words are sent, while in every sixth frame seven-bit voice and one-bit signaling samples are sent. In addition, each frame has an extra, or "S," bit whose sole purpose is to establish a pattern to identify which frames in a series contain the signaling bits.

The PCM channel bank equipment that is typically used in the analog-to-digital and digital-to-analog conversion process is composed of both common equipment and channel units (see Fig-

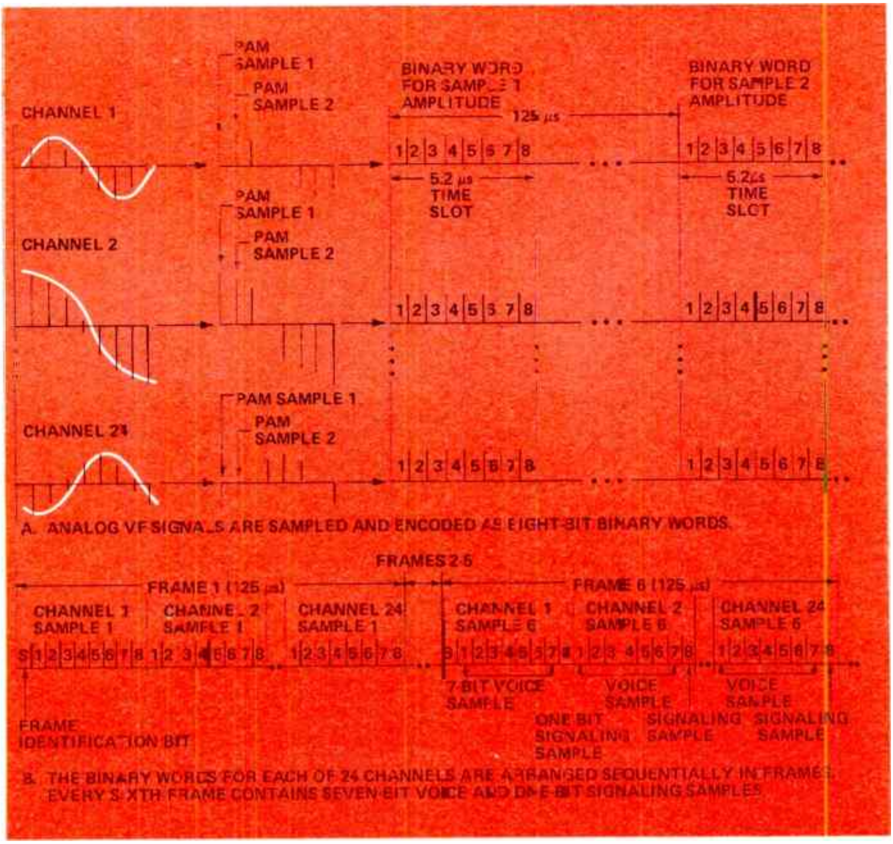


Figure 1. Basic encoding and organization pattern of signals in a 24-channel PCM transmission system.

ure 2). The transmit common equipment accepts pulse amplitude modulated (PAM) signals representing the vf outputs of 24 channel units (assuming a 24-channel system), sampling them sequentially to produce a stream of amplitude samples that it then converts to a bipolar digital format for transmission over one pair of wires. Receive common equipment converts a bipolar PCM signal arriving on a second pair of wires to a unipolar form, decodes it to produce a series of PAM signals, and routes these over a PAM bus to the 24 channel units. There is a wide range of channel units available, to cover a multiplicity of operating requirements, but the vf path is virtually the same in every case.

The voice path through a channel unit typically begins at what is referred to as a "2-wire drop" (see Figure 3), where a pair of wires – usually associated with the originating or terminating network of a switching system and traditionally referred to as "tip" (T) and "ring" (R) leads – provides an analog vf input/output facility. Because PCM transmission is inherently a 4-wire process (one pair of wires is required for transmission and another for reception), a hybrid coil performs a 2- to 4-wire conversion in the voice transmit path, and *vice*

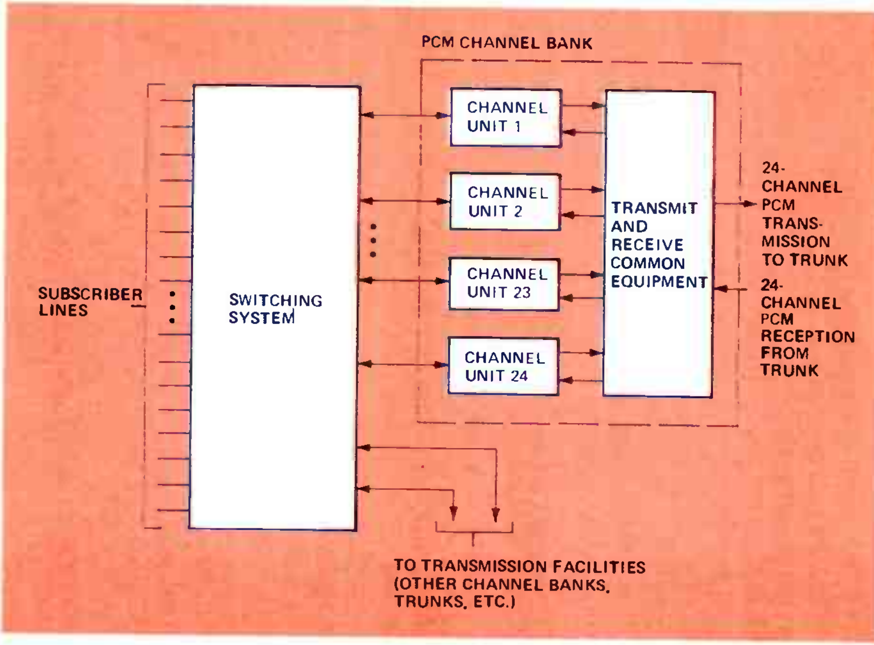


Figure 2. To increase the capacity of a transmission facility, the interface of a switching system and its trunks can include a PCM channel bank.

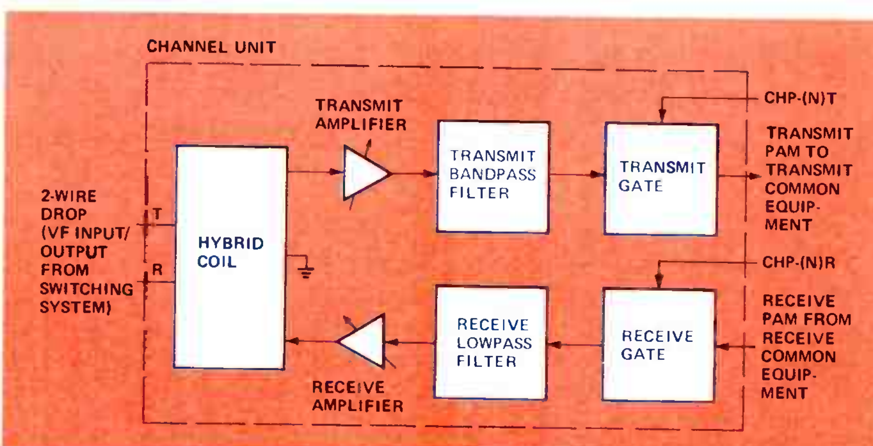


Figure 3. The transmit and receive vf paths through a channel unit typically involve a 2-wire-to-4-wire conversion and an analog/PAM interface.

versa in the voice receive path. If the input is already of a 4-wire type, this step is not necessary, so the voice paths go through isolation and matching transformers instead.

On the carrier (trunk) side of the coil (or transformer), the vf transmit path goes through an amplifier and a transmit bandpass filter to a transmit gate. This gate converts the vf signal to a PAM output which is sampled, or "gated out," at an 8-kHz rate by an enabling channel pulse transmit, or CHP-(N)T, pulse from the transmit common equipment. The voice receive path accepts PAM signals from the common equipment each time a channel pulse receive, or CHP-(N)R, pulse appears. These PAM signals are filtered by a lowpass filter, which also acts as an integrator to convert them to an analog format. This analog receive signal is passed through an amplifier whose output — a very close approximation of the original vf input — is connected to the 2-wire drop through the hybrid or transformer. With only minor variations, this is the method by which a vf channel is established between a switching system and a PCM transmission facility. The differences between PCM channel units lie mainly in their treatment of the signaling techniques that have evolved in the analog systems.

Although most of the signaling within the United States is accomplished with either loop or E&M techniques, the uneven growth of both population and technology has led to a situation in which any given switching center may have to work into other centers using different signaling methods. A system using loop signaling, for example, could have access to trunks leading not only to other loop-signaling systems, but also to E&M, multifrequency (MF) and single-frequency (SF) systems. When analog transmission facilities link such diverse systems, special "trunk circuits" are required to perform the necessary conversions from one signaling format to another. Trunk circuits, which generally include a number of relays and other relatively bulky devices, are widely used throughout the telephone industry to allow the various types of switching systems to operate into one another, and thus introduce an additional level of complexity to the processing of telephone calls. The interface, however, can often be simplified by introduction of PCM equipment.

In the relatively simple case of a PCM system joining similar switching networks, processing of signaling information is fairly straightforward. An interface between two switching centers using loop signaling, for example, could be provided using dial pulse originating (DPO) and terminating (DPT) channel units.

Loop Signaling Interface

Loop signaling systems operate by altering the current flow in a dc path. When a subscriber subset is "on-hook," for example, the path linking it to the switching center is open and no current flows. When the subset goes "off-hook," the loop is closed and current flows, energizing a line relay to give the subscriber access to the switching equipment. This "supervision" signaling conveys information regarding an originating subscriber's line condition to the switching system.

Address signaling provides the switching system with the location of the called subscriber, allowing it to select an appropriate trunk. If the selected trunk is part of a PCM transmission facility, a 2-wire drop connects the trunk selector to a DPO channel unit. A sensing circuit in the DPO unit (see Figure 4) immediately picks up the closed-loop condition and routes it as an encoded logic state to the transmit common equipment as transmit common signaling A (TCS-A) and B (TCS-B) information. The state data is then incorporated into every sixth frame of the transmitted bit stream as the eighth, or signaling, bit (TCS-A and TCS-B appear in alternate signaling frames, allowing the information to be updated more frequently than would be possible with only one signaling sample). At the receive end

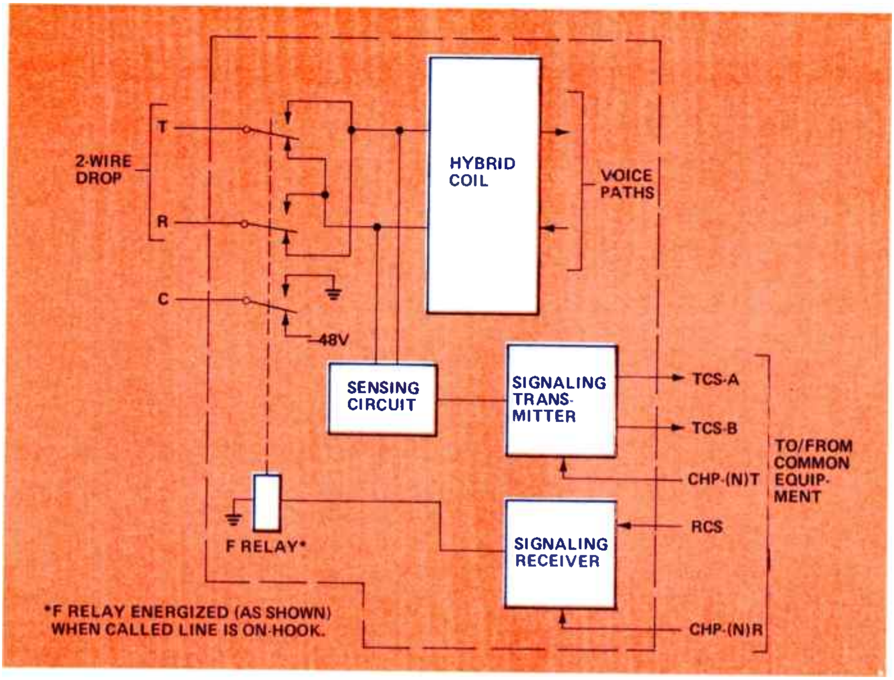


Figure 4. Basic dial pulse originating (DPO) channel unit signaling circuitry.

of the trunk, a DPT channel unit (see Figure 5) accepts the decoded signaling information on its receive common signaling (RCS) lead and energizes a loop-closing relay. This relay activation informs the terminating switch network that there is a request for service. The dial pulses are then forwarded over the signaling path (through the DPO, over the transmission facility, and through the DPT) to indicate to the network what subscriber is desired. The switching system checks the called line to see if it is idle and, if it is, rings it.

When the called subset goes off-hook to answer the ringing, it causes the polarity of the carrier drop battery provided by the central office to reverse. A sensing circuit in the DPT registers this and sends the answer supervision information as TCS-A and TCS-B signals back to the DPO. At the DPO, a signaling receiver de-energizes a relay and causes the originating line battery to reverse. In some applications, a holding ground is also applied over a C lead to maintain the connection. When the originating subscriber goes back on-hook, the entire circuit is released. Under some circumstances, a "calling party forced release" (CPFR) function may be added to the channel unit, allowing the called party to release the circuit.

Subscriber Carrier

In the United States, many telephone operating companies have begun to use PCM facilities to expand the capacity of subscriber lines as well as trunks. In such subscriber PCM systems, terminal equipment is placed in a neighborhood to convert local conversations to a digital format and transmit them as consolidated bit streams to central office terminating equipment. At the office, the signals

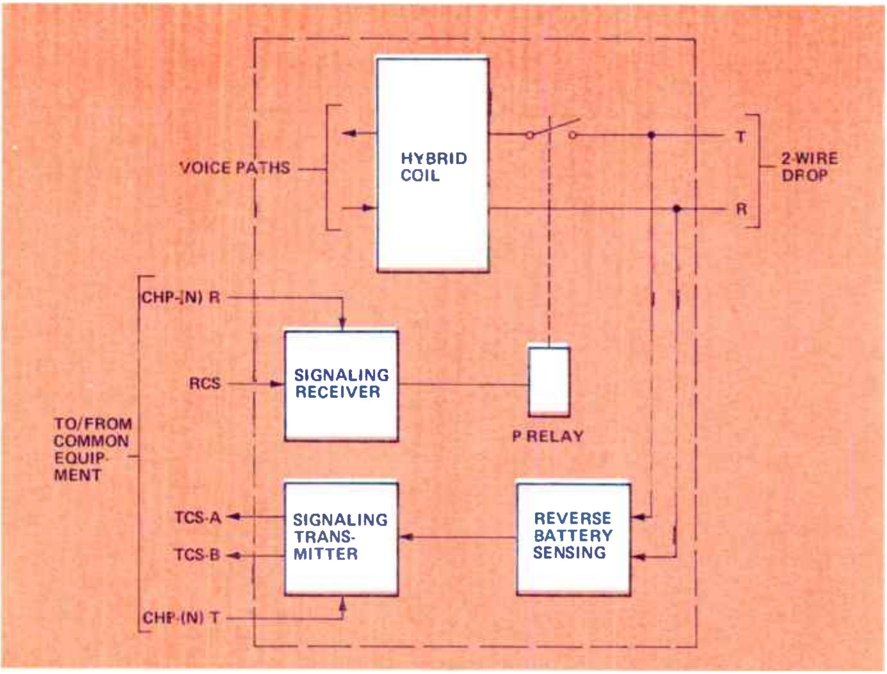


Figure 5. Basic dial pulse terminating (DPT) channel unit signaling circuitry.

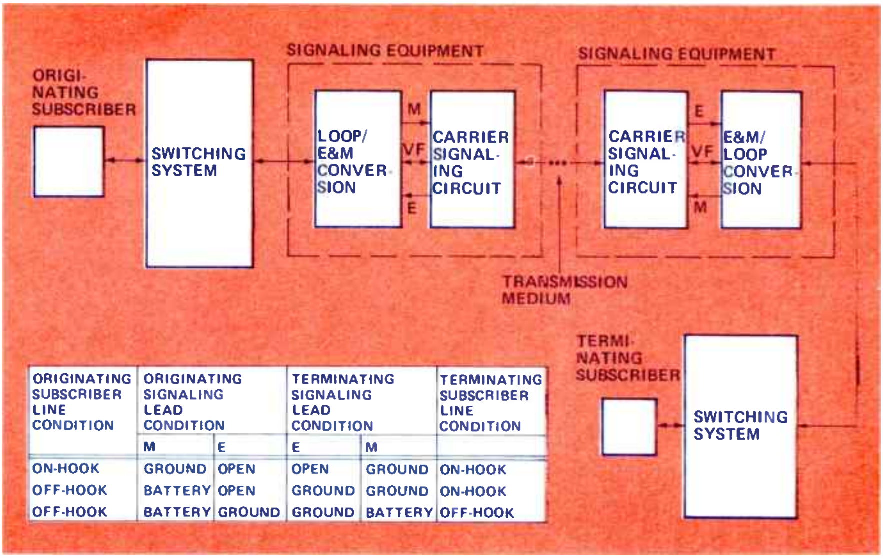
are returned to an analog state for switching and application to the direct distance dialing (DDD) network. Virtually all of the subscriber lines in use today operate with loop signaling, so the channel units provided by such manufacturers as GTE Lenkurt for subscriber PCM systems are based on loop principles. Additional capabilities are engineered into the units to allow for such uniquely localized information as type of ringing (bridged, divided or superimposed), presence of coins in a paystation coin relay hopper, number of subscribers served by a multi-party line, etc.

Loop signaling circuitry is usually an integral part of the vf transmission facility; that is, signals and vf information are sent over the same path. Other techniques separate the functions to allow signals to be sent simultaneously in both directions without interfering with the vf transmission.

E&M Signaling Interface

In E&M signaling, signaling equipment is introduced between the switching system and transmission facility to separate the vf and signaling paths (see Figure 6). An "M" lead transmits battery or ground (essentially off-hook or on-hook) information from an E&M converter to the carrier signaling circuit, and an "E" lead receives open or ground information from the carrier signaling circuit for eventual application to the switching system. The M lead thus reflects originating-end conditions, while terminating-end conditions are indicated by the E lead.

Typically, closure of an originating subscriber's loop (lifting of the handset) causes battery to be placed on the originating M lead. This condition is sent over the transmission facility to the called-end carrier signaling circuit. A ground is then presented over the



ORIGINATING SUBSCRIBER LINE CONDITION	ORIGINATING SIGNALING LEAD CONDITION		TERMINATING SIGNALING LEAD CONDITION		TERMINATING SUBSCRIBER LINE CONDITION
	M	E	E	M	
ON-HOOK	GROUND	OPEN	OPEN	GROUND	ON-HOOK
OFF-HOOK	BATTERY	OPEN	GROUND	GROUND	ON-HOOK
OFF-HOOK	BATTERY	GROUND	GROUND	BATTERY	OFF-HOOK

Figure 6. In a typical E&M circuit application, battery, ground and open conditions are conveyed simultaneously in both directions on E and M leads.

terminating E lead to inform the switching network that a request for service is being made. When the called line goes off-hook, battery is placed on the terminating M lead and sent back to the originating E lead, which subsequently has a ground placed on it. Thus, when the call is completed, there is a battery-to-ground loop between the originating and terminating networks. If either party should hang up (go on-hook), the connection is broken and all of the circuit elements released.

When the transmission medium linking such E&M systems includes a PCM facility, the PCM equipment replaces the carrier signaling circuitry.

Although there are several E&M signaling configurations commonly utilized in analog systems (simplex, duplex and composite, for example), the circuits in PCM channel banks can treat all of them in very much the same manner.

Dc signaling on the M lead from the office drop (see Figure 7) is converted to logic levels that appear at the signaling transmitter. The logic level representing the condition of the originating subscriber line is gated out every "channel time" by the CHP-(N)T pulse. The two outputs of the signaling transmitter are encoded and processed by the common equipment to become part of the bit stream. At the receive end, signaling information derived from the incoming PCM pulse train is gated into the channel unit on the RCS lead. When this information is logically combined with CHP-(N)R and Sig En (signal enabling) logic pulses, the signal receiver circuit energizes or de-energizes the E-lead relay. Relay contacts then either ground or open the E lead to send the signaling to the switching equipment.

Until the advent of carrier transmission, the dc nature of loop and E&M signaling techniques limited their usefulness to relatively short paths. For longer paths, and for networks equipped with carrier, ac signaling had to be developed. This solved the prob-

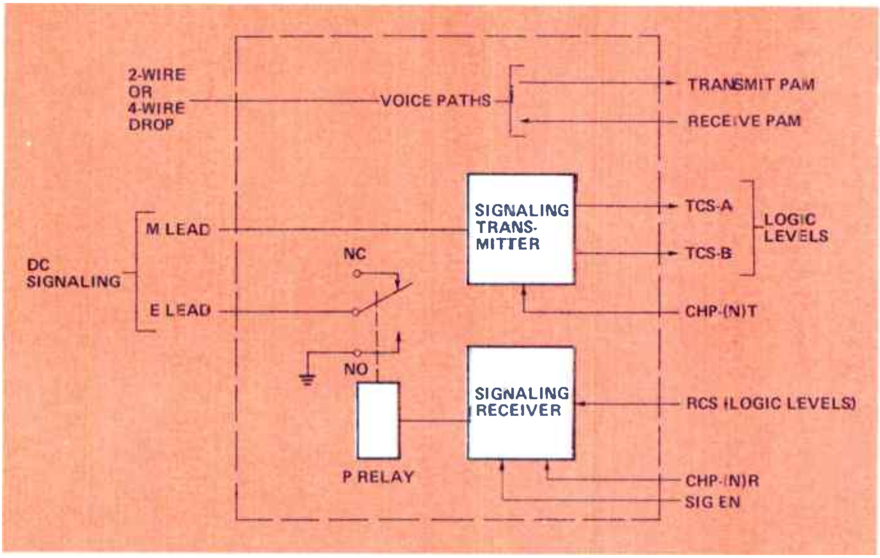


Figure 7. Basic E&M signaling channel unit circuitry.

lem of signaling over distances, but also increased the complexity of the telecommunications network.

Basically, ac systems operate by transmitting frequency tones that identify the same conditions as dc systems: on-hook, off-hook, called subscriber directory number, etc. In a single-frequency (SF) signaling system, for example, the dc state produced by a subscriber loop closure is used to energize a relay and apply a tone (usually 2600 Hz) to the trunk selected by the originating switch network. At the terminating end of the trunk, the tone is returned to a dc level, informing the switch network of a request for service. Similarly, the dial pulses interrupt the tone to produce a series of tone pulses that identify the called subscriber.

In a multi-frequency (MF) signaling system, five tone frequencies are available and each digit is represented by a different combination of two tones. Common control switching systems typically utilize MF signaling, converting dc subscriber signaling information to tones at the originating end of the system. The ac information is then sent over the transmission medium to the terminating switch network to complete the connection.

In the course of its processing, a telephone call might have to pass through several switching systems, each of which could utilize a different control and signaling mechanism (see Figure 8). This would entail numerous conversions of signaling information from one format to another to meet the requirements of the various systems, and a correspondingly large quantity of trunk circuitry throughout the network. When the amount of equipment needed to process one call is multiplied by the number of trunks linking the offices, it becomes apparent how complex the network must be. The complexity of the interface considerations can be markedly decreased by utilization of PCM transmission facilities because many of the conversion processes and trunk functions can be incorporated directly into the channel units, which can easily be

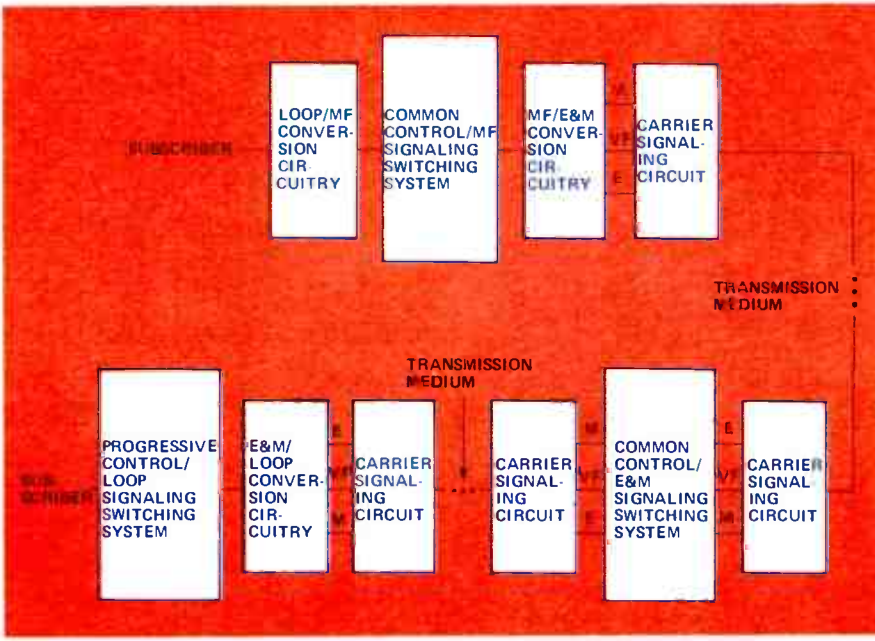


Figure 8. A telephone call may have to pass through a series of different switching systems and undergo a number of signaling format conversions.

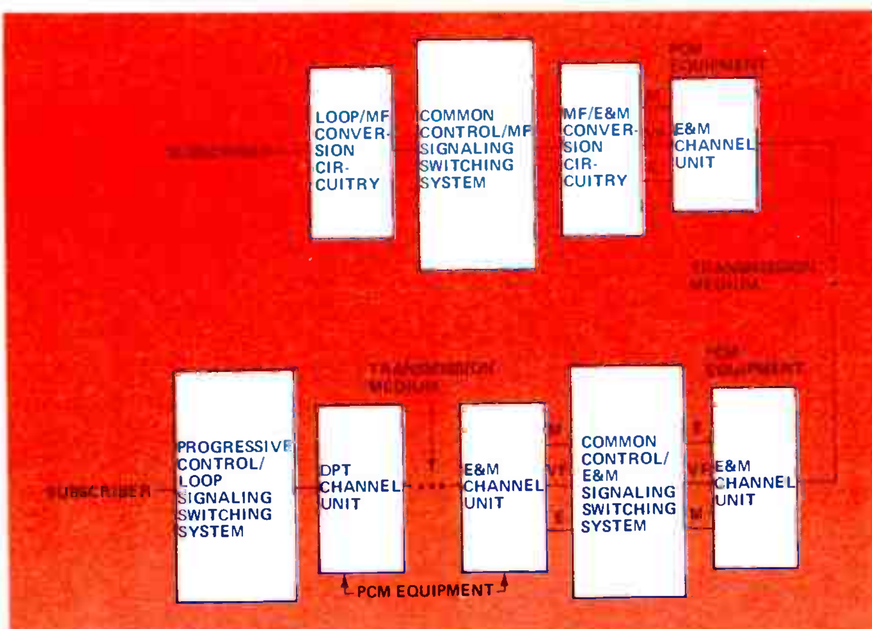


Figure 9. PCM systems can ease the problem of interfacing diverse switching systems.

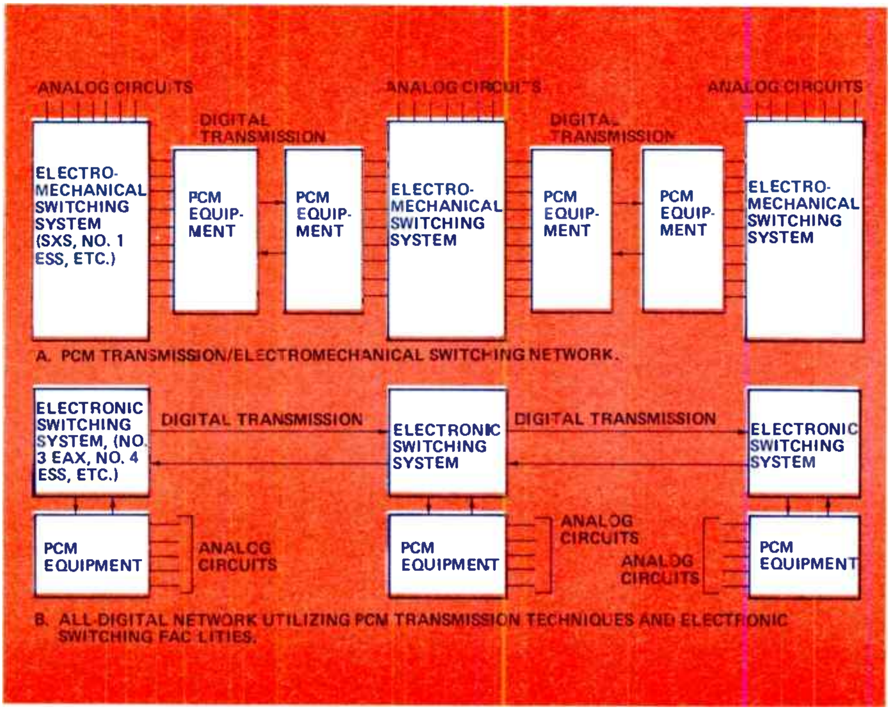


Figure 10. Analog signals must undergo a number of conversions in passing through a PCM/electromechanical network, but would need to be converted twice in an all-digital network.

changed to meet varying interface needs. This is possible because, once information is in a digital format, it can be treated as a separate entity, divorced from the terminal devices. It is therefore possible, for example, to accept loop signaling into a PCM system through a DPO and, by terminating the circuit in an E&M channel unit, perform a conversion at the carrier level (see Figure 9). In this way, analog-based conversion equipment such as trunk circuitry can be eliminated.

Many of the problems presented by the interface of transmission facilities and electromechanically based switching systems are eliminated by the latest generation of electronic switching facilities. Such systems as the No. 3 EAX and No. 4 ESS require that the information they handle be in what is essentially a 24-channel PCM format, thus reducing the number of analog-to-digital and digital-to-analog conversions necessary to convey a message between subscribers (see Figure 10). More importantly, perhaps, the number of signaling transformations is drastically reduced. Introduction of these new facilities makes possible, for the first time, a completely digital transmission network in which all information is encoded as binary words at the input and not turned back to an analog form until it reaches its final destination. The major problem encountered within such a network is maintaining synchronization of the PCM equipment with the switching exchange timing so that the transmitted and switched time slots corre-

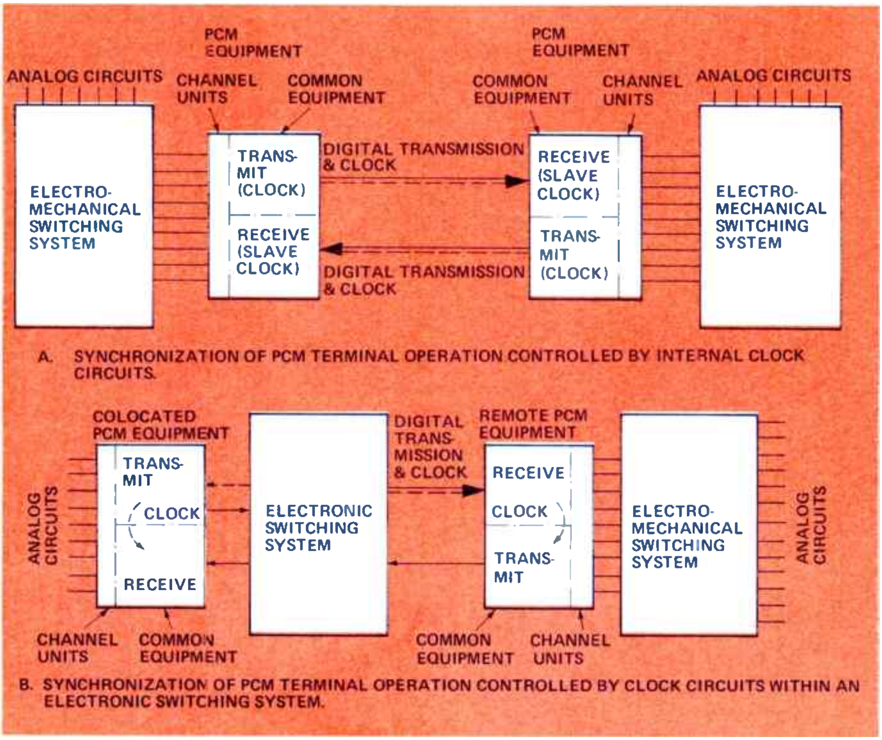


Figure 11. Timing control is essential in systems utilizing PCM techniques, and it can be implemented in several ways, depending upon the network configuration.

spond. To accomplish this, the new digital switching systems are equipped with external clock circuitry that exercises over-all timing control within their local networks.

Timing

When PCM systems operate with electromechanical switching facilities, timing is controlled by a 1.544-MHz crystal oscillator clock in the transmit common equipment. This clock generates 324-ns pulses that are used by a transmit digit generator to produce eight digits at each of 24 channel times and a ninth digit at the end of each 24-channel count. Digit pulses are distributed within the common equipment to control various logic functions. The digit generator also drives a transmit channel counter that produces the 24 transmit channel pulses; these pulses are distributed to the channel units.

In addition to this defining of the 24 channel slots and the eight time slots in each channel, the transmit clock controls a slave oscillator clock in the receiving terminal's receive common equipment (see Figure 11A). The frequency of this slave clock is determined by the timing used to produce the transmitted pulse stream, so that both ends of the line are operating at the same rate. A receive framing logic circuit also samples the incoming PCM signal at the receiver's framing bit time, to find the framing pattern. If the transmitting and receiving terminals are not fully synchronized, bits are added to the channel pulses, causing the receive timing to "slide" with respect to the transmit timing until an in-frame condition is reached.

To make certain that all of the PCM systems associated with it are synchronized, a digital electronic switching facility contains a master clock that exercises control over every PCM terminal associated with it. This switching system master clock is used by the PCM transmit common equipment in exactly the same manner as the internal clock to define time slots and control receive equipment timing, but can be supplied in different ways (see Figure 11B). If the PCM terminal is located near the switching facility (within the same building, for example), the clock can be inserted directly into the transmit common equipment. If the PCM terminal is located at a distance, the clock information can be incorporated into the digital transmission from the switching system. The receive common equipment then extracts the clock (determines the timing pattern) and connects it locally into the transmit common equipment for transmit timing. The latter process assumes, of course, that the PCM terminal can be controlled by an external clock mechanism; this capacity can be added optionally to the equipment produced by some manufacturers, and is designed into that of others, including GTE Lenkurt's 9002B PCM Channel Bank.

The advent of the new electronic switching systems brings closer to reality a world-wide communications network that can fully exploit all of the advantages and capabilities of digital transmission techniques. The technology needed to implement such a network is now available, and the greatest challenge to its realization currently lies in the gradual integration of all-digital facilities into existing telephone networks that are designed for vf transmission without over-burdening the economy of the systems.

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GTE LENKURT
1105 COUNTY ROAD
SAN CARLOS, CALIFORNIA 94070

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