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Research Model for Time-Separation Integrated Communication

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A new communication system concept which is an important step toward an all-digital telecommunication plant is discussed. A research model, called ESSEX (Experimental Solid State Exchange), which combines remote line concentration, time-separation switching and PCM transmission is introduced to demonstrate the concept. The model, which uses solid state devices, works at the speed of a full-size system.

I. INTRODUCTION

A communication system requires channels for transmission of information and switching arrangements to interconnect the channels. At present, the transmission problem and switching problems are handled separately. Transmission channels may be divided into three classes: space separation, frequency separation and time separation. All have been in use for some time. Switching arrangements may be divided into the same three classes.[1] The space-separation class includes all telephone switching systems in use today. Frequency separation systems have been studied and are not economically feasible at this time. Exploratory switching systems in the time-separation class are being considered in this country and abroad.

This paper reviews the use of time-separation techniques for transmission systems and for switching systems, points out that the availability of solid state devices has revived interest in the subject and indicates that techniques using these devices are now feasible for both systems. It shows that an integrated communication system using these techniques is much more attractive than a combination of subsystems using time separation and presents a research model which demonstrates the technical feasibility of such an integrated system

The research model is primarily a digital system. In it, information-producing terminals — in our specific case, telephone subscribers' sets — in a small group are connected over voice-frequency cable pairs to a small switching unit remote from the central switching point. This unit connects them to a time-separation or multiplex channel group and converts the signals to digital form. The digital signals are transmitted and switched at various locations and are reconverted to original analog form at another small remote switching unit, which serves another group of terminals, or at the originating switching unit.

A laboratory model of this system has been built. It is known as ESSEX (Experimental Solid State Exchange) and, as its name implies, is built of solid state devices.

The following sections discuss the background for the experiment, outline the general plan, describe the laboratory model and give some results.

II. BACKGROUND

The common control type of switching system has two basic sections: (a) the switching network for interconnecting channels and (b) the common control section. Many proposals and experiments have been made which use electronics for the common control section.[2,3] They offer many advantages over the slower electromechanical control systems. Electronic components are at least one thousand times as fast as the mechanical ones now in use. Common control systems made of such devices[2,3] time-share the circuits, and thus can carry out their work with fewer devices. One control unit plus one spare can handle a very large switching system, and it can be made so that it is sufficiently flexible to handle new services.

The development of an electronic common control system is substantially complete. This system could be modified for use with a time-separation system of the type discussed herein; therefore, it will not be treated in this paper. The switching network is another story.

Existing and most proposed networks are in the space-separation class. Large numbers of switches are required to implement them. Substitution of electronic switches for electromechanical switches may afford indirect saving in the control and reduce the cost of the switches, but it does not reduce the number of switches. Space-separation networks require many switches or crosspoints per line. Time-separation switching networks, in which one physical path carries many conversations by time sharing, require something in the order of two switches per line. In addition, they require a few bits of memory per line to remember which switch is operated at what time interval. The switches, although fewer in number, must operate much faster than those used in a space-separation network. Present solid state switches are sufficiently fast that speed is no problem. Such a network can now be built. And a time-separation switching network is an important part of the research model.

The switching system mentioned above is only part of a communication system. It may represent about one-half of the cost. The other portion of the cost is for the transmission channels. In a telephone system, this is primarily copper cost, the cost of the cable pairs between subscribers and central office, and between offices. One way to reduce the amount of cable is to locate part of the central office in small pieces near to groups of subscribers.[4] These remote pieces of the switching network are called line concentrators. They provide switching so that a group of subscribers may share the use of cable conductors between the remote unit and the central switching point. The number of cable pairs required between the remote unit and the central point may be reduced by about 80 per cent. Thus, a reorganization and dispersion of part of the switching network can reduce the amount of cable required. Line concentration is another important part of the research model.

Additional saving of cable conductors can be achieved by the use of either frequency-separation or time-separation techniques for interoffice trunks.[5] Cost savings depend on the lengths of the cable runs and the cost of the terminal equipment for multiplexing. The advent of solid state devices is affording new opportunities for reducing the channel length needed to prove in multiplexed channels in place of individual space separated channels. One such method is time sharing of the cable conductors through the use of PCM (Pulse Code Modulation) transmission. This is another important part of the research model.

The parts mentioned above could be all considered and used in a communication system such as is shown in Fig. 1. In such a system voice-frequency signals would be time-switched at the concentrator and then changed back to voice frequency. For PCM transmission they would be converted to digital signals and then back again to voice at the central switching point; then again time-switched and changed back to voice, etc. This process is quite involved and, in fact, unnecessary. It can be simplified by removing all the transitions between time separation and space separation except those at the ends of the system, thus producing

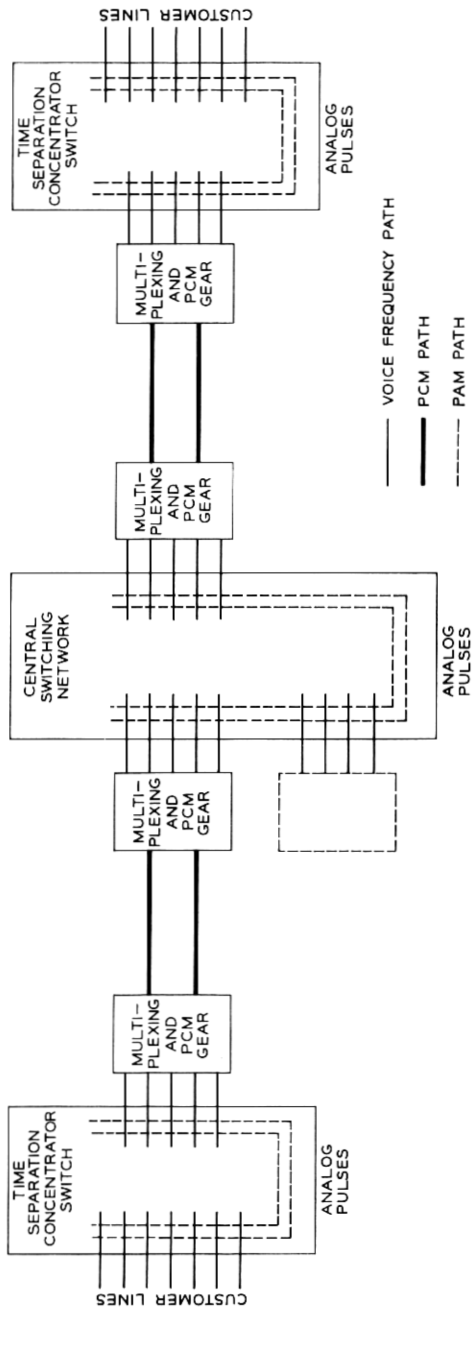

Fig. 1 — Combination of time-separation switching and transmission systems.

a more economical system than that achieved by just building up subsystems. Such simplification leads to the system shown in Fig. 2—the ESSEX System. Voice-frequency signals from a group of subscriber lines are switched at a remote concentrator unit and converted to digital signals. The digital signals are transmitted, switched at one or more central switching points and handled as digital signals until they leave the system at another concentrator or *trunkor*, which is a converter for connecting to voice-frequency trunks.

ESSEX employs all the parts mentioned above and combines them in a manner which minimizes the amount of equipment and cable conductors required and provides a uniform-quality fixed-loss path between any two voice-frequency terminals, independent of the distance and the number of switching points between them.

The quality is fixed by the characteristics of the line filters, the amplitude range of the system and the noise. The voice is coded in digital form, and the pulses are retimed and reshaped at regular intervals. Thus, in the ideal case, the code at the distant end will be the same as that at the transmitting end independent of distance. It follows that length of the transmission path has no effect on the loss and quality, except as increased length increases the probability of errors in transmission due to interference from external sources and to timing irregularities. ESSEX provides analog-to-digital conversion as near to the subscriber as feasible and then operates as a digital system. In addition, the switches at the central switching point are simplified, since they handle digital signals only.

Time-separation techniques for transmission systems and for switching systems have been under investigation for many years. The potential advantages of an integrated digital communication system and increased demands for various speeds of digital transmission have spurred the efforts on the present research model. The use of solid state devices makes the system attractive. Such devices require less space and less power, and are fast enough to do the job. As the speed of the devices improves, more operations may be performed with the same number of devices or the same operations may be handled by fewer devices, and the picture will become even more attractive.

III. BASIC PLAN

The basic plan has a number of remote line concentrators, using time-separation switching and transmission, connected at a central point in a time- and space-separation switching network. Trunkors, which act as connecting and converting units for trunks, registers, etc., are similarly

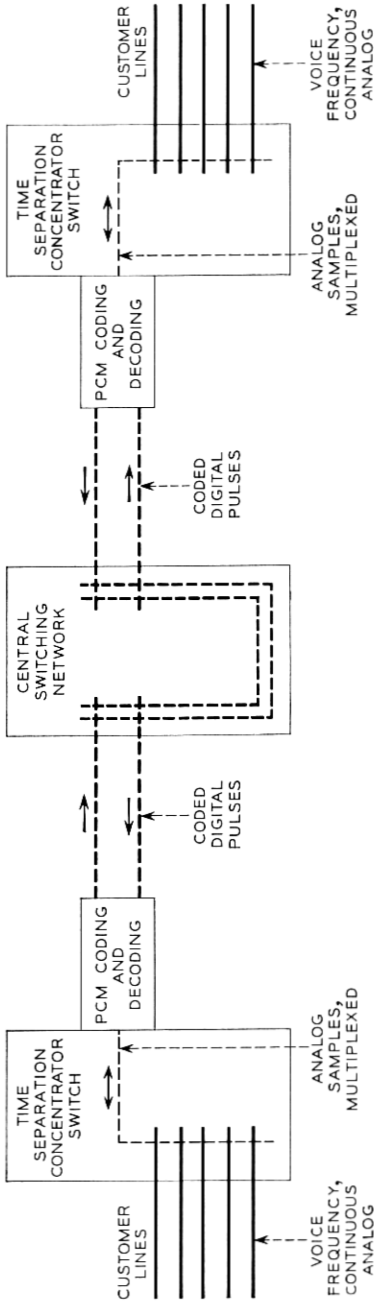

Fig. 2 — Integrated time-separation communication system.

connected. Each concentrator has some switching and control circuits located at the central switching point. The switches connect the four-wire transmission circuits from the concentrators to other concentrators, to trunkors or to routes to other offices. The control circuits have a memory which holds the information used to control both remote and central switches for the duration of a call. These circuits also control line scanning for supervision and handle programming for setting up and releasing calls. Each concentrator control unit is connected to the common control for the office.

Before going further into the system, it will be well to mention the sampling and transmission action. It is a well-known fact that, if a short time sample of a signal limited in frequency to $x/2$ cps is taken x times per second, transmitted and filtered, then any signal components in the band up to $x/2$ cps will be reproduced at the output of the filter.[6] In ESSEX, the sampling rate has been set at 8000 per second. Thus, the period between one sample of a message and the next sample is 125 microseconds, which is called a *frame*. The number of channels that can be inserted in a frame depends on the length of the sample and the guard space between samples. In ESSEX, each channel uses a time slot of 5.2 microseconds, so 24 channels are handled in a frame. Twenty-three channels are used for speech, and the 24th is used for supervisory functions. Each time slot has eight pulse positions, seven for the coded PCM signal and one for other functions. Thus, the pulse repetition rate on the four-wire digital transmission line is 1.536 mc. The four-wire system will use ordinary exchange cable pairs. Pulse regenerative repeaters are required every 6000 feet for transmitting pulses at the 1.536-mc rate in the case of 22-gauge paired cable. Closer repeater spacing may be required if the noise is greater than that now anticipated.

3.1 *Remote Concentrator*

A concentrator module consists of a *remote* unit and a *central* unit, as shown in Fig. 3. Let us consider the *remote* part of the line concentrator, shown on the left side of the figure, which is the starting point in the system. A maximum of 255 voice-frequency lines appear as inputs, and three cable pairs carry digital signals to and from the central unit. One pair, designated S, the send pair, takes PCM signals to the central unit. The second, the receive pair, R, brings PCM signals from the central unit. And the third, the control pair C, brings control words from the memory in the central unit. Each line requires a line circuit, which contains a gate and a filter. The line circuit, a plug-in package, is the lowest-order module in the system. These modules are added only as customers are connected to the concentrator. The ensemble of line-circuit packages makes up a two-wire bilateral switching stage controlled by a selector. The output of this stage is a two-wire time-separation PAM bus with 23 time slots or channels for use as links to the central office. A time diagram which may be helpful in visualizing some of the operation is shown on Fig. 4. The memory which controls the selection of the gates is located at the central point. The information from it is sent over the control pair C as eight-bit words in each time slot. These words pass through the selector to control the line gates. Each word designates a line gate number (LGN) and can select one of 255 gates.

The PAM two-wire bus must be converted to a four-wire bus so that the signals can be handled on a PCM basis. This conversion is accomplished by a circuit called a *time-division hybrid*. In brief, it permits a signal to pass from a line to the send bus or from a receive bus to a line, but *never* permits a direct connection from send to receive. PAM signals on the send bus are coded into seven-bit PCM signals and sent to the central point. Incoming PCM signals are decoded and presented as PAM signals to the two-wire bus and then to the voice-frequency line. Note that the line circuit is a passive circuit and that all the signal power needed is supplied by the common receiving amplifier in the receive bus. Timing signals necessary for the operation of this remote unit are generated by a local clock which is slaved to a master clock at the central switching point. Since both switching control and timing control signals originate at the central switching point, the remote unit is actually a

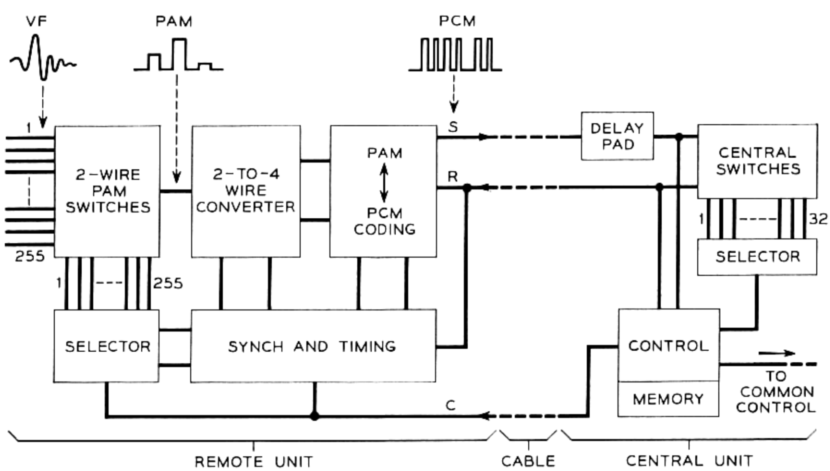

Fig. 3 — Line concentrator, showing both remote and central functions.

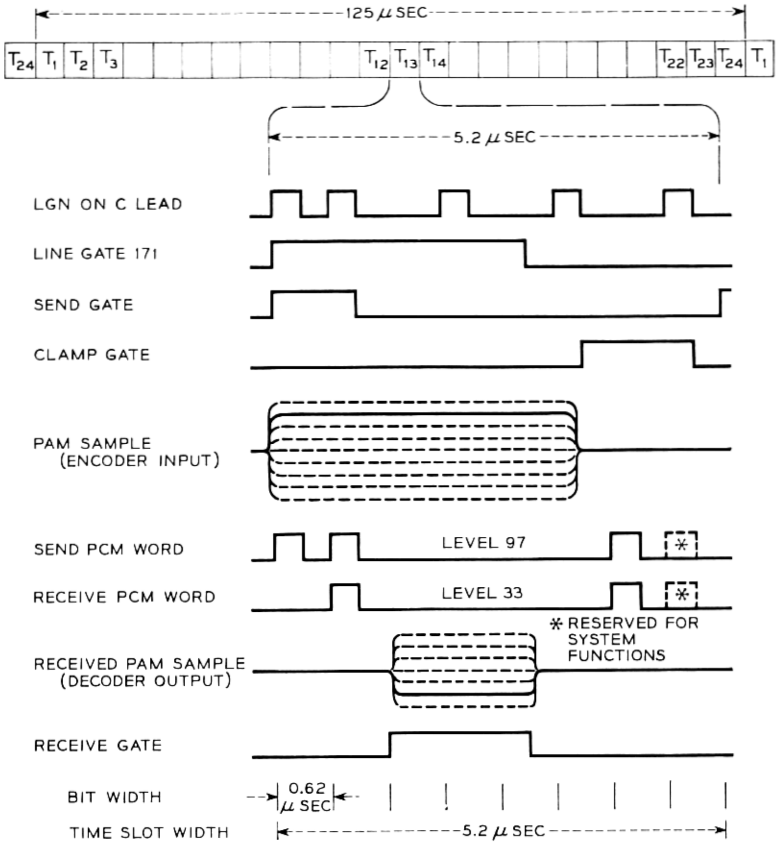

Fig. 4 — Timing diagram for remote concentrator.

slave. The problems of timing and synchronizing both remote and central units will be discussed in Section 3.4.

3.2 *Concentrator Central Unit*

The *central* unit of the concentrator module shown on the right side of Fig. 3 is made up of digital circuitry that includes the memory to control both remote and central switches, the central switches with their selector and a concentrator control unit. In addition, there is a delay pad and servo, which is discussed in Section 3.4. As mentioned above, the memory stores information which controls the operation of line gates. It also stores words to control the operation of the central switches associated with a particular concentrator unit and call progress information concerning the states of the calls being handled. For example, "on-hook" and "off-hook" conditions are recorded in this memory. The memory stores 24 bits of information for each time slot or channel, eight bits for the line gate, five bits for the central switch, eight bits for call progress marks, and three bits for checking. Each 24-bit word is read out every 125 microseconds; thus, the complete memory can be searched in this period to determine which channels are busy or idle or for any other pertinent information.

The central stage switches or junctor gates are simple digital AND gates which switch digital signals unilaterally. The switches handle low power, and thus the selector, which uses a five-bit input to mark one pair of 32 pairs of switches, is rather simple. The central switches for each concentrator are connected to the central switches of all other concentrators by junctors on a space-separation basis as in Fig. 5. Thus, each concentrator has access to all other concentrators, trunkors and junctors to other office modules over 32 separate paths in any of 23 time slots. A call from one concentrator to another must use the same time slot in each concentrator. The switching plan is really a four-stage network, one stage at each remote unit and one for each central con-

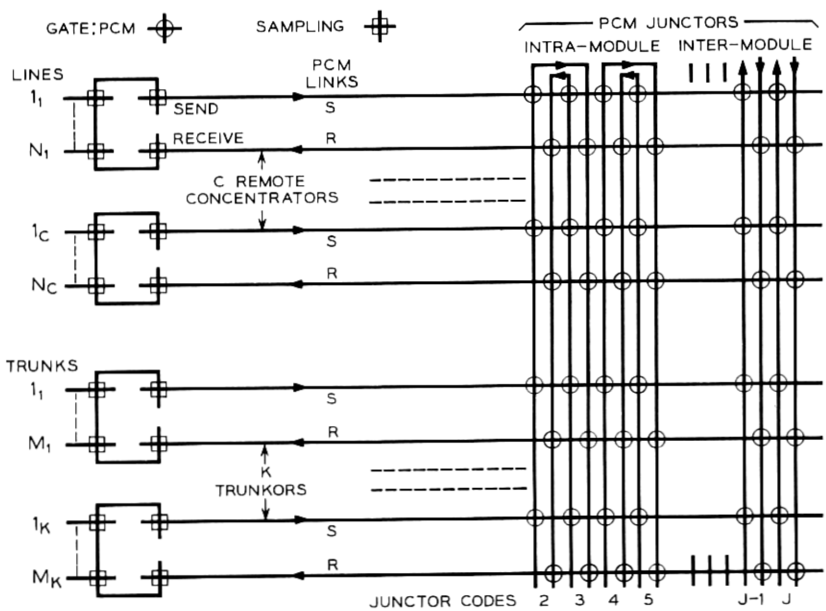

Fig. 5 — Switching plan.

centrator unit. Some blocking occurs due to the concentration to 23 channels and some due to time slot mismatch. Although a remote unit can handle up to 255 lines, about 115 lines, each submitting one tenth of an erlang, would load the 23 channels to 50 per cent of capacity. In the future, new services may use lines with much lower traffic, and then the large number of lines may be useful. If the call is to another module, the same number of stages are used, since only one switch is made in each central unit. The only difference is in the length of the junctor. Consider a call from a concentrator to a trunkor — a dial tone connection — and assume for the moment that there is no delay in the system. Information in the memory for concentrator A opens a gate in time slot 6 and opens the send and receive junctor gate pair 3 in the same time slot. Information in memory for the trunkor Z opens a gate in time slot 6 in the trunkor and send and receive junctor gate pair 3. Information then passes directly from A_6 to Z_6 and from Z_6 to A_6, and the operation is repeated 8000 times per second.

An important section of the central concentrator unit is the concentrator control, which works in cooperation with the common control. The division of responsibility between concentrator control units and common control is a field for further investigation, since the present division is based on judgment with limited knowledge of the problem. A detailed treatment of the organization and operation of the concentrator control will be given in a future paper. A simplified diagram of the control section is shown on Fig. 6. The most complex part is the logic which controls the generation, interpretation and modification of call progress marks. Some of these marks are operating orders to and from the common control. Supervisory information from the remote unit is held in the memory, and logical operations are performed on this information when necessary. Control of ringing, supervisory tones and answer indications are also handled in this section. Line scanning also is controlled here.

3.3 *Supervision, Dialing and Ringing*

Many auxiliary functions must be performed in order to use this transmission and switching system as a telephone system. Detection of "on-hook" and "off-hook" line conditions to determine the subscriber's wishes is done by scanning. The central control sends out a line designation in the 24th time slot, which is reserved for this purpose. This eight-bit word controls a transistor in the line package through the selector used to control the line gate. A combination of the pulse from the selector and current flowing in the subscriber's loop ("off-hook" condition) produces a pulse on a lead common to all such transistors. Thus, scanning requires little additional equipment in a time separation system. If the line is "off-hook", a "1" is returned to central in the eighth-bit position of the 23rd time slot on the S lead. Every fourth frame, a new number is sent to the remote unit, so that 255 lines are scanned in about one-eighth second. The result of the scan is stored in the call progress mark section of the memory if action is called for.

Switching networks using electronic crosspoints have a limited power-handling capacity; thus, it is necessary to use low-level tones. Ringing is done by sending tones in the voice band to actuate a tone ringer in the subset.[7] Ringing tone in the form of PCM signals is applied through a separate gate for each concentrator R lead, and audible ring in the same PCM form is applied through a separate gate for return to the originating end of the circuit (see Fig. 7). This arrangement permits full access on a time-separation basis to all 23 channels. It can be shown that this helps to reduce blocking. Busy tones or other tones in PCM form may be switched in the same way, and trunk splitting also can be

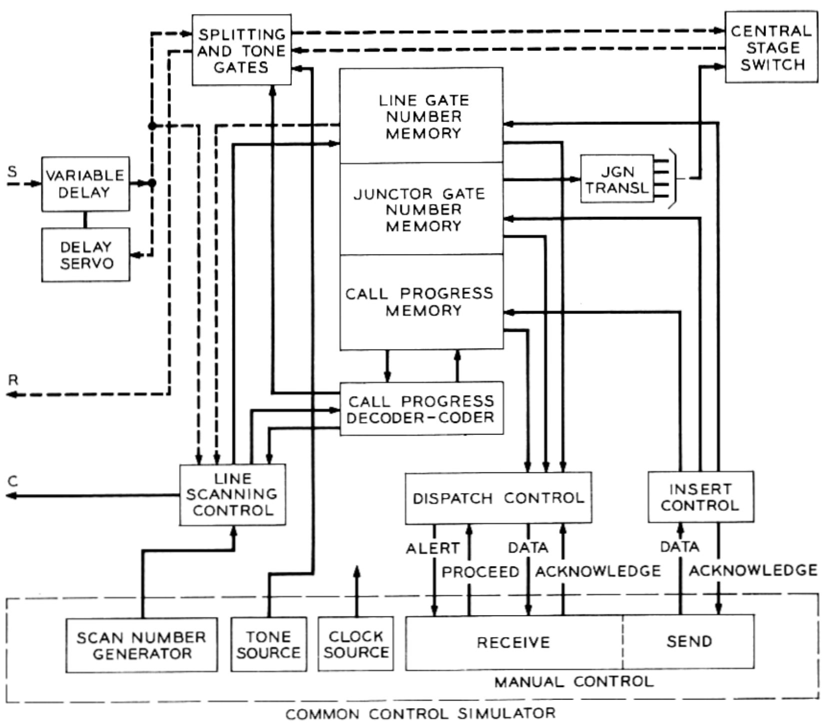

Fig. 6 — Line concentrator—block diagram of central unit.

taken care of in this fashion. This simple means for applying special tones is one more advantage of digital time-division switching.

Dialing signals are "in-band." Frequency-shift dialing with one frequency for "make" and another for "break" is used, and a form of multifrequency or pulse-coded signals may be employed. Registers connected to trunkors will be used to interpret the digits which will be assembled in the memory of the main common control. This is so similar to dialing methods in other electronic switching systems that no further detail will be given here.

3.4 *Delay, Synchronization and Timing*

The synchronization of a point-to-point four-wire PCM transmission system is straightforward. A clock times the sending end, and the receiving end is slaved to it. The same operation is used in the opposite direction. Synchronization between the two directions is not required. In the ESSEX system, which uses two-wire switching at the remote terminals operating under a central common control, over-all synchronization is necessary. It is a problem; unless all switches operate at the proper time, chaos will reign. The transmission delay, about 7 microseconds per mile for cable pairs, further complicates the problem. This problem was analyzed by Karnaugh, who has offered several solu-

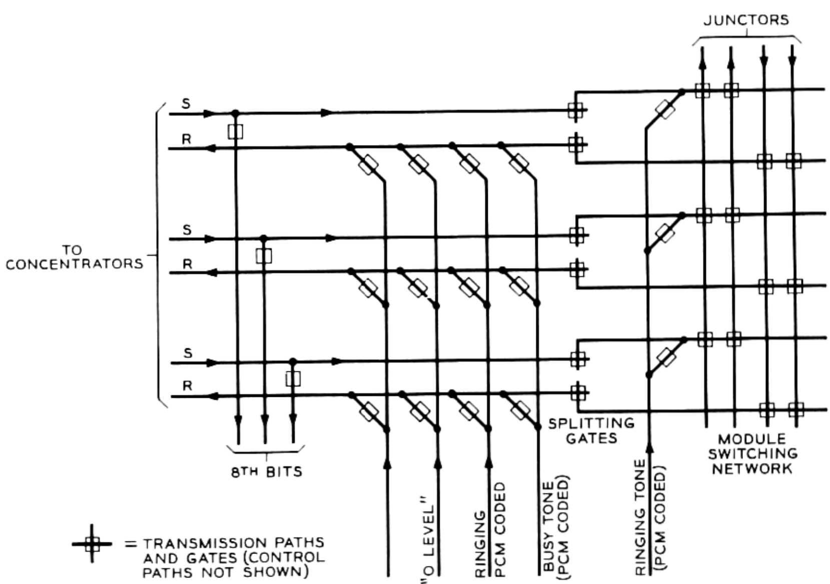

Fig. 7 — Switching of special tones in digital form.

tions.[8] One of these, the use of a delay pad, was adopted for use in the laboratory model.

Consider the complete concentrator shown in Fig. 3, which illustrates the delay-pad solution to the problem. Assume that control words are stored in the memory and that PCM words appear on the junctor pair, going in both directions at time τ. Just before τ, an eight-bit word is sent out to the remote unit and the central switch. The central switch closes at τ and permits the seven-bit word to go out over the R pair to the remote unit, so that it arrives there at $\tau + \alpha$, where α is the transmission delay. The eight-bit word on the C pair controls the line gate, so that it opens at $\tau + \alpha$ and the decoded sample that arrived on the R pair passes to the line. Now, in the opposite direction, a sample from the line passes to the coder and then to the S bus with some delay, d. The PCM representation of the sample arrives at the central switch, with an additional delay, α, at the time

$$t = \tau + \alpha + d + \alpha.$$

Every 125 microseconds after τ, the five-bit word again closes the central switch, and, if $\tau + 2\alpha + d = 125$ microseconds, the PCM signal would arrive just in time to pass through the junctor gate. However, α is dependent on the distance between the remote and central units, so the condition above is not satisfied. But it can be satisfied if a variable delay pad, x, is included in the send line, so that

$$\tau + 2\alpha + d + x = n(125 \text{ microseconds}).$$

A variable-length delay line provides the necessary delay x. Each concentrator, trunkor and intermodule junctor must be padded with such a delay to provide proper operation. Since the transmission time, α, varies slightly with temperature, a servo unit on the delay line automatically compensates for these small changes in α.

The clock at the remote unit is a crystal-controlled unit which is slaved to the master clock at the office module by monitoring the pulses on the C pair. Counting circuits are used to produce timing pulses at submultiples of the clock frequency. Once every 125 microseconds, a framing signal is sent in the 24th time slot on the R pair to the remote unit. When this signal is recognized, all counting circuits are checked, and, if out of frame, they are reframed.

3.5 *Modules*

The term "module" has been used in some of the preceding sections. It denotes a building block whose cost or complexity is significantly greater than the cost or complexity of connecting it to the system. ESSEX has a hierarchy of modules. The smallest one is the line package used to switch voice-frequency lines selectively to a group of PAM time-separated channels. It is a plug-in piece of hardware added at the time a line is put into service.

The next larger module is the concentrator, including both remote and central units. It is the basic multifunction unit in the model. The central office is built up of concentrators and trunkor modules and a common control unit. The whole switching and transmission array is made by running wires between such units. The proposal is to install sockets with junctor wires between them and to have the office grow by plugging switching units into these sockets.

The system as outlined so far permits the operation of only one switch in a time slot at the concentrator. For heavy intraconcentrator traffic, it is desirable to operate two switches simultaneously so that only one time slot is required. In this case, speech is switched directly in PAM form and does not pass to the central point. One way to operate two switches in one time slot is to provide extra line memory in the concentrator control, an extra control pair and an additional selector at the remote unit to control the second switch in a time slot. Such an arrangement could handle a maximum of 23 simultaneous calls between 46 customers in one remote concentrator. A concentrator module with these additions could then serve as a community dial office (CDO) or as a PBX with centralized control.

The largest module would be called the *modular center*. It would be made up of several concentrators and trunkors and use about 30 junctor pairs to serve between 2500 and 4000 lines, depending on the amount and characteristics of the traffic. Such a modular center could be located to minimize cable plant. Growth in an area could be handled by adding these central modules. For instance, a 10,000-line office would be made up of four modules, as shown in Fig. 8. These units might be interconnected by four-wire PCM junctors equipped with delay pads. With the present plan, each office module would have its own common control unit. Communication between the common control units in different modules would use the eighth-bit position of each time slot. A 192 kilopulse per second channel is proposed for this purpose. Office modules, distributed over an area, might use a single common office code, the same office code for each one until 10,000 numbers are used. This would help to conserve office codes.

The use of small central modules is only one way to handle central switching. Many valid arguments can be advanced to show that it is wasteful of common control equipment. There are many plans to have one common control serve several office modules, but these are beyond the scope of this paper.

3.6 *Use for Other Services*

Digital data signals in the voice-frequency band may be handled through line circuits just as they are now handled. High-speed baseband signals could be applied to the PCM channels through switches at the output of the encoder, and incoming data pulses may be taken out through switches ahead of the decoder. Since each channel handles eight bits in a time slot, one channel will handle 64,000 bits per second. If higher data rates are needed, more channels can be allocated for this purpose. The complete group could handle $23 \times 64{,}000$ bits per second.

Broader-band analog channels may be made available by changing the line package filter and by changing the sampling rate. If the address of a particular line terminal were stored in position n in the memory and again in position $(n + 12)$ on a modulo 24 basis, the sampling rate for the line would then be 2×8000, or 16,000 times per second. If it were stored in positions n, $(n + 6)$, $(n + 12)$ and $(n + 18)$ on a modulo 24 basis, the sampling rate would then be 32,000 times per second. Thus, by using several time slots in an ordered sequence for one line, the sampling rate may be increased, and a wider band may be provided. This is another type of flexibility.

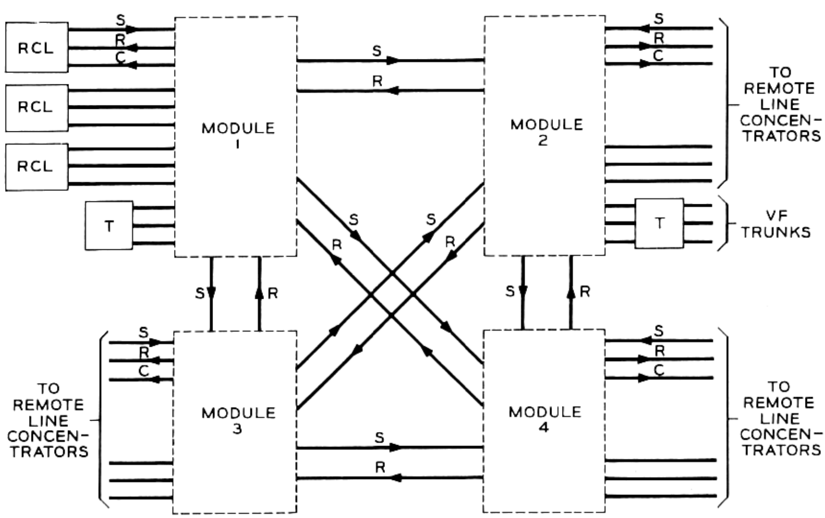

Fig. 8 — Interconnection of central switching modules.

IV. THE LABORATORY MODEL

The prime objective of the experiment is to demonstrate the technical feasibility of the system. Such research system experiments increase understanding of the operation of the system, unearth new problems caused by interaction of complex circuits which have been demonstrated individually, and provide the stimulation to invent new circuits and techniques to solve these problems.

Most research systems are highly skeletonized. This one is skeletonized only in the number of concentrators and trunkors. Two complete concentrators and one complete trunkor, along with a central clock, make up the model. Although each of these modules is capable of handling the maximum number of lines or trunks, the number of operating-line packages is limited to 12 per unit. However, a plugboard arrangement is provided, so that each package may be associated with any terminal on the selector.

Before discussing the model, it is appropriate to describe how it grew to its present state.

Initially, two partially equipped remote concentrators with a central memory were connected together, with no delay between them. Each unit contained a two-wire PAM selective switching stage, a time-division hybrid or two-wire to four-wire converter, and synchronizing and timing circuits. Tests were made on this phase of the system until the PCM equipment became available. In the next phase, the transmission path was opened, and PCM coding and decoding equipment complete with compressors and expandors were installed. These units introduced some delay, so the delay pads were added. The latest phase builds the system up to include two complete concentrators, a complete trunkor and an operator console to simulate many of the functions of the common control. This gradual evolution of the model has made it possible for one phase of the evolution to provide most of the environment for testing the circuits added in the next phase. It is a case where serial construction has saved a lot of work by reducing the amount of equipment needed to synthesize input-output gear that would have been needed to proceed in parallel on several parts at once.

4.1 *Layout of Model*

A layout of the laboratory model is shown in Fig. 9. The two racks at the left are a remote concentrator unit. The first rack contains the line selector, which takes the incoming serial eight bits of a word from the C lead, assembles them in parallel, selects a line gate and applies a sampling pulse to it. A group of 12-line gates is in the upper section of the rack, which also houses the plugboard that permits the interconnec-

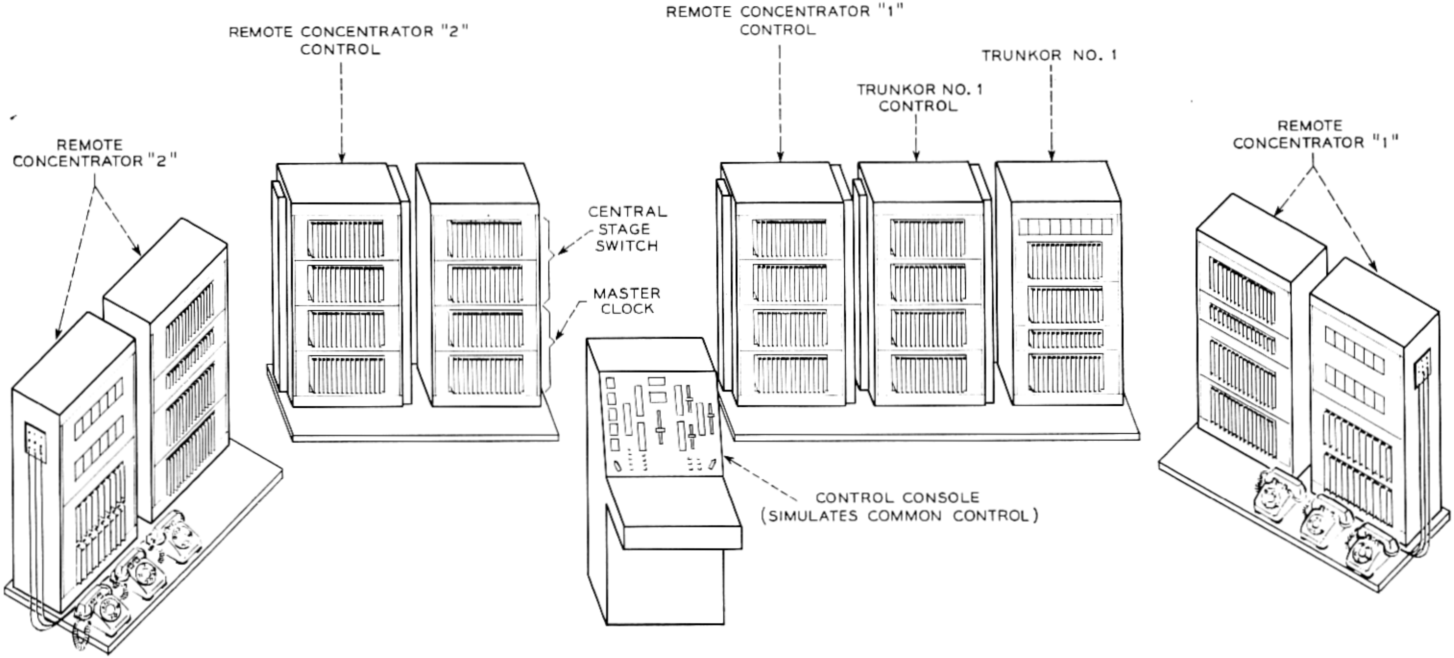

Fig. 9 — Layout of laboratory system.

tion of any package to any one of 255 selector terminals. The outputs of the gates are 23 time-separated channels on a two-wire PAM bus. This two-wire bus is connected to the second cabinet, which contains the time-division hybrid, encoders, decoders, synchronizing and timing circuits and other circuits common to the remote unit. The outputs from the second rack are three exchange-area type 22-gauge cable pairs, which handle digital signals at a 1.536-mc pulse rate. These cable pairs require a pulse regenerative repeater for each 6000 feet.

A second remote unit is located in the two racks at the right side of the figure.

The remote units are the only places where analog signals are handled. Since each of these units represents a small part of an office, the crosstalk problem is simplified, because the exposure to other circuits is minimized. This is an important feature in the organization of "single-wire-to-ground" switching systems.

The six racks in the center are all part of the office module. The third and fifth racks from the left are the control units for the two concentrators. Each one contains the delay pads, the three memory units, control circuits and logic circuits for a remote unit.

The sixth rack is the trunkor control unit, which is much the same as a concentrator control unit. The trunkor unit which converts from PCM to PAM and selectively switches voice frequency terminals for trunks, registers, etc., is located in the seventh rack.

The fourth rack has room for the printed circuit cards for a central stage switch serving 30 concentrators or trunkors. Each card holds the central switches and selector for one concentrator. It is presently equipped with only three switch cards, one for each of the two concentrators and one for the trunkor.

The arrangement for the junctor wiring is shown in Fig. 10. The upper half of this rack represents the *complete* central switching network for a 4000-line office module. The concentrator controls are connected by plugs, with only 420 wires being required to connect all 30 units, exclusive of power and clock pulses. The small size of this network demonstrates a major advantage afforded by PCM switching. Since the circuitry at the central module is all digital, the crosstalk in the wiring presents no formidable problem. The lower half of the fourth rack holds the master clock and timing circuits for the office module. Care must be taken in distributing timing pulses to the various control units to assure that timing pulses arrive at each one at the same time, plus or minus 10 millimicroseconds. This section also contains circuits to generate the supervisory control tones. These tones are switched, when needed, to the concentrator R lead under control of call progress marks in its memory.

Fig. 10 — Junctor wiring at rear of connectors for central stage switches.

A control console takes the place of the office common control. It provides a visual display of calling number, called number, time slot number, etc. An operator manually performs operations on the console to interpret instructions from the concentrator controls and to issue orders to them for setting up and taking down calls. The console is located in front of the group of racks and is used for testing and demonstrating the system.

Fig. 11 is a photograph of a portion of the laboratory system. Power supplies for the system, not shown in the layout, are mounted in racks similar to the others.

Fig. 11 — Section of the laboratory system.

4.2 *Circuitry*

Most of the circuitry is isochronous. Timing is furnished by a two-phase 1.536-mc clock. Rise and fall times in the order of 50 millimicroseconds are common.

The circuits in the model use commercially available transistors and diodes in conventional arrays . High-speed operation is achieved by use of clipping and clamping techniques, with a collector supply voltage much higher than the normal signal voltages. Since the emphasis is on the system, the circuits are not necessarily minimal. They are assembled on 5 × 8-inch wiring boards, which plug into sockets for convenience in testing and replacement. The boards or packages contain groups of basic building blocks, such as diode logic units, flip-flops, shift register stages, pulse amplifiers and blocking oscillators. The laboratory model uses about 4000 transistors and 12,000 diodes.

Most of the circuits use voltages in the range of -12 to $+12$ volts, with some collector supplies being as high as 25 volts. The total power drain for a remote concentrator is about 75 watts, with an additional $\frac{2}{3}$ watt for each operating subscriber set. A concentrator control unit requires about 50 watts.

Many unifunction circuits that probably arouse curiosity have been mentioned previously. The description of these would surely drag this paper too far into detail. It is planned to treat these details in two additional papers. However, it is unfair to leave the reader completely up in the air, so a few words are in order about some of these circuits.

The subject of the line gates has been investigated for some time, and

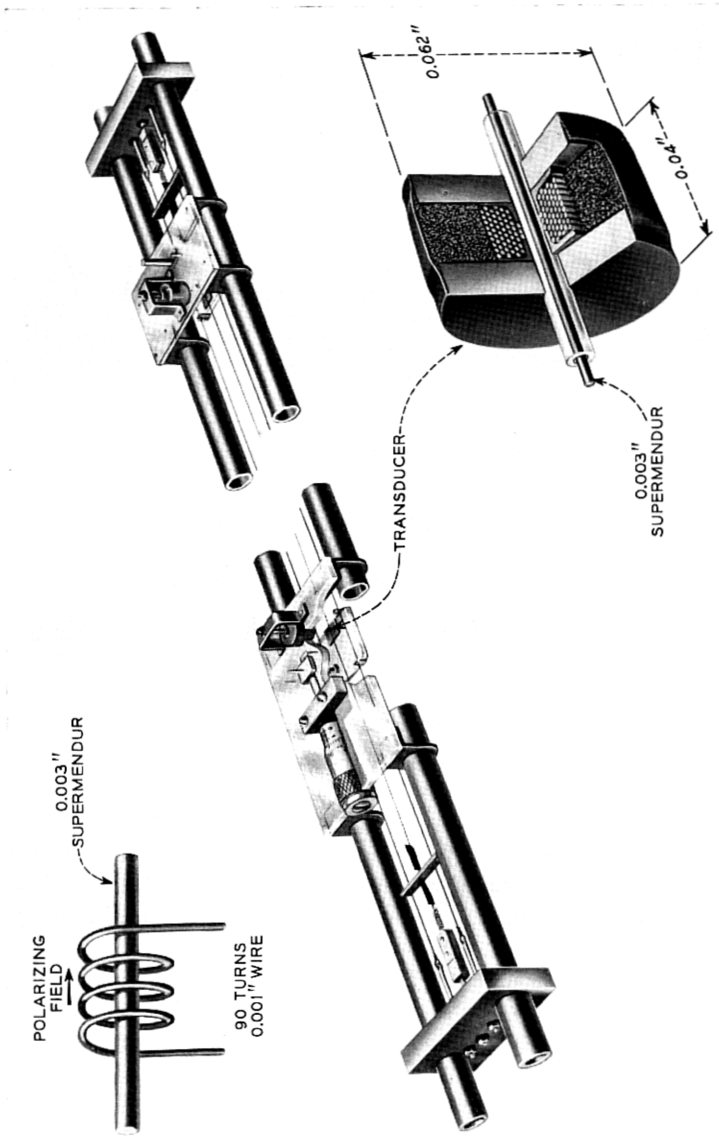

Fig. 12 — Magnetostrictive delay line.

has been published.[9] The time-division hybrid, a result of this experiment, is a circuit which permits a sample from a line gate to be passed to the "send" bus, held, stretched for coding, and then removed by a clamp so that there is no inter-time-slot crosstalk. Just after that sample passes through the common "send" gate and that gate is blocked, a common "receive" gate opens and passes an incoming PAM signal to the subscriber's line filter through his line gate, which is still open. This PAM signal is then dissipated by the subset which terminates the line filter. Approximately 123 microseconds later, the "send" gating operation is repeated. It is this time difference which provides the hybrid action, by preventing the receive signal from passing directly to the "send" bus.

The delay pads and the memories use magnetostrictive delay lines with transistor drivers and amplifiers. A typical line is shown in Fig. 12. The line, a 3-mil supermendur wire, is mounted so that the delay may be set manually any place in the range from a few microseconds to 125 microseconds. The servo unit for temperature correction is used only with the delay pads. It provides an automatic adjustment of ±1.5 microseconds.

These lines have a wider bandwidth than those in common use. The pulses applied are baseband, and the pulse rate is 1.536 mc. The total loss in the two transducers and the line is about 50 db. The drive circuit uses two transistors, and the receiving amplifier uses four transistors, and the line with this associated circuitry is a delay unit with zero loss.

4.3 *Performance*

The transmission characteristic of a channel between two voice-frequency terminals, exclusive of the subscriber loops, shows a loss of 6 db ± 0.5 db from 100 to 3200 cps and 3 db additional loss at 75 and 3500 cps. A channel will handle up to 6 milliwatts of sine-wave power. The signal-to-noise ratio is about 30 db. As mentioned above, the characteristics are independent of the length of line between conversion points and of the number of switching points.

Two research models of remote concentrators without controllers have been operating satisfactorily for more than six months. This part of the model uses about 1800 transistors and more than 5000 diodes. The performance of the components has exceeded all expectations for a research model. The model, as outlined, complete with controllers, trunkor and control console, has been operating for two months with equally satisfactory results.

Facilities are available for making listening tests to compare straight-through wire connections with the PCM connection, and only a few people have been able to detect a difference between these conditions. The quantizing noise on signals seems to be unnoticeable. The low-level noise resulting from the indecision of the coders during silent periods seems to be more bothersome than the quantizing noise on the higher signals.

V. CONCLUSIONS

A communication system concept has been described which uses time-separation techniques for transmission channels and for switching. It is primarily a digital system. In principle, the use of digital transmission with regenerative repeaters would provide fixed low loss and fixed quality connections between remote line concentrators. It would provide flexibility for new services. It might be arranged in a modular manner to handle growth, and to facilitate manufacture and installation. A full-size office of this type would require less floor space than existing electromechanical systems. A laboratory model using solid state devices throughout has been built and tested. It demonstrates the technical feasibility of the concept and gives an indication of the number of components that might be needed for such a system.

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