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This Issue in Brief

Transmission of Television by Pulse Code Modulation—The need for and advantages of digital transmission of video signals between television centers and transmitters are reviewed. The basic requirements for converting television broadcast signals into pulse code modulation are given.

An experimental equipment which employs discrete solid-state devices throughout is described. The video signal is sampled at 12.5 megahertz for parallel encoding into a ternary-based binary code. Serialization of the 8-digit code yields a low-disparity 100-megabit-per-second digit stream for transmission by any medium providing sufficient bandwidth. Some possible media are suggested. The signal can be regenerated even in the presence of quite severe distortion and a regenerative repeater suitable for use with coaxial cable is described. Criteria for assessing the performance of a pulse-code-modulation system are discussed, and comments on the performance of the equipment are given.

Pentomat *1000-T*, A Large Pentaconta Private Branch Exchange—The *1000-T* is a private automatic branch exchange for 200 to 9000 telephone lines. It is based on Pentaconta crossbar switching equipment to assure reliability and long life.

A preselection circuit is in control from the lifting of the handset to the return of dial tone indicating that a register is connected. The active phase of making the required connections follows a passive phase in which the path to be completed is determined. When the last digit is received by the register, a selection circuit takes control and similarly determines the path during its passive phase and operates the required switches during its active phase to connect the two parties and send ringing current to the called number. Only one of these circuits in a switching unit can be active at a time but all may be passive simultaneously. This increases the service obtained from a given number of switches.

Services available include calling a third number into an existing connection, transfer of an incoming call to another extension without operator intervention, initiating paging at a called number, calling of the operator by button with ringing when the operator answers, conference calls accommodating up to 15 lines, and automatic sending of preselected numbers frequently called. Speed services include keysets to speed up dialing to 10 digits per second, booking of calls to a busy number so that the call will be completed when that number is free, and direct dialing of an extension from the city network without operator assistance.

Concentrators may be provided for large exchanges to distribute incoming calls among the operators.

Teleprinter *Lo 133*—The *Lo 133* teleprinter will operate at 133 words per minute. The table model encompasses all the facilities of a telex station including page teleprinter with paper roll, tape reader, tape perforator-reperforator with its tape roll, and subscriber control box. It is faster, smaller, lighter, and more versatile than the design it replaces. Modular construction facilitates manufacture, maintenance, and repair. Modules are electrically interconnected by plugs and sockets.

Operation may be with a 5- or a 6-unit code and the type basket provides for 84 characters with 3 shift positions. Keyboards may be of either 3 or 4 rows with a maximum of 62 keys. The left-to-right movement of the type basket may be reversed for languages that require this. A special version automatically inserts shift combinations for letters and figures and thus operates similarly to a standard typewriter in this respect.

Computer Time-Sharing–A Review—Time-sharing is the simultaneous use of a computer by several users, each being the sole user at a particular time. It justifies the cost of a large computer by sharing the expense among many users, who may be in the same or different organizations.

A supervisory program assigns the computer for short intervals sequentially to each user with consideration for designated priority ratings. At the end of each such interval the running program is stopped and all of its active data are transferred from the active core memory to an auxiliary memory, from which the information for the next program, previously stored, is transferred to the core memory. This is called swapping. A clock controls all time intervals and a register is set to give each program a set number of intervals.

Each user has a control console and a teleprinter for communicating with the computer. Some systems provide for graphic presentation of, say, an electrical network, with ability to revise and recall on command. Curve plotters permit the computer to present graphs, schematics, maps, et cetera, to the user.

A command language is required for interaction with the supervisory program and generally used or special computer languages must also be accommodated.

Fine-Guidance Error Sensor, an Electronic Scanning Star Tracker—An inertial attitude-control system despins the Aerobee sounding rocket after launch and points it to within 4 degrees of a desired star. For fine control a boresighted star tracker senses errors to point the rocket to within 30 seconds of arc of the star. During 3 to 5 minutes of flight above the atmosphere, several stars can be successively acquired and tracked for study.

An optical lens system focuses starlight on a photocathode. Only a small stream of the electrons liberated thereby passes through a limiting aperture in a plate to the input dynode of a secondary-emission multiplier. The instantaneous photocathode area seen by the aperture is scanned in two dimensions by deflection coils. With no control input and no star signal a clock pulse initiates 4 raster scans. A star-selection circuit selects the brightest star in the field of view. This initiates the tracking mode to supply an error signal to control the rocket. If no star is found, acquisition scanning is continued.

Deltaphone—The Deltaphone, one of the most efficient of modern luxury streamlined telephone instruments, makes a clean break with the traditional telephone shape both in handset and body. Its special features are lightness, small size, excellent transmission efficiency, a tone caller (instead of a bell) with volume controlled by the user, and dial lighting without external power.

Its adoption by the British Post Office and its immediate success in world markets show the value of combining modern aesthetic taste with sound engineering.

Sound-Reinforcing Systems—Modern sound-reinforcing systems require expert design. The planner must first examine his problem and then specify the necessary equipment. Each problem (concert hall, lecture room, theater, or cathedral) has its own requirements. The engineer now has versatile equipment to work with which includes special microphones, loudspeaker arrays, transistor amplifiers, and so on. The equipment is engineered in accordance with standard equipment practice, and special attention is given to make it both visually and aurally unobtrusive.

In cathedrals there are special problems of reverberation, and the planner must incorporate delay systems tailored to suit the particular setup. In other cases the absence of reverberation must be compensated for. An electronic means of increasing reverberation time has been devised by P. H. Parkin in conjunction with the Council for Scientific and Industrial Research of Great Britain. Tuned resonators containing microphones feed tuned amplifiers and loudspeakers. The naturalness of the system remains unimpaired. In some cases, although the cost of a sound system is high, it is less than the cost to modify physically a building or give it special architectural features.

Behavior of Telephone Subscribers Using Push-Button Selection—Observations of subscribers were conducted in the quasi-electronic switching center *HE-60* in Stuttgart to measure the selection delay, inactive holding times, key actuation times, and interdigit pauses.

On the average, nearly 2 digits per second are sent on push buttons on local calls, which corresponds to nearly 3 times the speed of dial selection.

Key actuation times $t_i \leqq 30$ milliseconds, and interdigit pauses $t_p \leqq 70$ milliseconds, occurred less than 0.1 percent of the time.

After a 1-year trial period that permitted the telephone users to become familiar with the push-button telephone set, an increase in selection speed of about 10 percent was observed on local calls, compared with the selection speed at the beginning of the trial period.

Optical Subcarrier Communications—The narrow beams attained in optical transmission require highly accurate location and tracking of targets, the large information bandwidths suggest the use of modulated radio-frequency subcarriers, and the wide variations of attenuation and perturbation in transmission through the atmosphere make applications in space most attractive.

The phase of a beam of coherent light passing through a crystal of potassium dihydrogen phosphate (KDP) will be shifted if the crystal is suitably stressed by an electric field. By modulating the electric field, the light is phase modulated. Useful systems thus require the production of narrow optical beams and precision phase measurements.

Three systems are described. An electro-optical direction and ranging system uses a continuous-wave radio-frequency subcarrier and phase comparison rather than pulses as in conventional radar. An optical rendezvous guidance system employs a wide-angle telescope and scanning sensor on the chase vehicle that goes automatically from scanning to tracking mode when the wide-angle light source on the target vehicle has been acquired. The third system is a transmitter and receiver for communication including television.

Transitions in the Occupation Condition of a Group of Switches—A group of N junctions is in state X at instant t if X junctions are busy at t. This state is said to "belong" to a class whose limits are a and b when the number of occupied junctions lies between a and b. A change of class will be called "transition."

A study of the transitions is made for the general case and a formal solution of the problem given in matricial notation.

Exact computation of the transition frequencies is carried out in the case of statistical equilibrium for disjoint classes (no common junction) and for overlapping classes (n common junctions).

Transmission of Television by Pulse Code Modulation

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1. Evolving Digital Network

The philosophy [1] and principles [2] of pulse code modulation [3] are now well established, and multiplex digital systems for local-area telephony are appearing in commercial service. It is envisaged that vast digital communication networks exploiting the advantages of pulse code modulation will grow, in some instances eventually superseding the present analogue methods for the transmission of information. The ever-increasing need for data transmission can obviously be met more efficiently if the digital mode is retained throughout all systems, but it is perhaps less obvious that video information can benefit by use of digital techniques. However, the transmission of television signals over coaxial cable is notoriously difficult. This has led to extensive use of microwave systems to convey signals between television centres and transmitters. Expansion in the volume of television and other traffic will lead to increased congestion in the microwave spectrum which will encourage a return to use of closed media for broadband signals. Pulse code modulation provides an effective alternative to vestigial sideband transmission on cable, and in the future may be essential in overcoming many of the difficulties associated with transmission through long-haul waveguide and optical guides.

The broadcasting companies may soon use digital techniques for handling video signals in the studio. Processing for long-distance transmission can then be a purely digital operation. Nevertheless, conversion to the established analogue form for ultimate radiation will almost certainly be maintained for a long time to come.

A digital system is more readily adapted to online switching of television signals. A further advantage is that an arbitrary mixture of signals may be transmitted simultaneously on the same route by use of time multiplexing techniques. Higher-order multiplexes of telephone traffic lead to a digit rate commensurate with that required for television, so that routes may be interchanged if the need arises.

These considerations illustrate some of the advantages of digital television transmission both in its own right and as an element in an integrated digital network. There are, of course, other possible applications of digital television outside the public communication system.

2. Design Considerations for Television

2.1 Signal Parameters

The video signal used for broadcast television is essentially broadband. Depending on the standards adopted, the bandwidth may range from 3 megahertz for the 405-line system to 10 megahertz for the 819-line system. At the present time, most of the European administrations are moving towards the use of 625 lines. The video bandwidth for 625-line monochrome television is 5 megahertz and at least 6 bits are required for a reasonably faithful reproduction through a digital system. This leads to a minimum digital rate of 60 megabits per second and a minimum transmission bandwidth of 30 megahertz. Because of certain practical imperfections and limitations the actual bandwidth required is greater than this. The apparent extravagance is offset by greater system flexibility and increased immunity to noise and other disturbances in the transmission path.

There have been many attempts to improve transmission efficiency by exploiting "local" redundancy in the signal. The principal redundancy, however, is very unevenly distributed in time, and cannot be effectively utilized without storage of an impracticably large number of consecutive frames.

Synchronizing and blanking are largely redundant. Because it is periodic, this redundancy can be readily used, providing that adequate safeguards are built into the system. Then only one code is needed to specify the position of synchronizing edges, and a substantial proportion of the blanking intervals are available for digital injection of other traffic such as music channels and remote control signals; on suitable routes data and multiplexed telephony might ultimately be included with no increase in channel bandwidth.

2.2 Type of Encoder

The two fundamental approaches to encoder design are based on parallel and serial encoding. In the former the level comparisons are performed simultaneously and the number of comparators used is one less than the number of code characters. In a serial encoder, the comparisons are made sequentially using only one comparator. For each decision, the comparator is supplied with an offset notation which depends on the results of previous decisions within a given sampling interval. The encoding time is therefore longer in a serial encoder.

Thus for encoding television the parallel technique is preferable, offering higher speed capabilities and simple, though frequently extravagant circuitry. Non-standard codes are easily produced and there is more freedom than with the serial coder to introduce such complexities as code translators, in order, for instance, to ease the transmission problem.

2.3 Number of Quantizing Levels

The number of levels required is determined mainly by noise considerations and the subjective effects of quantizing. The International Radio Consultative Committee (CCIR) requires that, for long-distance picture transmission, the ratio of peak-to-peak signal to weighted root-mean-square noise should not be less than 52 decibels. If it is assumed that (A) only one independent link is encountered on a transmission route, (B) quantizing noise predominates, (C) all quanta are exactly equal, and (D) only one level is used to describe the television synchronizing pulse, a minimum of 45 levels is necessary to satisfy this signal-to-noise requirement. This increases to 56 levels for the weighting time constant used by the British Post Office.

Available evidence [4, 5] suggests that, under typical viewing conditions, the eye can distinguish about 120 distinct shades of grey, but only a small proportion of transmitted pictures need such fine quantization. With up to 60 or 70 levels hard edges are apparent in areas of almost uniform tone. These hard edges, which tend to be very obtrusive in a quantized picture, are more apparent on certain test signals. They become blurred and less objectionable in the presence of thermal noise. In regions of fine detail the quantizing steps are not visible, and very few levels are required. The type of code chosen will set the precise number of levels used. This must lie within a range providing a satisfactory balance between final picture quality and system economy. It may be concluded that for the majority of programme material between 50 and 100 levels are adequate provided that impairments are not compounded by connection of independent links in tandem.

Most situations likely to be encountered in a well planned network should be adequately covered by 128 levels. In colour television, the chrominance signal transgresses the amplitude range of the luminance signal. Because of this and other stringent requirements, more levels are required for a colour signal. If theoretical performance is realized, 256 levels should suffice.

2.4 Sampling Frequency

It is now generally accepted that the minimum sampling frequency should be at least $2 \cdot 3$ times the maximum frequency present in the signal. This allows for the practical realization of filters necessary to remove unwanted frequency components introduced by sampling. Other factors, such as phase stability in the chrominance channel, may place further constraints on choice of sampling frequency for colour television.

Greatest flexibility and economy is attained in an integrated network if the sampling frequency for a television channel is suitably related to sampling frequencies and multiplexing factors used in other parts of the network. There may also be some advantage in correlating the sampling and television line frequencies. Chrominance intermodulation would then be static rather than mobile, and ideally synchronizing jitter due to use of a single code would be eliminated. These two requirements will in general be mutually exclusive. Greatest long-term economy and flexibility should result if timing is related to network parameters.

2.5 Code

For best performance and greatest ease of circuit design, the processes of encoding, transmitting, and decoding require different code properties. A high degree of redundancy would result if one code had to possess all the necessary properties, so the concept of code translation is therefore introduced.

There are several methods of achieving the required ends. One of them uses a ternary-based binary code [6] where three levels or groups of levels are represented by pairs of binary digits. Some possible allocations of digit pairs are shown in columns 2 and 3 of the table.

(1) Level Number	(2) Digit Pairs (Fixed)	(3)	(4) Digit Pairs (Alternating)
1	1 0	0 1	1 0
2	0 0	1 1	0 0 or 1 1
3	0 1	1 0	0 1

These may be extended to cover 3^n levels with $2n$ digits in a number of ways. One of them, which uses the combinations of columns 2 and 3 alternately in building up the code raster, is the *C* code in the parlance of W. Neu. It exhibits the property of unit distance, which means that only one digit changes between adjacent levels. This is desirable in a parallel encoder and minimizes errors due to doubtful decisions. The *C* code is readily translated to a low-disparity code suitable for line transmission by using *00* and *11* alternately to represent the centre of the three levels, as shown in column 4 of the table. This is Neu's *B* code, which has equal numbers of marks and spaces over a period, and never has more than four similar digits consecutively. These attributes ease the regenerator problem, since the need for direct-current restoration, difficult at this speed, is obviated and frequent transitions for the extraction of a retiming signal are guaranteed. The *B* code may be decoded directly by weighted addition, so may individual combinations of columns 2 or 3. In practice, prior translation to one of the latter gives better results.

In an alternative approach the Gray code may be generated, translated to pair-selected ternary notation for transmission and to binary numbers for decoding. This provides the same basic properties.

2.6 Quantizing Law

In a telephone channel, the signal amplitude distribution permits a noise advantage at low levels by use of non-linear quantizing. Complete measurement of the statistics of television signals is impracticable but, based on a number of restricted investigations, it has been suggested by Seyler [7] that if synchronizing and blanking are ignored all levels are equiprobable, at least over a sufficient number of picture frames. When a linear ramp, with or without gamma correction, is displayed on a monitor with controls optimized for normal picture viewing, quantizing is more apparent in the centre of the amplitude range. This in itself may suggest a non-linear law. Nevertheless it is possible to alter the monitor settings to accentuate the effect of quantizing in any part of the range. Amplitude distributions will in fact differ widely over the range of picture material encountered, and while uniform quantizing will not be ideal for most individual frames, it provides a reasonable compromise solution. The desirability of using a linear law is further substantiated by the fact that the display-tube gamma is approximately cancelled by the non-linear characteristic of the human eye over the appropriate range of light intensity.

3. Experimental Terminals

3.1 Vision Channel

A block schematic of the all-solid-state equipment, based on the original ideas of W. Neu [6], is given in Figure 1. In accordance with the above discussion, a parallel encoder generates an 8-digit ternary-based binary code providing 81 levels, or an equivalent fully occupied binary capacity of 6·34 bits. In conjunction with a sampling frequency of 12·5 megahertz, this yields 100 megabits per second for transmission.

The encoder is divided into 14 identical subunits [8, 9], each discriminating a group of 6 adjacent levels. The codes are obtained by the appropriate interconnection of the subunit outputs. Each subunit is preceded by a coarse discriminator which offers to it a range of signals only slightly exceeding the range which it encodes. Here, as in most of the equipment, current steering techniques are used. Transistors in the encoder are selected, but in the digital circuits device parameters are not very critical. Code translation is by rearrangement of the digit pairs. The signal is decoded by weighted addition of the stretched parallel digits.

3.2 Sound Channel

The signal is sampled at television line frequency, and an amplitude-modulated pulse 2 microseconds wide is gated into the television signal during the line synchronizing pulse. Thus sound and vision are encoded by the same encoder. The effective number of levels in the sound signal is increased by the integrated effect, over 25 samples, of small random fluctuations added to the pulse-amplitude-modulated signal.

Channel performance is limited by non-linearity in the pulse-amplitude-modulation gate. This causes intermodulation, unnoticed on speech but occasionally objectionable with music. In judging performance, allowance was made for the comparatively low sampling frequency. In commercial use at least two samples per line would be employed.

Transmission of the sound channel by pulse density modulation of an extra digit has also been demonstrated. Performance was better, but the method is extravagant in channel capacity. It has been concluded that the sound should be encoded independently and injected digitally during the line blanking period as suggested in Section 2.1. Encoding techniques for a music-quality channel have been investigated separately.

4. Digital Transmission

4.1 Transmission Media

Any transmission medium of adequate bandwidth will carry the digital signal, but a contained rather than radiated transmission is preferable; of principal interest are coaxial cable, long-haul waveguide, and optical guides.

Initially, coaxial cable is the most attractive. Cable attenuation and realizable broadband gain dictate, for presently available techniques, a repeater spacing of 1 mile on 4·4-millimetre (0·174-inch) diameter cable carrying a binary signal at 100 megabits per second. Conversion to low-disparity ternary coding permits a slight increase in repeater spacing.

Long-haul waveguide, with repeaters spaced at about 20 miles, and optical guides may well provide the very-high-capacity systems of the future. Mode conversion/reconversion effects in waveguides add distortion from which an analogue signal cannot be retrieved. In optical guides the discrete quantum interactions between atomic particles of matter and electromagnetic radiation add to signal impairment. Recourse to digital transmission therefore becomes essential.

4.2 100-Megabit-per-Second Regenerator

The terminal regenerator included in the experimental equipment was designed for a repeater spacing of 960 yards (880 metres) on

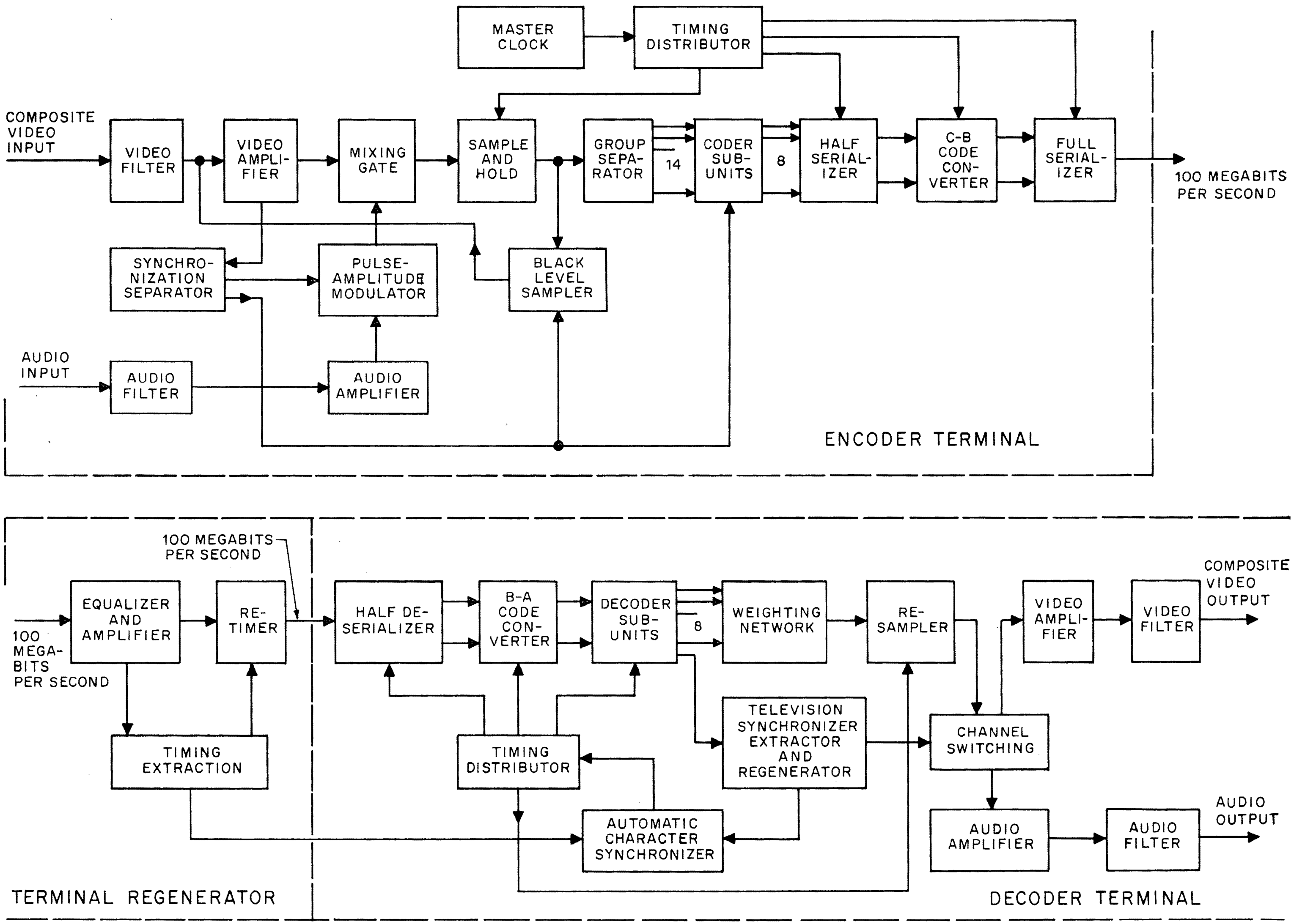

Figure 1—Schematic diagram of 81-level pulse-code-modulation system.

small-bore coaxial cable (4·14 millimetres (0·163 inch)) [8, 9]. It is shown as part of the block diagram. The wideband transistor amplifier has a gain of 65 decibels and substantially flat response from 30 kilohertz to 90 megahertz. The cable, equalizer, and amplifier are designed to give an overall response which is 12 decibels down at the pulse repetition frequency of 100 megahertz. Retiming is obtained by differentiating the digital signal and filtering out the pulse repetition frequency in a coaxial helical resonator with a loaded Q of about 400.

The incoming code is sampled with short pulses derived from the 100-megahertz sine wave. A tunnel diode set-reset flip-flop serves as a pulse stretcher to re-establish full baud pulses.

5. Performance Assessment

5.1 Testing Philosophy

The transmission of television on analogue routes is now well established, and over the years suitable testing procedures have evolved [10]. Many of the standards specified have been established as the result of carefully conducted subjective tests. In a pulse-code-modulation system the sampling and quantizing processes introduce forms of impairment which are not encountered on an analogue transmission route. It has already been found necessary to lay down new test procedures and specifications for digital transmission of telephone traffic and this must follow for television.

Tests carried out on the present equipment were by no means exhaustive, and the subjective effects were judged by only a very limited number of observers. More-thorough tests are needed to establish new test procedures, particularly in correlating subjective and objective performance.

5.2 Subjective Performance

The principal subjective effect is noise enhancement due to quantizing. This is only apparent in parts of some pictures at certain settings of monitor brightness and contrast controls. It only becomes objectionable with a very limited range of picture material. The actual quantizing steps are not visible on a wide range of ordinary pictures, but with a linear ramp signal they are quite noticeable. The steps become increasingly apparent as the number of levels is reduced, but on some pictures they can scarcely be detected with only 9 levels.

Although they were intended mainly for monochrome television, colour pictures, using the PAL system, have also been transmitted between the terminals. Instrumental imperfections cause intermodulation, principally between three times colour subcarrier and the sampling frequency. This gives objectionable patterning in large areas of saturated colour.

A test card devised by the Society of Motion Picture and Television Engineers has tapering lines in the horizontal and vertical directions. In a sampled system Moiré patterning on the vertical lines is similar to that caused by the line structure on horizontal lines. The test card, part of which is shown in Figure 2, is therefore useful in assessing system performance, revealing not only the effects of sampling but also those of certain system deficiencies. A photographic record of a picture transmitted by 4 or more bits seldom shows the effects of processing even though they may be visible on the actual display. This test card and a linear ramp are the two most revealing subjects both for direct observation and for photographic illustration.

5.3 Noise

Techniques for the measurement of noise, in particular, differ from those employed on analogue systems. In the latter, noise level will be either constant or vary uniformly over the signal amplitude range. Instruments are available for the direct measurement of signal-to-noise ratio, even in the presence of the synchronizing signal.

In a pulse-code-modulation system, the magnitude of the error signal, usually referred to as quantizing noise, depends on the number of quanta traversed by the signal. If the number is sufficiently large, the noise power will be $S^2/12$ where S is the step size. In areas of uniform grey, a static signal, with inevitable small disturbances superimposed on it, may exactly straddle a discrimination threshold. Noise power can then rise to a peak of $S^2/4$. The same picture area at a slightly different potential, where no threshold is activated, will yield a noise power dependent only on decoder circuit noise.

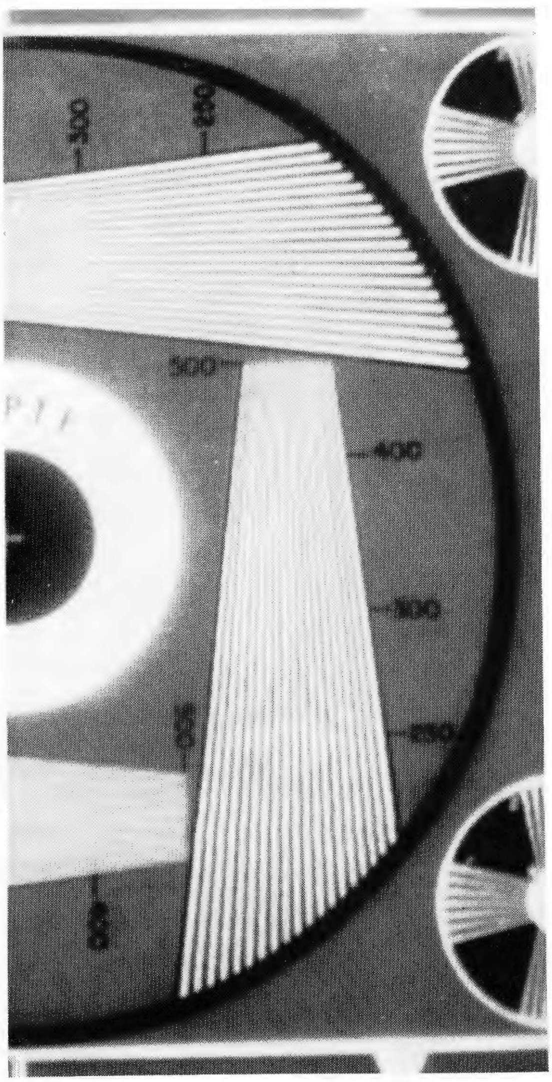

Figure 2—Part of test card of Society of Motion Picture and Television Engineers after transmission through a pulse-code-modulation system. Exposure is 1/15 second.

The analogue system instrument is effective in measuring the static signal noise. Noise originating in this mode becomes significantly apparent only if the small disturbances which cause it are sufficiently regular to cause patterning. Measured values were all within 0·5 decibel of theoretical, while at most transitions they were better than this.

Because quantizing noise is in fact an error component it can only be measured in the presence of a signal. The simplest way of performing such measurements is to inject a sine wave, or combination of sine waves in a narrow band, which is removed by filtering, after decoding. The residue is mainly quantizing noise. A single sine wave was used and the residue was found to have a substantially flat spectrum with peaks at harmonics of the input signal.

Another approach uses a linear ramp. The input is subtracted from the output, again leaving a residue of quantizing noise. This method is more difficult to instrument accurately.

5.4 Pulse Tests

Standard pulse and bar tests are normally applied to transmission systems. The waveforms, which have to lie within certain limits for acceptance, are photographed and measured very accurately. In a pulse-code-modulation system, especially with the T pulse and equivalent rise time for the bar, jitter is likely to occur on edges, and limits for this may have to be added to the specifications.

Figure 3 shows the response of the present terminals to a $2T$ pulse and bar. Imperfections in the analogue circuits preceding the encoder are responsible for the overshoot and ripple on the final output.

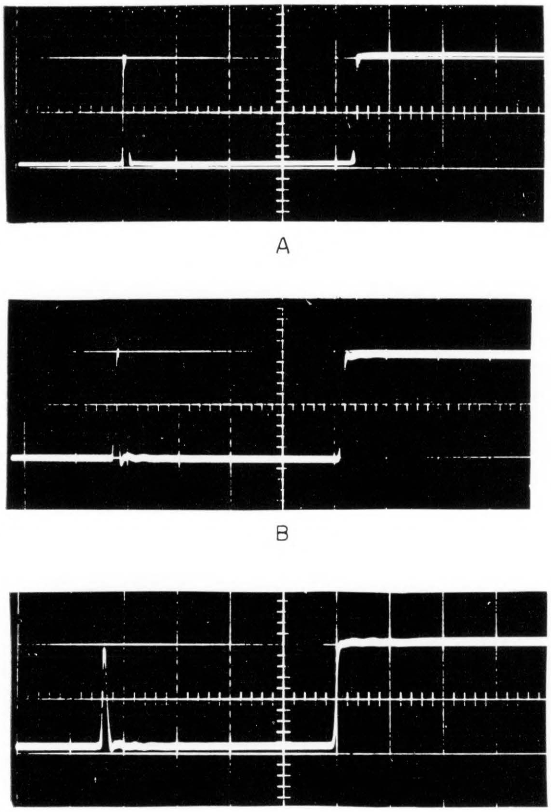

Figure 3—Pulse and bar response. *A* is the input, *B* the output of the encoder drive amplifier working into a resistive load, and *C* is the final output. The horizontal scale is 2 microseconds per division.

6. Concluding Comment

For monochrome television the subjective performance of the experimental system described is satisfactory, though it may not fully meet all the tests which would be specified for commercial service, especially when several systems are required to operate in tandem.

In future developments, the specific techniques employed may not necessarily be perpetuated. For instance, generation of a non-redundant binary code can provide a standard interface for compatibility of equipment from various sources. Translation to redundant ternary, or higher radix, for transmission is then advantageous, at least for cable where noise is not the limiting factor.

The experiments have been worthwhile, insofar as in the light of knowledge gained it is clear that an equipment with perfectly satisfactory performance could be designed.

7. Acknowledgments

A number of people, in particular Messrs. C. C. Cock, D. A. Burgess, and G. A. White, have contributed to the experimental work associated with this paper, and their help is gratefully acknowledged by the author.

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John D. Weston was born in London in 1930. In 1958 he obtained a B.Sc. (Eng) degree from London University, having studied part time at Northampton Engineering College.

He joined Standard Telecommunication Laboratories in 1952 where he worked initially on transistor evaluation and then on distributed amplifiers. For the past 10 years he has worked on various aspects of pulse-code-modulation television and now leads a team studying the processing of other forms of visual information.

Pentomat *1000-T*, A Large Pentaconta Private Branch Exchange

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D. MOURADIAN
Bell Telephone Manufacturing Company; Antwerp, Belgium

1. Introduction

The Pentomat* *1000-T* crossbar private automatic branch exchange will handle from 200 to 9000 extension lines. Its specifications take into consideration the requirements of several European and American countries to permit widespread application.

To assure reliability and long life the proved standard components, such as relays and multiswitches, of the Pentaconta† crossbar equipment have been used.

2. Equipment and Cabling

2.1 Equipment

The equipment practice also follows that of systems using Pentaconta components. The multiswitches and relays are mounted in standard frames, which are assembled on bays that are accessible from both sides. A bay holds 5 frames, an intermediate distributing frame, and a combined fuse and lamp panel. Several bays are grouped into switch racks of a convenient length.

2.2 Cabling

Plug-in cables interconnect frames in the same or different bays. This reduces considerably the work and time needed for installing the exchange and simplifies later expansion.

2.3 Floor Plan

A floor plan of an exchange for 1000 lines is shown in Figure 1.

*Trademark of Bell Telephone Manufacturing Company.
†Trademark of International Telephone and Telegraph Corporation.

3. Facilities

3.1 Facilities for Subscribers

(A) Calling another local or city subscriber into a city conversation.

(B) Automatic transfer of a city call to another local subscriber or to the operator in the case of a wrong manipulation.

(C) Paging using audible, visual, or radio-emitted codes at the called number initiated by a prefix or suffix dialed by the calling party.

(D) Privileged lines that can call the operator by pushing a button of the subset without lifting the handset. When the operator answers, the calling number is rung.

(E) Rapid conference call in which 15 subscribers can be grouped quickly into a conference.

(F) "Selectomat" automatic number sender by which any one of 30 preset numbers are called by pushing an individual button for that number.

3.2 Facilities for Operators

(A) Holding, parking, and automatic supervision of incoming calls.

(B) Indicator lamps to identify the local subscriber number connected to the operator.

(C) Keyset calling of city numbers.

(D) "Autodial" permitting the operator to send any one of 10 preset city numbers by pushing only one button of the keyset.

3.3 Special Facilities

3.3.1 *Keysets*

The normal dial sets may be replaced gradually and easily by keysets to simplify and speed up calling.

3.3.2 *Booking*

When a local line is found busy, the caller pushes a recall button and replaces the handset. The called line is then supervised by the local connection circuit and when the line becomes free ringing current is sent to the caller. On lifting the handset the caller hears ringing tone as ringing current is sent to the called party.

During the waiting period, the calling line may establish or receive another local or city call. The booking condition is released when the called party remains busy for more than 4 to 6 minutes or if the calling party fails to answer.

3.3.3 *Direct Dialing of an Extension*

A subscriber of the central office network may dial any unrestricted extension of the private exchange without intervention of the operator. If the desired extension is busy, the call is routed automatically to the operator. This facility considerably reduces the work of the operator and saves time for the caller.

3.3.4 *Metering*

The 3 following methods of metering are available.

(A) Meter per subscriber in which a single meter receives metering impulses from central offices and then registers a total amount for all services incurred by the private branch exchange.

(B) Meter per city line in which each trunk to the city exchange is provided with a meter that is placed on the private-branch operator's desk. At the end of each call the city line circuit alerts the operator to note the charge and extension number, both being shown by indicator lamps on the operator's desk.

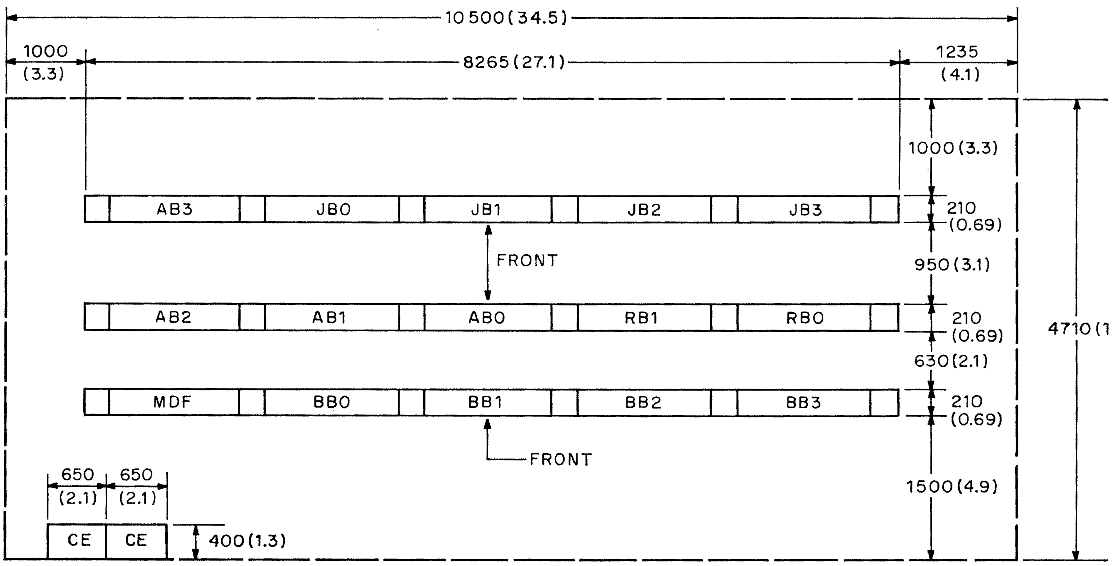

Figure 1—Floor plan for 1000-line exchange with 72 trunks and 64 local connecting circuits using fixed frames 2.81 meters (9.2 feet) high and weighing approximately 450 kilograms per running meter (300 pounds per running foot). Dimensions are in millimeters (feet). The functions of the frames are as follows:

MDF, main distributing frame
AB, *A* section bay
BB, *B* section bay
JB, junction bay
RB, register bay
CE, charging equipment.

(C) Registered metering in which a record is made on perforated or printed tape of the number of the extension making the call, the number of the called city subscriber, length of the call in minutes, tariff code, total charge for the communication, and the date and hour.

3.3.5 *Concentrators*

A concentrator is provided for installations with a large number of city lines. Incoming calls are automatically and equitably distributed among the private-branch operators. Each incoming call is routed to a pair of operators provided that at least one operator is present and free. The call is indicated on both desks so that a burned-out signal lamp on one desk will not prevent service.

Further operations are analogous to those used in cases of direct access.

For an outgoing call, the operator pushes a button and a free link circuit in the concentrator seizes a free city line. If there are several directions of city lines, a start button is provided per direction.

4. General Characteristics

4.1 Traffic Capacity

For an average traffic per extension not exceeding 0.18 erlang and for up to 5000 lines, the total loss of calls during preselection or selection remains below 3 percent.

In these circumstances and with a busy time of about 300 milliseconds for preselection and selection circuits, the probability of having a waiting time of 1.5 seconds in preselection or selection remains below 1 percent.

For equipments over 5000 lines it is necessary to gradually reduce the average traffic value to 0.15 erlang per extension if the same grade of service is to be granted.

4.2 Technical Characteristics

The nominal supply of 48 volts may vary between 44 and 56 volts.

The maximum line loop resistance is 1000 ohms, including the subscriber set. The maximum allowable leakage between *a* and *b* wires or between one of these wires and ground is 20 000 ohms.

The speed of the dial may vary between 8 and 12 interruptions per second in the worst circumstances. With keysets the maximum speed is 10 digits per second.

4.3 Signaling

The frequency and periodicity of the different signals conform with the recommendations of the International Telegraph and Telephone Consultative Committee (CCITT).

4.4 Transmission

Table 1 shows the major transmission characteristics of the exchange.

5. Switching Principles

In addition to meeting the communication needs of the subscriber: reliability; fast operation; easy installation, maintenance, and expansion; and flexibility are important elements in designing a switching system.

The following principles of the existing Pentaconta crossbar switching system have been used.

(A) Complete separation of the speech path from the control network.

(B) Use of a link system with conjugate selection.

(C) Possible use of mutual-aid circuits (entraide).

To provide certain required characteristics of this private branch exchange, some new switching concepts were applied.

(A) Complete separation of preselection and selection functions and their control by separate circuits.

(B) Distinction between a passive and an active phase in each of the control circuits.

(C) Conjugate selection over three stages without an independent group selection element when serving 1000 lines.

Preselection starts when the calling subscriber lifts the handset and ends at the receipt of dial tone. Selection starts on receipt by the register of the last dialed figure and ends when ringing current is sent to the called party.

In systems with centralized control, preselection and selection functions are usually combined in one (possibly duplicated) circuit, generally called a marker.

TABLE 1
TRANSMISSION DATA

Description	Frequency in Hertz		
	300	800	3400
Maximum insertion loss in nepers (decibels) for local and trunk calls	0.2 (1.74)	0.1 (0.87)	0.1 (0.87)
Minimum crosstalk attenuation in nepers (decibels) for local and trunk calls	8.5 (73.6)	8.5 (73.6)	8.5 (73.6)
Minimum unbalanced attenuation in nepers (decibels)	5.0 (43.4)	5.5 (47.8)	5.5 (47.8)
Minimum crosstalk attenuation in nepers (decibels) through common tone circuit	6.5 (56.5)	6.5 (56.5)	6.5 (56.5)
Minimum crosstalk attenuation in nepers (decibels) in line-lockout condition	5.0 (43.3)	5.0 (43.4)	5.0 (43.4)

However, these two functions are completely distinct and independent of each other in time and may therefore be effected by two separate control circuits, the preselection control circuit and the selection control circuit.

Each of these functions occurs in two successive phases. The first phase is called the passive phase. During it the preselection or selection control circuit sends information to or receives it from the connected circuits and prepares the marking of the inlets and outlets of the different stages. During this phase no real switching action is performed. The second phase is called the active phase. During it the preselection or selection control circuits control the switches in the various stages by marking the corresponding inlets and outlets.

The control circuits may operate simultaneously in any possible combination during their passive phases but not during their active phases.

This is a simple way to increase considerably the service provided by a switching element without an increase in hardware.

For reliability these common control circuits for preselection and selection have been duplicated.

If preselection and selection are to be performed at the same moment, both preselection and selection control circuits start simultaneously in their passive phases. If, for example, a selection control circuit first ends its passive phase, it will start immediately on its active phase, simultaneously blocking the preselection control circuit from starting its active phase.

In this way, the time that either control circuit must wait before continuing its switching operation is maximally equal to the time needed by the active phase of the other control circuit.

Reduction of the total active time of preselection and selection control circuits to about 300 milliseconds permits conjugate selection over three stages when the exchange employs several line switching elements.

6. Line Switching

6.1 Junction Diagram

Figure 2 represents the junction diagram of a 1000-line switching unit.

6.1.1 *Switching Network*

The fundamental switching unit is of 1000 lines with concentration by means of a link arrangement.

An *A* stage is formed of 20 *A* sections. Each *A* section has 52 outlets represented by the horizontal bars to which 50 subscribers are connected. They may be connected to any of the 16 inlets represented by the vertical bars.

A second stage, called the *B* stage, comprises 8 *B* sections with 40 + 12 outlets. The 40 outlets allow the interconnection of the *B* section with the different *A* sections, while the other 12, called mutual-aid outlets, allow the interconnection of this *B* section with other *B* sections.

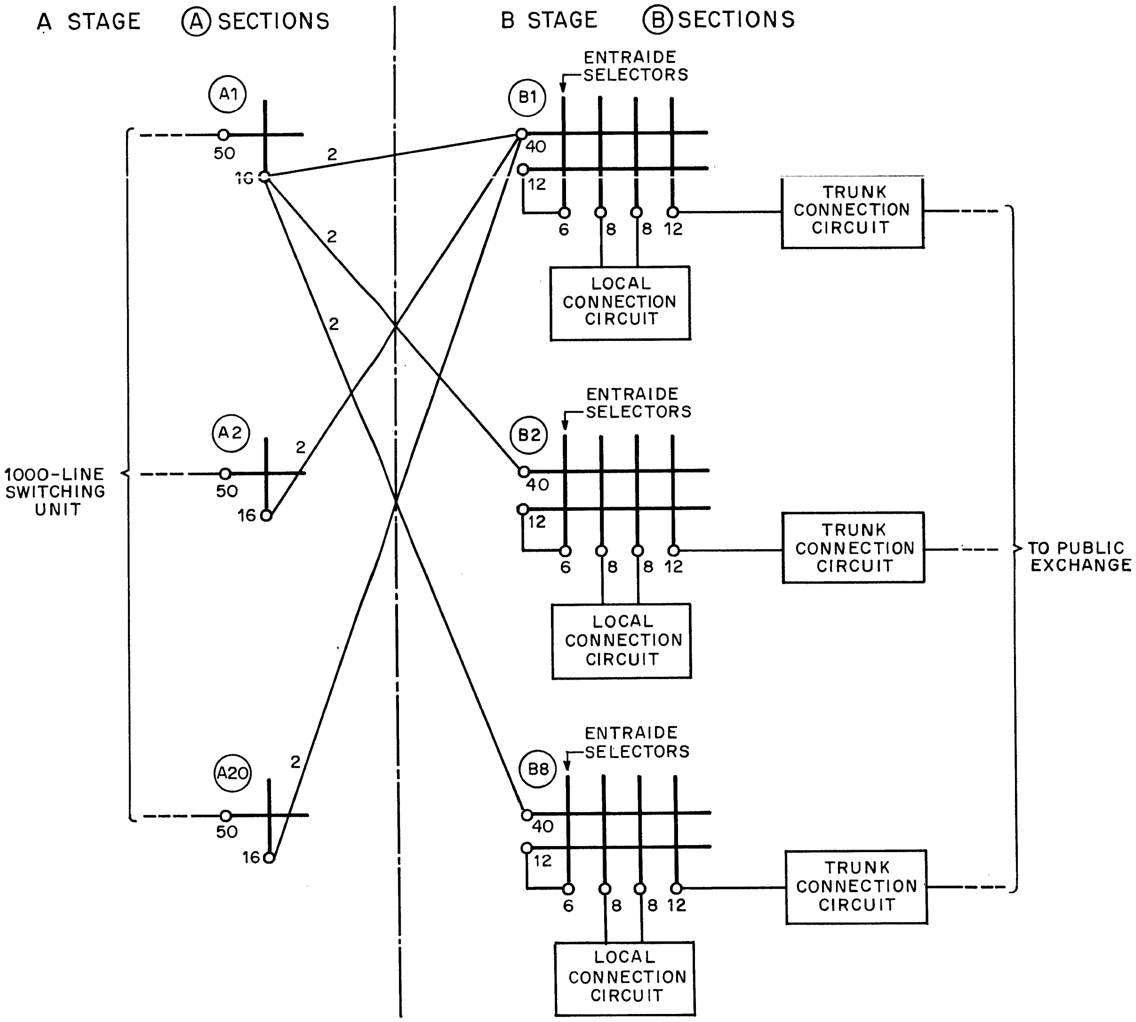

Figure 2—Link arrangement for 1000-line switching units.

The *A* and *B* stages are interconnected according to a regular distribution pattern between the outlets of the *B* sections and inlets of the *A* sections. In this way, and seen from the *A* section, each local line has access through 16 inlets to each *B* section via 2 links.

If both links are occupied a path is established through one of the mutual-aid outlets to another *B* section allowing a direct connection to the given *A* section

The local connection circuits and the city line circuits are distributed equally over the *B* sections.

6.1.2 *Control Equipment*

6.1.2.1 *Registers*

Figure 3 shows the access of the local connection circuits to the registers. The registers are connected temporarily to the local connection circuits and receive, from the calling line, the number of the called line or of the desired direction. At this moment they call for a free selection control circuit that will control the selection.

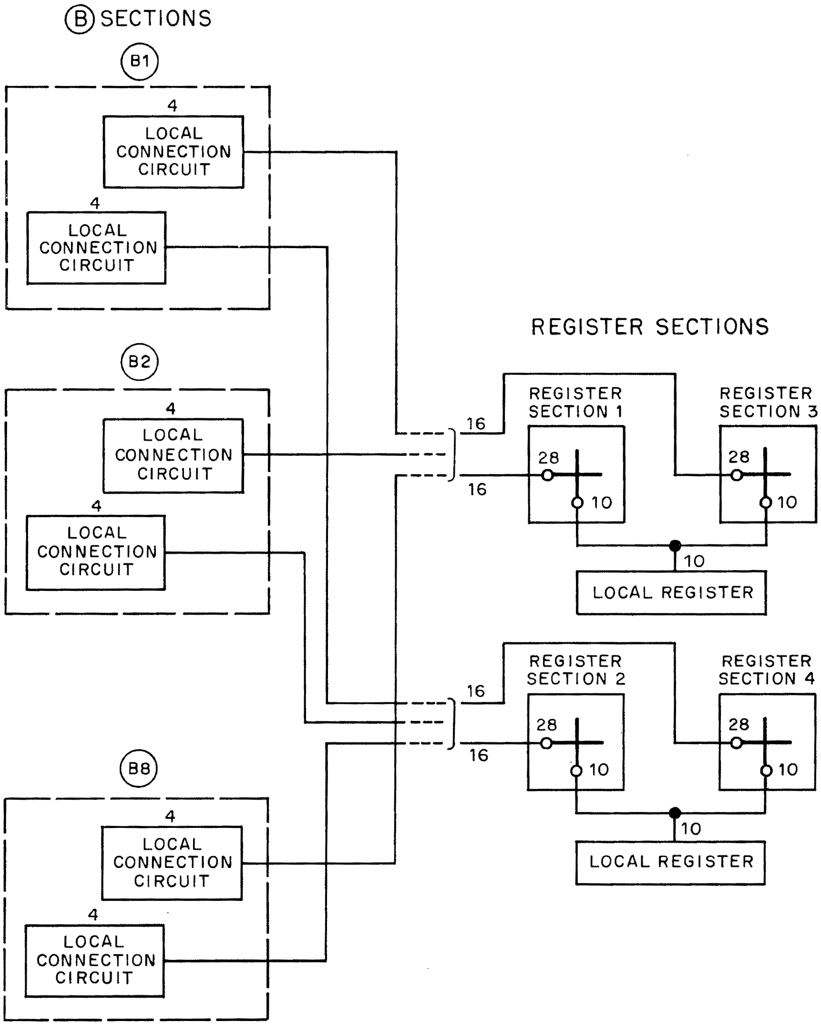

Figure 3—Access of local connecting circuits to local register circuits.

6.1.2.2 *Control Circuits*

Two preselection and two selection control circuits are connected to the line switching unit.

Through a free local connection circuit, the preselection control circuit connects the calling party to a free register.

The selection control circuit is connected momentarily to the registers to control the through-connection of the call.

6.2 Operating Principles

Using Figure 4 the establishment of a local connection will be described. It requires two distinctive operations, preselection and selection.

6.2.1 *Preselection*

When the handset is lifted, the line relay operates and creates a calling condition in the corresponding *A* section, which calls for a free preselection control circuit.

We suppose that several *A* sections are calling at the same time. At this moment the preselection control circuit passes from rest position into the passive phase and selects, by means of a changing preferential access chain from the calling *A* sections, one having at least one free path to a *B* section.

The preselection control circuit scans, and selects as above, the *B* sections to find one with at least one free link to the chosen *A* section and at least one free local connection circuit giving access to a free local register in that *B* section.

The incoming and outgoing points of the switching element are then known and if no other preselection or selection control circuit is active the preselection control circuit will enter into the active phase.

The preselection control circuit now connects a free register to a free local connection circuit of the chosen *B* section and simultaneously controls the connection of the calling line to this local connection circuit.

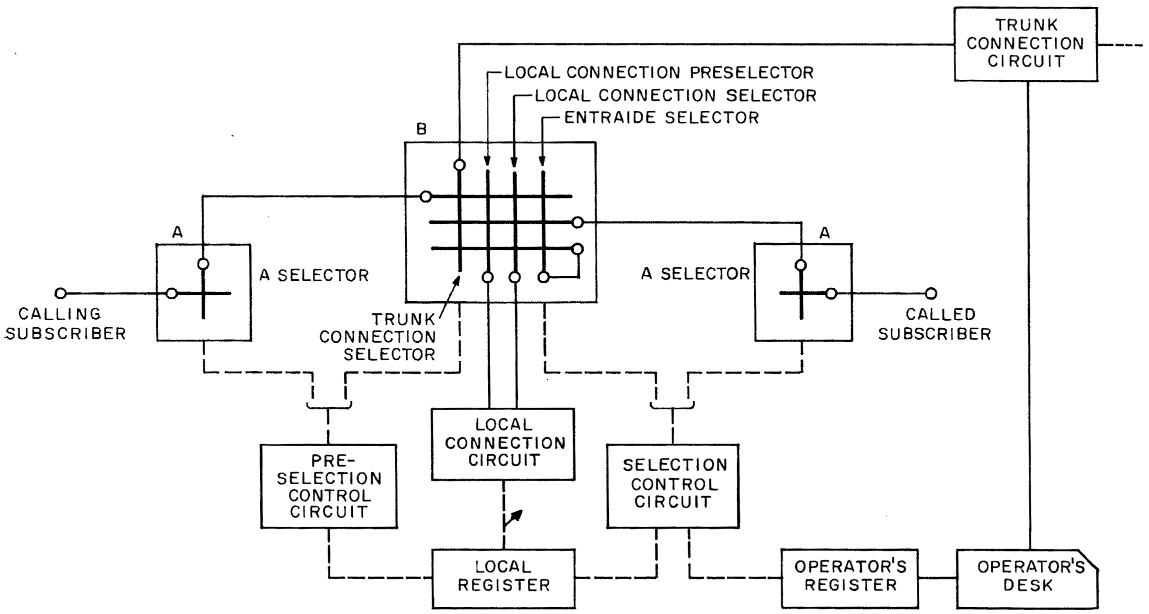

Figure 4—Simplified junction diagram for 1000-line switching unit.

Therefore the preselection control circuit controls the operation of the horizontal bars in the *A* and *B* sections and, after being informed of their proper operation and of the effective connection between the local connection circuit and the register connection circuit, it transmits the class of the calling line to the local register, whereafter the successive operation of the selectors in the *B* and *A* sections occurs.

The local register sends dial tone to the calling party and is disconnected from the preselection control circuit, which becomes free for a new preselection.

At this moment other control circuits may pass into active phase.

6.2.2 *Selection*

On receipt of dial tone, the calling party transmits the number of the desired line to the local register. When the number is complete, the local register calls a selection control circuit at random from those that are free. At this moment the selection control circuit enters into the passive phase and receives from the local register the code of the called line. In the selection control circuit this code is converted to determine the corresponding *A* section and the geographical position of the line in this *A* section. The incoming and outgoing points of the switching element being known, the selection control circuit passes into the active phase if no other control circuit is active at that time. The selection control circuit initiates the operation of the horizontal bars that correspond to the called party in the *A* section. In the *B* section the horizontal bars corresponding to a free link to this *A* section are operated simultaneously.

If the called line is free, the selection control circuit receives this information from the *A* section and transmits it to the register by operating the local connection selector in the *B* section and the *A* selector in the *A* section.

The register is then disconnected from the selection control circuit and from the local connection circuit, which sends ringing current to the called line and ring-back tone to the calling line.

If the called line is busy, the selector control circuit informs the local register of the busy condition of the called line. The local register decides then, depending on the classes of the called and calling subscribers, whether the local connection circuit is to be released or whether the selection is to be completed to allow for a possible cut-in into the existing conversation.

In both cases the selection control circuit is released and becomes available for a new selection.

6.2.3 *City Connection*

6.2.3.1 *Automatic Outgoing City Call*

Preselection remains unchanged. After receiving dial tone, the calling party sends the prefix corresponding to the wanted city line group. The register calls for the selection control circuit and is connected to it as for a local selection.

The selection control circuit, receiving the order to establish a city connection, scans the *B* sections to find one with at least one free link to the *A* section of the calling party and at least one free junction.

The selection control circuit chooses one of the suitable *B* sections and one of the free junctions in this *B* section.

The connection of the junction to the line is made after which the selection control circuit and the local register are released.

6.2.3.2 *Incoming Call Via Operator*

The operator sends by keyset the number of the called line. This information is stored in the operator's register. To avoid delay operator's registers are individual.

The operator's register calls for a free selection control circuit. The connection is made in the same way as in the case of a local register. All further selection operations are similar to those described for all local selection.

7. Group Switching Element

7.1 Junction Diagram

Figure 5 is a junction diagram for 2000 lines.

7.1.1 *Switching Network*

When several line switching units are provided, their interconnection is aided by a supplementary *C* stage.

The number of *C* sections in the *C* stage depends on the number of line switching units and the required traffic.

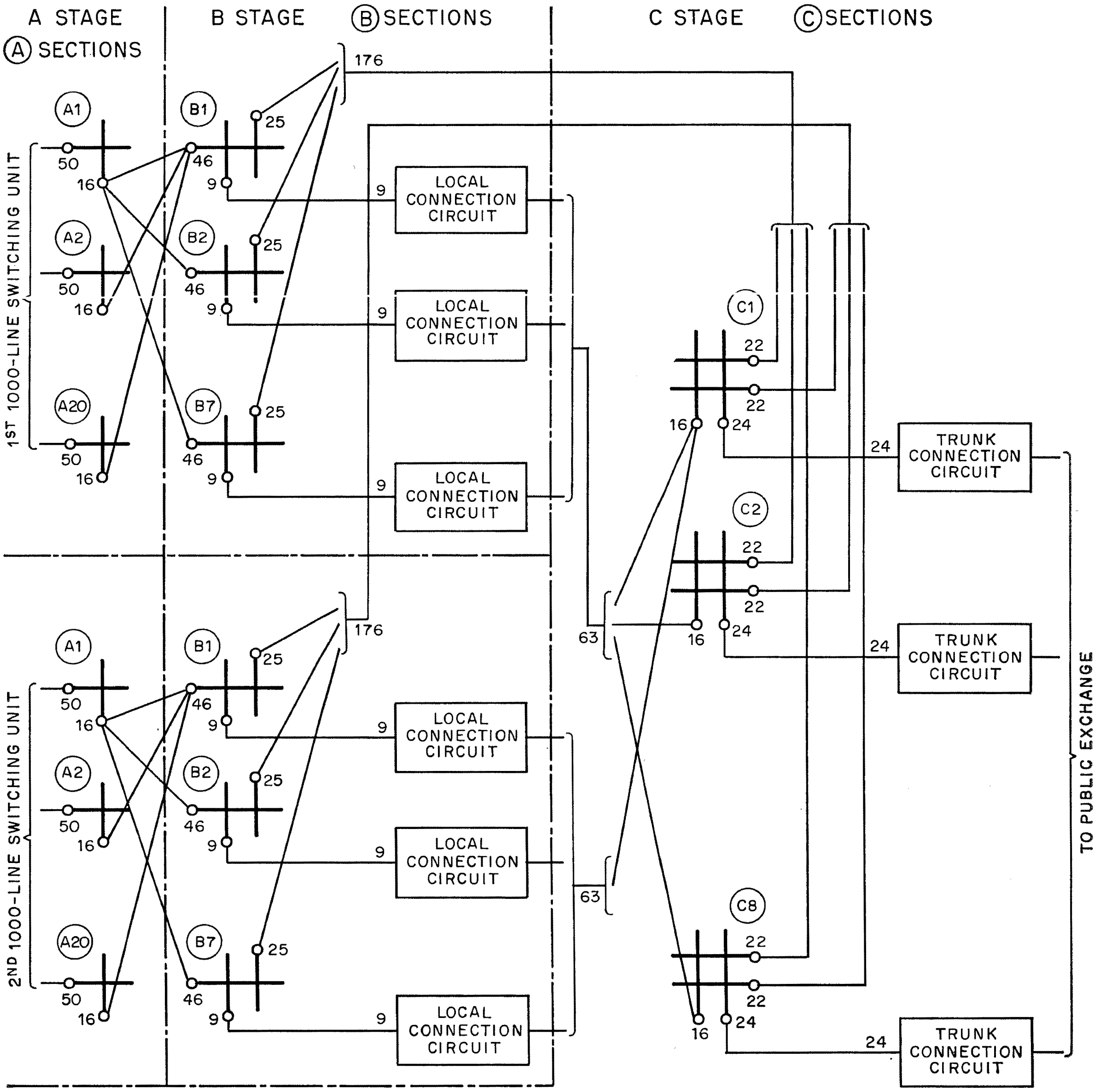

Figure 5—Link system arrangement for 2000-line conjugate switching unit.

The 52 outlets of each C section are divided into a number of groups equal to the number of line switching units. The outlets of a group corresponding to a line switching unit are equally distributed over all the B sections of this unit.

From each C section it is possible to reach a given A section through any B section of the same line switching unit.

It has to be noted that due to the use of conjugate selection over the three stages, mutual aid between B stages becomes superfluous.

7.1.2 *Control Equipment*

7.1.2.1 *Registers*

Each line switching unit has its own group of registers and each group has access to two register concentrators, which allow the through-connection of the registers to the selection control circuit of the called-line switching unit.

7.1.2.2 *Control Circuits*

Each line switching unit has its own control circuits: two preselection and two selection control circuits.

The preselection control circuit controls the switching within the unit of which it is part and has access only to the A and B sections of that unit.

The selection control circuits have access not only to the A and B sections of their units but also to all C sections. They control the conjugate selections over all three stages, A, B, and C.

It is to be noted that during the time a selection control circuit is working with a C section, that C section cannot be reached by any other selection control circuit.

7.2 Operating Principle

The preselection function is identical to that described in Section 6.2.1.

On receipt of the complete number of a called local line, the local register, by means of a changing preferential access chain, is connected to one of the two register concentrators in the line switching unit to which the register belongs. See Figure 6.

On receipt of the necessary information from the local register, the register concentrator, also by means of a changing preferential access chain, is connected to one of the two selection control circuits for the line switching unit in which the selection is performed.

The selection control circuit passes into the passive phase and receives, through the register concentrator, the necessary information concerning the identity of the called subscriber.

Simultaneously, the selection control circuit via the register concentrator, local register, and local connection circuit calls for a connection to the C section to which the selector of the local connection circuit belongs. This connection is made by means of an access chain under control of the selection interference circuit.

Once the selection control circuit is connected to the C section, no other selection control circuit can be connected to the same C section.

At this moment the starting point in the C section and the point of arrival in the A section are known and the selection control circuit initiates the search for a free way between the A and C sections via a B section. This way being determined, and if at this moment no other preselection or selection control circuits of the same unit are active, the selection control circuit passes into an active phase.

From this moment the selection control circuit operates simultaneously the horizontal bars in the A, B, and C sections.

When the called line is free, the selection control circuit through the register concentrator and local register successively operates the local connection, B, and A selectors in the C, B, and A stages, respectively.

When the connection with the called line is completed, the local register, register concentrator, and selector control circuit are released.

On release of the selection control circuit, the blocking for active phase of the other selection and preselection control circuits of the same unit is released. At the same time the engaged *C* section becomes accessible to another selection control circuit.

The establishment of outgoing and incoming city calls is performed in a similar way.

8. Performance

8.1 Reliability

To assure full reliability, duplication with automatic change-over in case of failure has been provided for all vital common circuits: preselection and selection control circuits, access chains to these circuits, ringing circuit and generator, tone oscillator, and +48-volt inverter.

The assignment of a specific function to each relay makes switching simple and flexible. In this way the operation of the exchange is largely independent of a possible failure of any component.

8.2 Grade of Service

Lost calls are minimized through the use of the link system and through uniform distribution of traffic over the various sections and circuits.

8.3 Speed of Service

The separation of the preselection and selection functions under their own specific control circuits combined with simultaneous operation during their passive phases reduces pure switching time as well as waiting time due to the control circuits to a minimum. As a result waiting time for dial tone or the time between reception of the last digit and sending of ringing tone is maintained below 300 milliseconds.

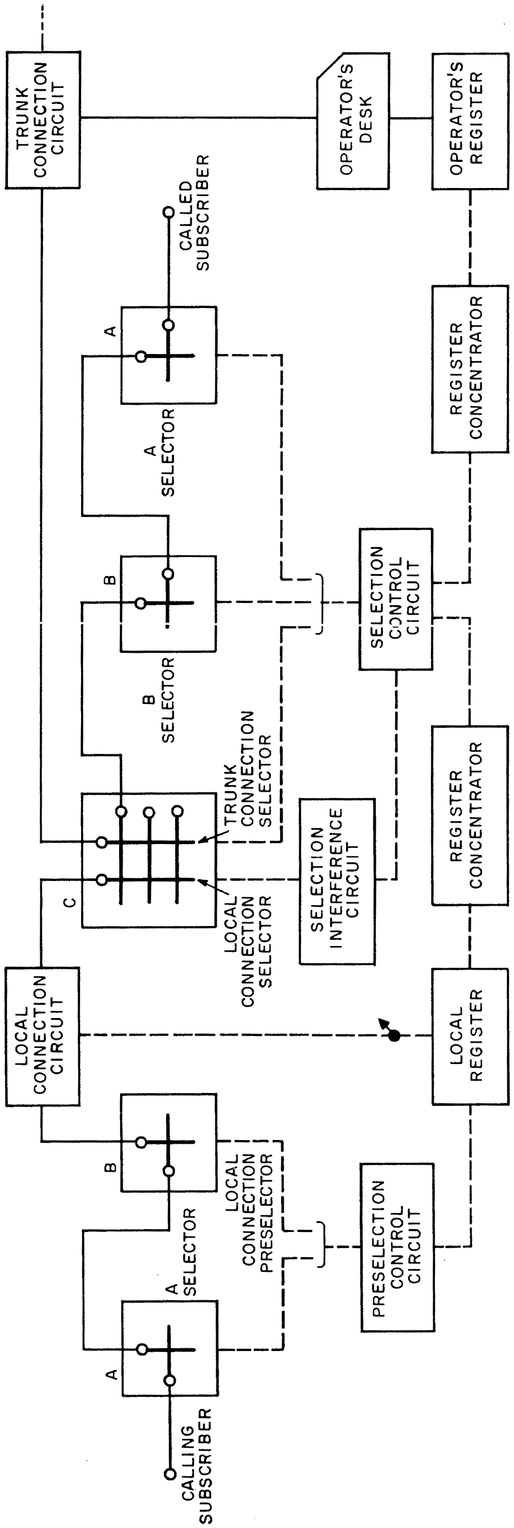

Figure 6—Junction diagram for conjugate selection on three stages.

J. Van Mulders was born in Aalst, Belgium, on 9 March 1930. He received from Ghent University the diploma of Civil Electro-Mechanical Engineering in 1953. In 1955 he was awarded the certificate of Industrial Electronics of the Faculté Polytechnique de Mons.

In 1955, he joined Bell Telephone Manufacturing Company as a telephone engineer. In 1960 he became head of circuit development for private automatic branch exchanges and since 1964 has been head of the department for development of private automatic branch exchanges.

D. Mouradian was born in Saïda, Lebanon. He obtained the diploma of Civil Electronic Engineering from Liège University in 1959.

In 1960 he joined the Bell Telephone Manufacturing Company as a telephone switching circuit design engineer. Since 1964 he has been head of the circuit development team for private automatic branch exchanges.

Columbus Medal Presented to Reeves

The City of Columbus gold medal was awarded to Alec Harley Reeves "for a life dedicated to development and progress of telecommunications and in particular for the invention of pulse-code modulation, an ingenious system which is being diffused all over the world and which makes it possible to extend telephonic transmission to the greatest possible distances without loss of quality."

The City of Columbus medal is issued by the city of Columbus, Ohio, in the United States, to a person of any nationality who has devoted his life to the study of problems in communications. The recipient is designated by the scientific committee of the International Institute of Communications in Genoa, Italy. The medal was presented in Genoa, the birthplace of Christopher Columbus, at the 14th International Convention on Communications to Mr. Reeves, who is a research scientist for Standard Telecommunication Laboratories He has been in the International Telephone and Telegraph System since graduating from college in 1923.

Teleprinter *Lo 133*

W. KAISER
Standard Elektrik Lorenz AG; Stuttgart, Germany

1. Introduction

The *Lo 133* is a new teleprinter, the designation *Lo* signifying Lorenz, and *133* indicating its telegraph speed of up to 133 words per minute. It replaces the *Lo 15* teleprinter which has given reliable service for many years. The *Lo 133* is not only faster than its predecessor, but also smaller, lighter, more versatile, and more modern in design and appearance.

2. General Features

The table model shown in Figure 1 includes within its cover all the facilities needed for a normal telex subscriber station: page teleprinter with paper roll, tape reader, tape perforator-reperforator with tape roll, and subscriber control box. Additional devices may be added. The design recognizes the continuously growing demand of subscribers for tape and telex facilities in a single convenient compact unit. It is 12.5 inches (320 millimeters) high, 19.25 inches (490 millimeters) wide, and 24.6 inches (625 millimeters) deep.

Reduction of mass and small operating movements in the printing unit permit a maximum speed of 133 words per minute or 100 bauds. By simply changing the gear ratio between the motor and the printer lower maximum speeds may be obtained. The time-proved principle of a stationary platen and a moving type basket permits good readability of the text while printing. A type basket is used since it gives excellent printing quality, easy exchange of type, and a large number of copies.

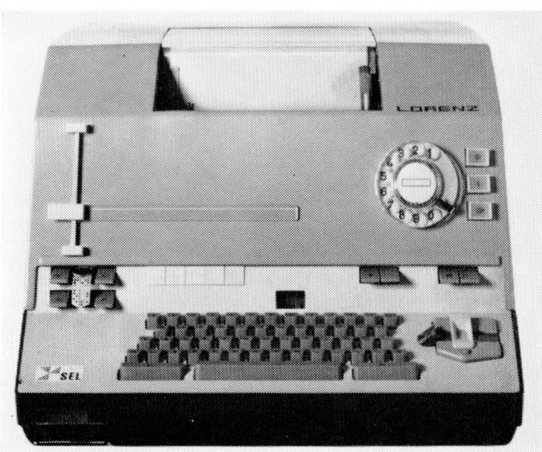

Figure 1—*Lo 133* teleprinter table model with built-in subscriber box.

A modular construction facilitates maintenance and replacement work and gives flexibility in adapting the teleprinter to different requirements. The page printer in the automatic-send-receive version including the motor stop switch consists of only 13 functional units, each on its own die-cast frame. All electrical connections among these units are made by plugs and sockets. The units may be taken apart and reassembled without readjustment. If units have to be replaced, only a few adjustments are necessary. The positions of the units with respect to each other are fixed by adjustable pins, disks, et cetera.

To simplify maintenance was one of the key design points. Modular construction helps by making all parts easily accessible. Synthetic oil and grease lengthen the period between lubrications and give reliable operation over a larger temperature range. The fully encapsulated ball bearings are filled with synthetic grease and need no further lubrication during the life of the teleprinter. Special anticorrosive treatments make this teleprinter resistive to climatic influences. The *Lo 133* is designed for heavy-duty application.

It may operate with any 5-unit start-stop code and preparations have been made for some 6-unit codes. The type basket will print a maximum of 84 graphics if all three shift positions are used.

The *Lo 133* meets the latest recommendations of the International Telegraph and Telephone Consultative Committee (CCITT), such as the full usability of all 20 combinations in the answer-back drum and the suppression of punching of the combination WHO ARE YOU into the tape. Even at a speed of 133 words per minute the time of only two code combinations (carriage return and line feed) is needed to return the type carriage to the start of a new line.

3. Details of Design

Figure 2 is the teleprinter with silencing cover removed, while Figure 3 is the layout of the functional units. Not numbered are the main frame and the base tray.

The *main frame* consists of the base plate, the side frames, the main shaft with the printer cam assembly, and a cross shaft. Subunits on the main frame are the traverse, which holds the bars that transfer the position of the sliders in the selector store to the moving type basket, and the special function unit, which senses and controls special functions such as carriage return, line feed, bell, answer-back release, et cetera. It also controls the printing bail and the shift bar. The main frame also supports the operation hours counter which can be viewed through a window. The main frame is mounted on the base tray through four shock absorbers and the machine may be removed from the base tray after sliding back two latches. Connections are made by plugs and sockets.

The *keyboard* with its flat slope, the mask, and the short stroke of the keys resembles closely the appearance and the operational ease of an electric typewriter. Any layout in three or four rows up to a maximum of 62 keys is possible.

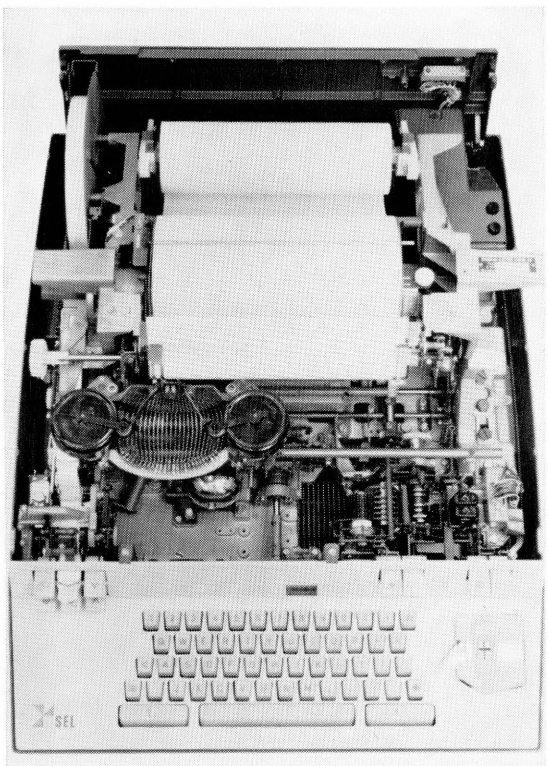

Figure 2—Teleprinter with silencing cover removed.

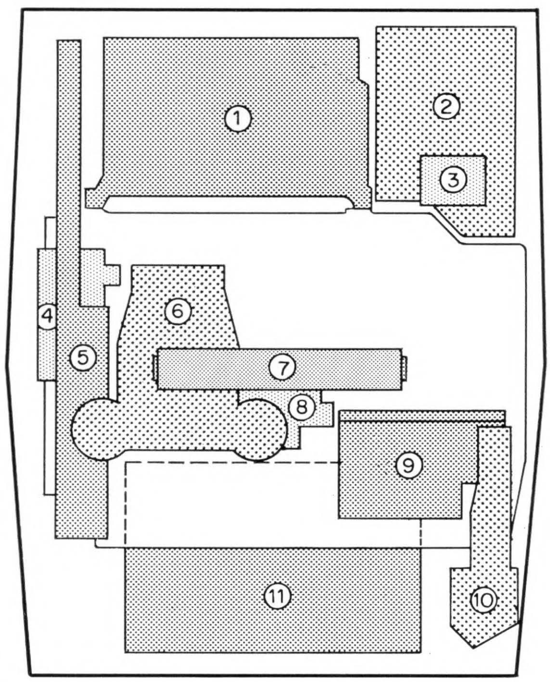

Figure 3—Layout of units.

1—motor
2—relay unit and power supply
3—motor switch
4—selector
5—tape perforator with tape roll
6—type basket carriage
7—paper platen
8—carriage drive
9—transmitter
10—tape reader
11—keyboard

Figure 4 shows the principle of coding. Plastic code plates are snapped onto the keybars. A pair of selector bars is provided for each code element. If a keybar is pressed down, one of the pair of selector bars is pressed down and the other one pressed up or vice versa. The pair of selector bars is linked together by T-shaped levers which transform the up-and-down movement of the selector bars into a sideways movement of the connecting bar and thereby actuate the transmitter contact levers. A change in keyboard layout requires only changes of key identification buttons and code plates. A row of additional control keys is located immediately above the keyboard.

The *transmitter* converts the combinations encoded in the keyboard or sensed by the tape reader from the parallel mode into the serial mode, adds start and stop pulses, and transmits the telegraph combination thus formed to the line. A row of transmitting contacts is operated by the camshaft. The answer-back device on this unit uses a detachable plastic drum with pins that are broken off to form the answer-back sequence.

The *selector* operates on single-current signals. Figure 5 shows the principle. The selector magnet has two armatures: the start-stop armature (not shown) and the selector armature, which senses the code elements. For maximum receiving margin with interruption as well as with short-circuit keying the holding magnet principle is applied. If a start pulse is received, the start-stop armature releases the camshaft, which rotates at a rate corresponding to the signaling speed. There is one sensing lever per code element and all sensing levers drop against the cam. The cam has slots corresponding to the times for each code element and permits only the sensing lever for that element to travel into the slot when a mark pulse is received. This motion permits it to actuate the corresponding intermediate sliders providing mechanical storage of the received code combination.

After all five elements are sensed the camshaft releases the printer clutch and comes to a standstill until a new start pulse is received. The released printer clutch lets the printer camshaft rotate, senses the position of these intermediate sliders, and transfers this reading via transmission bars to the type basket carriage to select one of the type bars. To keep the kinetic energy low all shafts in the receiver part, that is, the selector cam, the printer, et cetera, rotate only 180 degrees for each received character.

The *type basket carriage* is shown in Figure 6. The code bars, which are moved by the transmission bars, are located at the rear of the

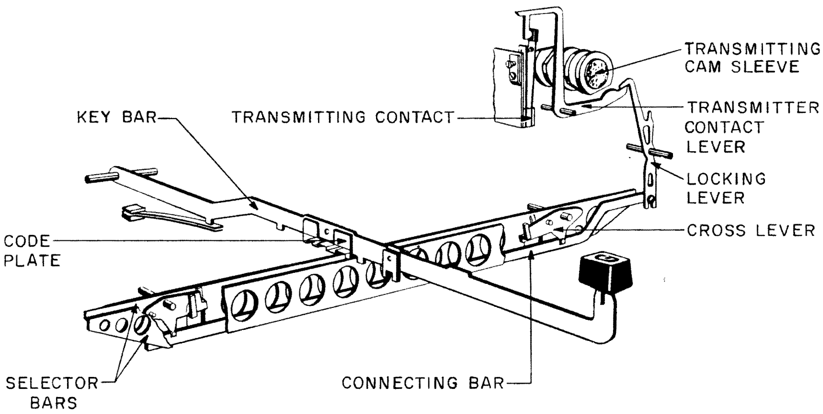

Figure 4—Principles of coding.

carriage. One of the levers can fall into the slots of the code bars to select one of the type bars. Levers and type bars are coupled to each other by pulling wires. To reduce the mass to be moved when the case is shifted, the pulling wires are arranged so that only the segment carrying the type bars is moved while the rest of the carriage remains stationary. In this way it is easily possible to have 3 shift positions (Figure 7). The type bars are much shorter and lighter than in the old *Lo 15* to achieve the printing speed of 13.3 characters per second with ample safety factor. Because of the low mass, the printing energy, despite the faster motion, does not exceed the normal 1 to 2 kiloponds per millimeter. The type levers are driven against the printing ribbon and paper by a spring, which is released by the printer cam assembly. Adjustment of this spring controls the printing energy for the number of copies. The printing energy is thus practically independent of the operation speed of the teleprinter and, as already mentioned, only the motor gears are involved when changing the speed of the machine.

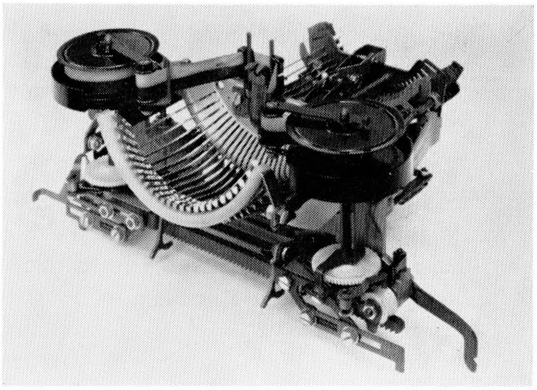

Figure 6—Type basket carriage.

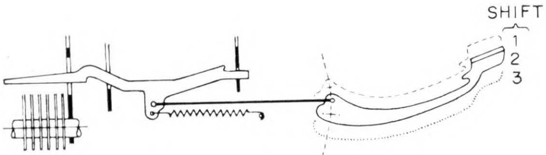

Figure 7—Shifting on the type basket.

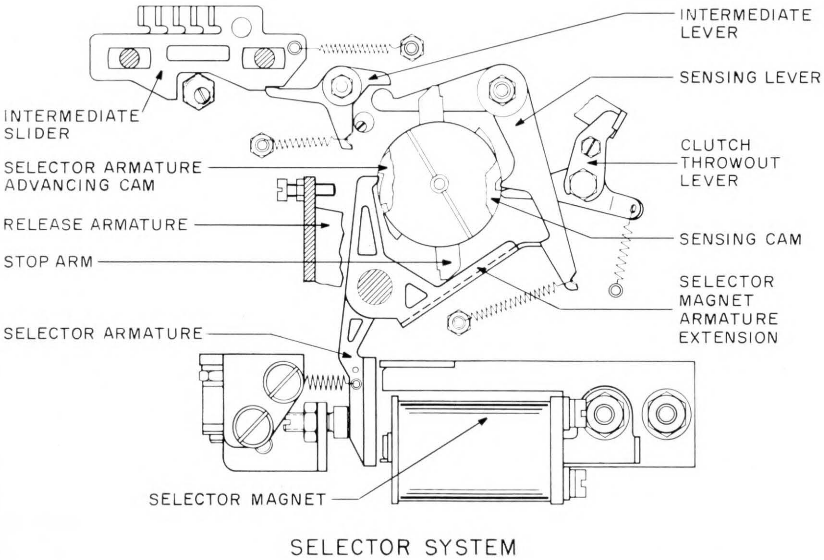

Figure 5—Selector system.

The printing ribbon spools are mounted on the carriage and after printing a character the ribbon always returns to its rest position below the printing line. A clear, nearly flickerfree, view of the printed information results.

The carriage is moved back to the start position of a new line by a spring and is slowed down by a dashpot. The low mass of the carriage (only about $\frac{1}{3}$ of the mass in the *Lo 15*) permits carriage return within 150 milliseconds, the time for the combinations carriage return and line feed at 100 bauds.

The *carriage drive unit* is located on the base plate below the carriage. A clutch moves two pawls that alternately engage with the teeth on a bar on the carriage and thereby move it smoothly character by character.

The *paper platen* is stepped by a ratchet wheel device. Three rates of line feed may be selected manually to provide line spacing of 3, 4, or 6 lines per inch. The platen is adjustable to two standard paper widths of either 8.5 inches or 210 millimeters. A paper-exhaust contact disconnects the teleprinter from the telex network if the paper supply requires replenishment and keeps it inoperative until a new paper roll is inserted.

The *motor* is fully covered to give protection against accidental contact, reduce radio interference, and allow forced-air cooling. Dust entering the air duct cannot be blown into the teleprinter. Governor-controlled and synchronous motors for normal voltages and frequencies are available as drive units. The motor with its associated electrical components, including a filter for radio interference suppression, forms one self-contained plug-in unit. The governor is temperature compensated; it can be adjusted while the motor is running.

The *tape reader* is mounted on the right side of the page printer. It is switched on or off manually by keys on the front plate. Step-by-step operation is possible, too. Motor-driven pins sense the code combinations in the punched tape and operate change-over contacts that are connected in series with the distributor contacts in the transmitter unit. The tape retaining lid allows unobstructed view not only of the punched hole combination just being read but also of the adjacent combinations. The tape moves from right to left and may be started in any position. A "tape-out" sensing device stops tape reader operation automatically in case of damaged feed holes, opening of the tape retaining lid, or end of tape. Operation is also stopped if "break-in" of the distant station occurs.

The *tape perforator* is mounted on the left side of the teleprinter. The unit is operated from the receiving mechanism and records incoming messages. In conjunction with the page printer it can be operated either as a reperforator or a keyboard perforator, because the subscriber box allows the local preparation of punched tape. The perforator may be switched on or off manually by two keys on the front plate. If a call is received during local operation, the subscriber box returns automatically to the receiving mode and switches the perforator off to avoid mutilation of the prepared tape. The tape is transported by a sprocket feed wheel moved by a ratchet device; this ensures close tolerances of holes on the tape. Operator errors can easily be corrected by stepping back the tape with the backspace key on the front plate and over-punching the faulty combinations. A control device on the perforator prevents punching of a maximum of four combinations selected at will, for example, combinations 32 and WHO ARE YOU. The tape reel container is located at the rear end of the left side frame. A "tape out" contact may be provided. The box for paper cuttings is under the perforator and may be removed from the front through an opening in the base tray.

A *motor switch* may be mounted under the base plate. It switches the motor off automatically after the end of a message. The operating time may be adjusted between 30 and 120 seconds at all speeds. The motor starts again on receipt of a space element from the line or by operation of the letters key on the keyboard.

4. Special Versions

The *Lo 133* is available without built-in subscriber box and the associated dial or push buttons, which are unnecessary in some countries. Another special version will automatically insert the shift combinations for letters and figures into the keyed text. A mechanical buffer store with a capacity of 7 characters is used for this. Special transmitter and keyboard units are required for this feature. The keyboard, which is shown in Figure 8, looks and operates very similar to that of a typewriter.

The receive-only version is shown in Figure 9. The perforator attachment can be used but the keyboard, transmitter, and tape reader units are not needed.

A special platen is available for using sprocket-feed paper instead of normal roll paper. The paper supply is then mounted externally at the back of the teleprinter.

As mentioned earlier the *Lo 133* can have three shift positions of the type basket and therefore three characters on each type bar. The third shift may be used for an additional alphabet, such as Greek, or for numerals in data transmission protected by a 2:3 constant-ratio code. The conversion to the third shift may be by using combination 32 or by a sequence of combinations, such as *SSSS* in data transmission.

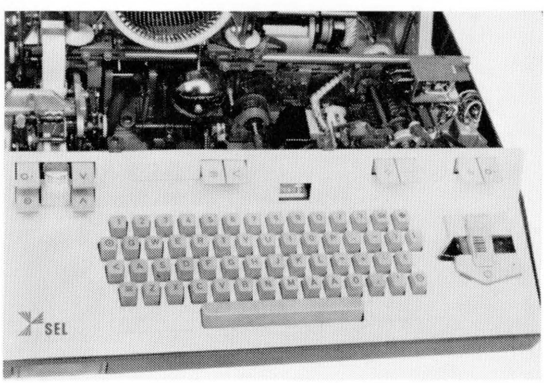

Figure 8—Machine with automatic shift to letters and figures.

The code recognition unit for special functions may be extended to recognize not only the special control functions needed for teleprinter operation, such as, carriage return, line feed, et cetera, but also additional combinations or a sequence of combinations.

The type basket moves normally from left to right while printing. With only a few changes right-to-left printing can be had as is needed for some languages.

To facilitate use in radio communication automatic carriage return and line feed may be provided. It is also possible to add control keys on the front plate for the local release of special printing functions, such as carriage return, line feed, letters, and figures. They serve to control the print unit if these combinations have been mutilated during radio transmission.

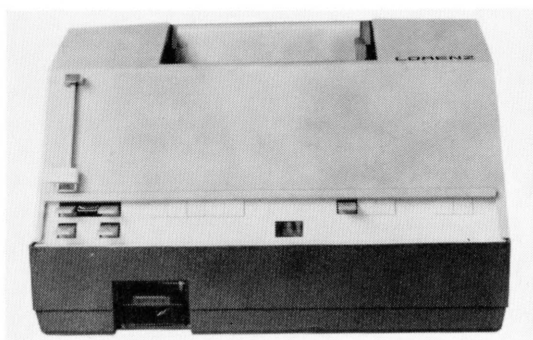

Figure 9—Receive-only version.

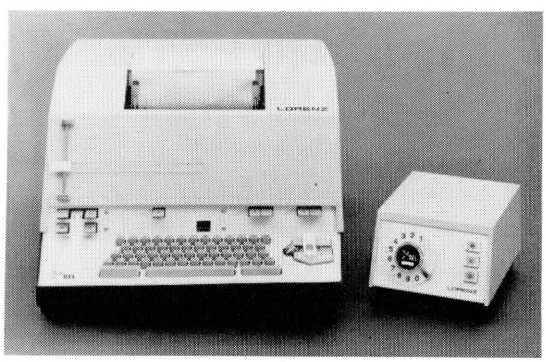

Figure 10—Teleprinter with separate subscriber box.

The relay and power supply unit in the rear right corner is normally used for the subscriber box. A separate subscriber box is available as shown in Figure 10 and the space left empty in the machine may be used for the following purposes.

(A) The *Lo 133* has been designed for single-current keying. An electronic converter built into the relay box allows double-current operation.

(B) In another version the relay box takes up the electronic line relay which allows use of the teleprinter not only in the normal range of line currents from 35 to 60 milliamperes but also with much lower values.

(C) A two-color ribbon may be used to distinguish between incoming and outgoing traffic by printing either in black or in red. This feature is normally built into the teleprinter and functions mechanically. A special magnet can be attached for electrical selection of the two colors.

(D) The tape attachments may be switched on and off electrically by magnets mounted to them. They can be operated remotely by special combinations detected in the code recognition unit.

(E) The built-in power supply allows operation without a subscriber box as an off-line machine to produce programming tapes. If a narrow type face is used a maximum of 104 characters per line instead of the usual 69 to 72 characters per line can be printed.

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Computer Time-Sharing—A Review

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1. Introduction

This article reviews time-sharing, a recent way of using computers in which a given information processing power is made available to several remote users. First, time-sharing, its present services and its future ones, will be defined. Then, the main hardware and software features of a time-sharing computer will be pointed out. Features which are desirable but not essential will also be mentioned.

Engineers and programmers have solved the most urgent problems in time-sharing. The use of a time-sharing system in fields other than scientific computation and management data processing has not yet been envisaged. Nevertheless, the results obtained to date in these two fields will facilitate the approach to new fields of application: industrial process control and telephone network control.

2. General Presentation

2.1 Definition

Time-sharing is the simultaneous employment of a computer by several users; each one has the illusion of being the only person using the machine. In a typical time-sharing system, the users communicate with a central computer by means of remote consoles. The users can run and debug their programs on-line as they would with a conventional computer. Debugging is the process of testing, correcting, and simplifying the operating instructions or program for solving the particular problem presented to the computer.

The time-sharing system shares computer time among all the programs; each program has control over the processor in turn for a specified quantum of time Q. At the end of this time slice, the running program is stopped and, if necessary, stored on an auxiliary memory; the next program is loaded into core memory if it is not already there and runs for time Q, et cetera. Multiprogramming is made possible by the interrupt system, which enables the interruption of a running program and the switch-over of processor control to another program, according to predetermined priority criteria. In this way, tasks of the same nature and length assigned to the computer by several users at approximately the same time will be finished almost simultaneously.

It should be noted that multiprogramming can be used in a classical computer center with only one input access point to the computer. The main purpose then is to provide better use of computer time. The computer can in fact execute program *P2* while it is awaiting completion of an input-output operation requested by program *P1*.

2.2 Services Provided by a Time-Sharing System

Time-sharing provides for many simultaneous users, improves man-machine communication, provides better solutions to present problems, and enables an approach to new fields.

2.2.1 *Many Simultaneous Users*

One of the advantages of time-sharing is the number of simultaneous users possible. For instance in the Compatible-Time-Sharing System (*CTSS*) of the Massachusetts Institute of Technology, 110 consoles are connected to an International Business Machines Corporation computer, *IBM 7094,* and 30 of them can be used simultaneously. In Machine-Aided Cognition or Multiple-Access Computer (Project *MAC*), now being implemented on a General Electric computer, *GE 645,* about 500 consoles will be available of which 150 to 200 will be able to operate simultaneously.

Thus a time-sharing system can provide direct assistance to a large number of engineers, research workers, students, et cetera.

2.2.2 *Improvement in Man-Machine Communication*

In a classical system, the programmer writes a program on paper. The program is punched on cards or paper tape and is then written (by the computer) on a magnetic tape. Sometimes it is loaded on a magnetic drum before being compiled or assembled. These various stages usually require several days rather than a few hours; in fact, the problems raised by the organization of data processing centers are often inadequately solved. In this way, the programmer loses precious time before he can even start debugging.

Moreover, when the machine is saturated, the programmer may often be allowed only one debugging run per day, which entails exceedingly long waiting times.

Time-sharing considerably improves the whole operation by enabling direct conversation with the computers. This conversation is carried out simultaneously with several users, and the computer then becomes a practical tool quickly accessible to all users.

2.2.3 *Better Solutions to Present Problems*

Time-sharing improves the running of programs that require frequent interventions by the user.

2.2.3.1 *Scientific Problems*

Time-sharing provides scientists, research workers, and engineers with a tool which has the capabilities of both a desk calculator and a computer.

These users want to be able to write their programs easily; they can do so by using a problem-oriented language such as FORTRAN. They want also to interact with the computer (stop a program under execution after a few results have been obtained, modify a parameter value and run the program again, et cetera). A time-sharing console is readily adapted to their needs.

2.2.3.2 *Debugging*

Whatever the kind of programs to be debugged, only time-sharing offers the capabilities of speed and efficiency. In fact, the programmer need not use intermediate means, and numerous errors can thus be avoided. The program is directly introduced using a typewriter; typing and syntax errors can be corrected immediately. Errors are no longer detected and corrected with the help of comprehensive printouts. On the contrary, printouts of some memory areas and some registers are asked for, and corrections are then typed and sent to the core memory.

In this way, step by step, but quickly, the programmer debugs his program.

2.2.3.3 *Business Data Processing*

If a company has several branches, each one generally uses a small computer for its own needs. A time-sharing system using a large central computer can handle the data processing for the entire company. Each branch can have access to its own files (inventories, personnel lists, et cetera) or to common files (documentation, for instance) independently of the other branches by sending commands through the consoles.

2.2.4 *New Capabilities*

2.2.4.1 *Information Retrieval*

The main feature of an information retrieval system is a bulky master file that must be scanned quickly to answer an inquiry. Time-sharing makes use of mass memories that can be controlled directly from the consoles. Therefore, time-sharing offers a real solution to these problems. Moreover, oscilloscope displays enable on-line reading of documents.

2.2.4.2 *Text Editing*

A user can type a text on a console typewriter. Then, with the help of a few commands, he can modify this text, add a word or line, substitute one word for another, or delete a complete paragraph. Finally, he can ask that the amended version of his text be printed out on the typewriter.

This capability to edit text helps in the actual writing of programs.

2.2.4.3 *Education*

Teaching programming is more efficient with a time-sharing system. As the student receives a quick answer from the computer, he can ascertain his errors more rapidly and therefore learn more quickly.

This way of teaching is also applicable to other fields, such as foreign languages, mathematics, or physics. The computer asks the student a question and he must choose from several answers; the answer given is stored and the correct answer shown.

Experiments of this sort have been performed at the Massachusetts Institute of Technology.

2.2.4.4 *Graphic Data Processing*

The invention of new peripheral devices and the establishment of some special programs give invaluable aid to engineers and research workers.

Since drawings are generally far more explicit than text, it is advantageous to be able to use them as inputs to or outputs from a computer. Thus graphic data processing is a useful new field.

With a peripheral device such as Sketchpad (Section 3.3.3), the user can draw a diagram (an electrical network, for instance) on a screen with a light pen. A special program stores the drawing in memory. The user can call back on the screen parts of the drawing and modify them. He can then call the complete amended drawing back on the screen. As numerical values can be introduced, another special program can effect computations and display the results on the drawing; for example, the values of the current in the various branches of the electrical network can be displayed. Viewing the results, the user if necessary can modify some parameter values or even the network structure itself. In this way many solutions can be examined quickly.

These new programs and peripheral devices improve communication with an ordinary computer system. They are all-the-more attractive in a time-sharing system, as the same capability is provided for several users simultaneously.

2.2.5 *Response Time*

The higher the number of simultaneous users the system can accommodate, the greater the efficiency. However, this number should not be so high as to increase waiting time considerably. In particular, short computations should not take longer on a time-sharing console than on a desk calculator.

The response time for a given command, issued by a particular user, depends on the length of the program that corresponds to the required service, the number of other active users, and the length of their programs. But above all, the response time depends on the method employed for the allocation of computer time to the various users. To our knowledge, no general study of this question has been carried out. At present, computer time allocation is experimentally adjusted according to users' reactions.

3. Hardware Necessary for Time-Sharing

3.1 Essential Features

A computer intended for use in a time-sharing system should include the following features.

(A) Memory protection is necessary since the users' programs should neither disturb each other nor destroy the supervisory program (the program in charge of the general management of the machine).

(B) Interruption of the program under execution must be possible each time the supervisory program has to carry out a specific job (request from a console, end of an input-output operation, error, et cetera).

(C) A built-in clock enables automatic interruption of the program under execution after a time Q has elapsed and switchover of control to the next program.

(D) Dynamic program relocation is necessary. To give quick service, several programs or program segments are stored simultaneously in core memory. When one of them has been completely executed, it must be stored in another medium; the memory area thus released becomes immediately available for new programs or program segments. It should be possible to load a program in any memory area.

(E) Auxiliary stores are necessary. Parts of the supervisory program and programs interrupted during execution that cannot remain permanently in core memory must be transferred to an auxiliary memory with very short access time. Users' files and programs, library programs, and some infrequently used supervisory subroutines must be stored in a bulky mass memory.

(F) Consoles equipped at least with a typewriter must be connected to the computer through telephone lines and data transmission terminals at both ends.

3.2 Implementation of Essential Features

Machines recently designed for time-sharing have all the above features. However, implementation differs among manufacturers.

3.2.1 *Memory Protection*

3.2.1.1 *Protection of Users' Programs*

It is necessary to prevent any user program from altering core memory areas outside its own limits. Several methods are available.

(A) Lower-limit and upper-limit registers. The *IBM 7030* computer uses two limit registers, loaded by the supervisory program, that define the memory area allotted to a program. On execution of any instruction involving memory reference, the address is automatically and simultaneously compared with the contents of both registers by a hardware device.

The General Electric *600* series computers use a single reference register, the base address register, which contains the location address of the program and its length. As before, the address comparison is automatic. This register is also used for program relocation in the *GE 625* and *GE 635* computers.

(B) Assignment of a protection key to each program. A protection key is also associated with each memory block; before reading or writing in a memory block, the protection key of the program is automatically compared with that of the block. The block can be used only if the two keys are identical.

This technique is used on the *IBM 360-67* computer.

(C) Programmed protection. In a user program, it is possible to include a subroutine to ensure memory protection by comparing each address with the bounds of the memory area assigned to the program. The execution time is obviously much longer, and this solution can be envisaged only for program debugging.

3.2.1.2 *Two Modes of Operation*

The computer operates in two modes. In the master mode the supervisory program has access to the entire memory, whereas in the slave mode any user program has access only to the area assigned to it.

3.2.2 *Interrupt System*

The interrupt system enables the processor and the peripheral devices to obtain any needed service from the supervisory program. Types of interrupts include the following.

(A) Input-output interrupts occur as soon as a call from a console or an input-output command has been initiated, and also when a peripheral device has completed its task or when it is out of order.

(B) Interrupts due to incidents occur when a user program tries to obtain access to a core memory area that has not been allotted to it or to use instructions of the master mode.

(C) End-of-job and end-of-allotted-time interrupts are indispensable in time-sharing systems. However, it is also useful that incidents such as overflow, parity error, et cetera, be signaled through an interrupt.

Interrupts are transmitted through suitable circuits to a register having one bit per interrupt type. The supervisory program then determines the action required.

3.2.3 *Clock*

The processor must have a clock which issues an interrupt at the end of a given time interval. This clock generally has a register the contents of which are decreased by one at regular intervals. When the register contains zero, the clock issues an interrupt and the supervisory program reloads the register. In this way, a clock interrupt is issued at the end of the time interval allotted to each program. This ensures the actual sharing of processor time and permits the system accounting to be done.

In some time-sharing systems, a clock interrupt order is issued at regular intervals to permit the system to detect and take charge of calls originated by the consoles.

3.2.4 *Dynamic Program Relocation*

When several programs are stored simultaneously in core memory, it should be possible to load them starting at any address. The programs are therefore written with relative addresses. When the execution of a particular program ends (end of job or end of allotted time), the memory space it occupies is available for loading new programs.

Dynamic program relocation is effected by means of either of two devices described hereafter.

3.2.4.1 *Base Address Register*

The base address register contains the starting address of the program under execution. Addresses are automatically incremented with the contents of that register at execution time. When execution of a program is complete, the other programs are "packed" to regroup the available memory space in a single area.

After packing has taken place, only the starting addresses of the programs must be modified. It is the "allocator" part of the supervisory program which manages the memory allocation table.

This system is used in the *GE 625* and *GE 635* computers.

3.2.4.2 *Page-Turning System*

In the system described above, the processor carries out program packing, which entails a delay in the actual execution of users' programs. A hardware device called a page-turning system avoids this loss of processor time.

A special logic unit splits the programs into fixed-length segments called pages. A table in the memory contains the addresses of all pages of each program. This allows the various pages of a program to be scattered in the memory (see Figure 1).

A logic unit automatically looks up the table of pages to find the locations of the pages of a program, thus enabling that program to be run. This table look-up is made without any loss of time since it does not call upon the processor. If the table indicates that a particular page is not in core memory, a logic unit issues a request to the supervisory program, which will then look for the missing page in the auxiliary memories.

Referring to Figure 1, after page 3 of program 2 has been executed, the next instructions to be executed will be those on page 4; page 3 can be replaced by page 6 of program 2 (not at present in core memory) or by a page from another program. Thus, instead of packing programs, the system operates through page replacement. The programmer need not take care of paging. This solution is costly in hardware as it needs 11 specialized registers in the *GE 645* computer, 16 registers in the *IBM 360-67,* and 32 registers in the Atlas computer.

Although it is more costly than the base address register, the page-turning system is attractive as it avoids physical displacement of programs in core memory. Moreover, memory allocation is simplified and lengthy programs can be run without the programmer being concerned with calls to the various pages.

3.2.5 *Auxiliary Memories*

In time-sharing systems, active users are numerous and all programs cannot be stored simultaneously in core memory. An auxiliary memory with a very short access time is therefore necessary. Moreover, users' files and programs should be quickly accessible, and a large direct-access memory should be connected to the system.

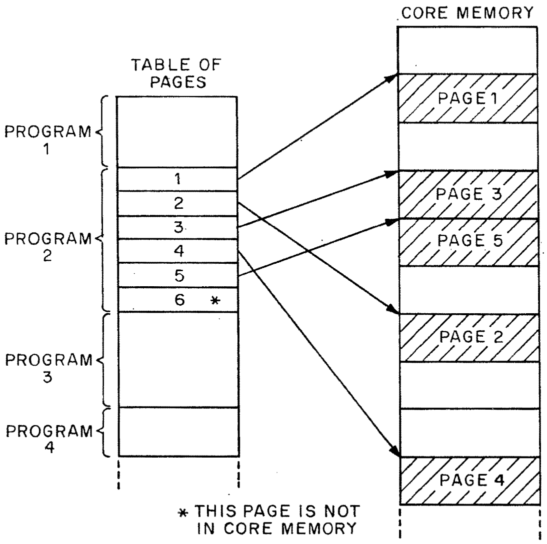

Figure 1—Page-turning system.

3.2.5.1 *Auxiliary Memory with Short Access Time*

The memory used at present is a magnetic drum. Programs interrupted during execution are transferred from core memory to drum, and programs to be executed are loaded from the drum to the core memory. This double operation is called "swapping." The drum is thus considered as a direct extension of core memory.

An interesting example is the General Electric "fire-hose drum" with capacity of 4-million 36-bit words and average access time of 8.5 milliseconds. This drum is directly connected to the core memory of the *GE 645* computer.

3.2.5.2 *Large-Capacity Direct-Access Memories*

Large-capacity disc units are used. Their direct-access feature shortens the waiting time involved in file searching.

In the Compatible-Time-Sharing System, the *IBM 1301* disc unit is the "heart" of the system, for it contains all useful files and programs.

3.2.6 *Consoles and Data Transmission Terminals*

Communication with the machine is effected through a console usually equipped with a typewriter. The user sends commands and introduces programs and data by means of the typewriter. By the same means, he receives the results and also messages from the supervisory program.

Each console is connected to the computer through a telephone line. The computer is not interrupted on reception of each character. At the computer end, as one of its functions, the data transmission terminal assembles characters in messages. When a message is complete an interrupt is sent to the computer, which can then process the whole message.

3.3 Complementary Features

The features described in Sections 3.1 and 3.2 are essential to a computer used in a time-sharing system. Other features, although of a less peremptory nature, add to the efficiency of the system.

3.3.1 *Large Core Memory and Fast Processor*

The extensive time-sharing supervisory program must be stored entirely or in greater part in core memory; for instance, the supervisory program of the Compatible-Time-Sharing System occupies 32 000 words in the *IBM 7094* core memory.

Moreover, it is attractive to store as many programs as possible simultaneously in core memory to reduce interrupts caused by swapping. Therefore, the larger the core memory the better the service provided.

For a given number of users, the faster the processor, the shorter the response time.

3.3.2 *Large-Capacity Auxiliary Memories*

Magnetic cards are attractive in time-sharing systems for storing infrequently used files and programs. Their capacity varies between 1×10^8 and 6×10^9 characters, and their average access time is between 100 and 500 milliseconds. The cost per character is low.

3.3.3 *Special Peripherals*

The manifold capabilities of these peripherals provide a new type of user-machine conversation.

Curve plotters permit graphs, schematics, maps, et cetera, to be obtained directly from the computer. Cathode-ray tubes provide for an immediate display of results. Sketchpad (developed at the Massachusetts Institute of Technology) permits the user to draw a graph on a cathode-ray tube with the use of a light pen, then to store the drawing in memory, call it back, modify it, et cetera.

For example, to draw the arc of a circle, the user points the light pen to the center and presses the "circle center" button. The user then chooses, by means of the light pen, one of the ends of the arc (which has the effect of defining the radius) and presses the "draw" button; the final position of the light pen defines the other end of the arc.

Various buttons enable drawings to be rotated, translated, magnified, erased, et cetera.

A description of the drawing that appears on the screen is stored in core memory; it can be transferred to an auxiliary memory. A library of drawings can thus be accumulated; a complex drawing can be composed by means of elementary drawings existing in the library.

These peripherals offer a new field of application for time-sharing. They will be very useful in the numerous cases in which an exchange of graphic information simplifies the conversation between user and machine.

4. Time-Sharing Software

4.1 Essential Features

The software of a time-sharing system should include at least the following.

(A) Supervisory program for the allocation of memory space and processor time to each program and for machine management in general.

(B) A command language employed by the user to give general commands to the system (independently of any specific user program).

(C) A debugging language to enable on-line program debugging from the consoles.

(D) A symbolic programming language to simplify program writing.

Library programs included in classical systems are also part of time-sharing software.

4.2 Software Items

4.2.1 *Supervisory Program*

4.2.1.1 *Memory Space Allocation*

Programs are written with relative addresses so that they can be loaded anywhere in core memory. The supervisory program must manage the memory allocation table that contains the starting address of each program; it must decide which programs to transfer to the magnetic drum when a new program is loaded in core memory; and finally, it must manage the table for allocation of drum areas intended for program swapping.

4.2.1.2 *Processor Time Allocation*

When a program is loaded in core memory for execution, a maximum running time is assigned to it so that the processor time will be shared among all users.

The supervisory program loads the clock register with the time allotted to each program. Two situations may arise: Either the same time Q is allotted to each program and the supervisory program switches processor control from one program to another every Q seconds, or the time allotted depends on the priority level of the program. Priority assignment can itself be a function of several factors (program length, author, et cetera). The active programs are then distributed over a number of queues, each queue corresponding to a different priority level. The supervisory program is responsible for priority computation and queue management.

4.2.1.3 *Interrupt Servicing*

Each interrupt must be controlled by the supervisory program, which first stores the state of the interrupted program—that is, the contents of various registers (instruction counter, accumulator, index registers, et cetera). It then looks for the nature of the interrupt (clock, peripheral unit, or fault) and finally determines the action required depending on the nature of the interrupt.

A clock interrupt is issued every Q seconds. The supervisory program looks for calls coming from the consoles. If there are none, the interrupted program is restarted. Otherwise the messages received are decoded and analyzed.

If the message is a user command to the system, the priority of the corresponding program is determined and its identification is introduced into a queue. If the message was intended for the user's program, no action is taken; the message will be read by the user program.

After the messages have been analyzed, the interrupted program is started again unless another program with a higher priority has been introduced by one of the commands, in which case the latter is executed.

An input-output interrupt occurs in one of the three cases that follow.

(A) When the program under execution issues an input-output request, this request causes an interrupt. The supervisory program sends out the request and transfers control to the next program, for the processor should not stay idle while a peripheral device is working. The program interrupted is not taken in charge by the supervisory program before completion of the input-output operation (also signaled by an interrupt); it is taken from the queue.

(B) When an input-output operation is complete, the supervisory program reintroduces the program into a queue, where it again becomes ready for execution.

(C) When an incident occurs in a peripheral unit, an interrupt is issued. The supervisory program determines the identity of the peripheral device and the cause of the incident (parity error, mechanical failure, et cetera) and sends a message to the operator who will carry out the action required.

An interrupt is issued when an incident occurs in the computer (for example, overflow, parity error, or attempt to go outside allotted memory area). The supervisory program determines the nature of the incident and transfers control to the corresponding servicing subroutine.

Interrupt servicing subroutines are part of the repertoire of the supervisory program; these subroutines are run quickly since they should never significantly slow down the execution of users' programs.

4.2.1.4 *Peripheral-Device Allocation*

When a read or write instruction appears in a program, the peripheral device used is designated by its logic identity. The allocator subroutine of the supervisory program allocates the peripheral devices needed by the program and establishes the correspondence between logic identity and physical identity. It also allocates an area of an auxiliary memory to each user for storing files and programs.

4.2.1.5 *File Management*

In the following, the word "file" refers to both programs and data.

The users' files have various utilization rates. It would be too expensive to store them all in rapid-access auxiliary memories. The files used less frequently can be stored in slower (and cheaper) auxiliary memories. A hierarchy is thus established among files based on file utilization rate and among memories based on the storage cost per character.

For instance, memories can be ranked as follows: magnetic discs, magnetic cards, magnetic tapes, and files—according to the date of their latest use. The supervisory program will have to check regularly that auxiliary memories are adequately used and to initiate file moving if necessary. A file requested by a user should be found quickly regardless of its present place in the memory hierarchy. For this purpose, the supervisory program will have to maintain a file directory for each user.

The distribution of files over the various hierarchy levels should not be such that savings made on memories are offset by the cost of lengthy processing; a compromise must be found by experiment.

4.2.1.6 *Checking Functions*

When a user requests access to a particular file, the supervisory program must check that the user is allowed to read, write, or both read and write in that file.

The supervisory program must also check the condition of auxiliary memories. A daily copy of the contents of the disc memory is usually maintained on a magnetic tape. When the supervisory program detects an error in the disc memory, it may initiate partial or complete reloading of this memory from the magnetic tape.

4.2.2 *Command Language*

The following commands (with examples from Compatible-Time-Sharing System) should be available to the user.

(A) A command for entry to and another for exit from the system (for example, *log in* α,β and *log out,* where α is problem name or number and β is user name or number). The first command identifies the problem and the user; the second one tells the system that the user has completed his intervention—his files must be closed, the directory updated, and the time used logged.

(B) A load command and a start command that allow the user to load a program and start program execution (for example, *load* α_1, α_2, ..., α_n, where α_1, α_2, ..., α_n are file names or numbers, and *start*).

(C) An input command that permits the user to introduce a program directly from a console.

(D) A start compilation command (for example, *mad* α, which will initiate the translation of program α by the *MAD* compiler).

(E) A temporary stop command which allows the user to stop execution of his program when he wants to modify it or the data, or to reflect on the results obtained.

4.2.3 *Debugging Language*

A number of commands should be available to the user for program debugging.

It should be possible to modify a line in a program, to delete lines, and to insert new ones. It should be possible to stop a program under execution and ask for printout of the contents of some registers or memory areas. It should also be possible to modify these contents.

4.2.4 *Symbolic Language*

A symbolic programming language should be available to the user for a time-sharing system to be of practical use. This language should be an assembly language at least (a language in which mnemonics are used for instruction codes and symbolic names for addresses).

On the other hand, such high-level languages as FORTRAN, ALGOL, and COBOL are obviously highly desirable.

4.3 Complementary Features

The following features of time-sharing software are not strictly necessary but add to the service provided or increase the system efficiency to the user.

(A) A command for indication of processor time used.

(B) A command for printout of the user's file directory with such indications as file names, memory space used, and memory space available.

(C) A command for printout of the user's files themselves.

(D) Interconsole messages that permit users to communicate among themselves. This facility could be very useful when several people are working on different parts of the same project.

(E) Special problem-oriented programming languages such as LISP, COMIT, and IPL for non-numerical information-processing problems, GPSS, SIMSCRIPT, and SIMULA for simulation problems, and STRESS and COGO for civil-engineering problems.

5. Conclusion

Time-sharing is a big step toward the improvement of man-machine relations; it permits undelayed conversation between man and machine.

The electronic computer has been used up to now either to relieve man of routine work or to carry out complex and lengthy computations. In a time-sharing system, the computer can be used as an assistant to the engineer or the research worker in his creative work, as it enables him to scan a large number of solutions quickly.

We noted earlier that the improvement of man-machine communication, not the equipment cost and efficiency, has been the prime concern of designers. It is quite clear that the internal operation of a time-sharing system requires a great deal of management, which uses up memory space and processing time.

Some problems have apparently been solved in an empirical or experimental fashion. For instance, we know of no theoretical studies on methods of allocation of processor time to various programs or on the optimization of information storage in memories with various hierarchy levels.

Finally, because of the very nature of time-sharing, it should be possible to apply it to real-time problems such as the control and checking of industrial processes or the control of a telephone network. The same computer could control several industrial processes or several telephone exchanges. To our knowledge, no theoretical or practical study of the effects of real-time constraints on a time-sharing system has been made.

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Hertz Premium to Heeks, Woode, and Sandbank

The Heinrich Hertz Premium of the Institution of Electronic and Radio Engineers has been awarded to J. S. Heeks, A. B. Woode, and C. P. Sandbank of Standard Telecommunication Laboratories (London) for their paper entitled "The Mechanism and Device Application of High Field Instabilities in Gallium Arsenide." The paper appeared in *Radio and Electronic Engineer,* the journal of the Institution, volume 30, number 6, pages 377–387; December 1965.

Fine-Guidance Error Sensor, an Electronic Scanning Star Tracker*

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1. General

The fine-guidance error sensor is a boresighted star and planet tracker developed for use as an error sensor for the fine-attitude control system under development for the Aerobee *150-A* sounding-rocket program (Figure 1). The fine-attitude control system is to operate in conjunction with the presently developed inertial attitude control system, which is used to despin the rocket after launch and to point the rocket, including the tracker and experimental package, to within 4 degrees of a desired star. The tracker then acquires the target and provides error signals for the fine-attitude control system to point the rocket within 30 arc-seconds of the star. During its 3 to 5 minutes above the atmosphere, several successive stars can be tracked and studied.

The fine-guidance error sensor is rigidly mounted to an experimental unit which, in turn, is rigidly mounted within the nose cone. The tracker is boresighted with the experimental unit so that they point in the same direction. In addition to the two-axis error signals, several signals are provided for telemetry.

The tracker has two modes of operation, an acquisition or coarse sensing mode covering an 8-degree-diameter field of view centered on the boresight axis, and a tracking or fine sensing mode in which the field of view is approximately 16 arc-minutes. In the tracking mode, error signals with a resolution of 12 arc-seconds root-mean-square on a third-magnitude star are provided in two axes. A unique feature of the tracker is its ability to scan a large field of view, select the brightest star, switch to a much smaller field of view, and provide position information of excellent resolution on the selected star.

The basic star sensor consists of an optical lens, photo sensor, and electronics. The lens system gathers and brings to focus stellar radiant energy at the photocathode of a multiplier phototube, the heart of the system. The multiplier phototube has a photocathode surface which forms an electron image of the focused star image. It is constructed in such a way that, when an accelerating voltage is applied between the photocathode and an internal mechanical limiting aperture, electrons from only a particular area of the photocathode will pass through the limiting aperture. This area is called the instantaneous photocathode area. When projected through the sensor lens, it represents a region in space defined as the instantaneous field of view. Following the aperture is a secondary-emission dynode structure that provides signal amplification of approximately 10^7.

To use the tube in a star-tracker system, a deflection coil is positioned around the multiplier-phototube image section to provide deflection of the electron image. By applying the proper deflection currents, the electron image can be

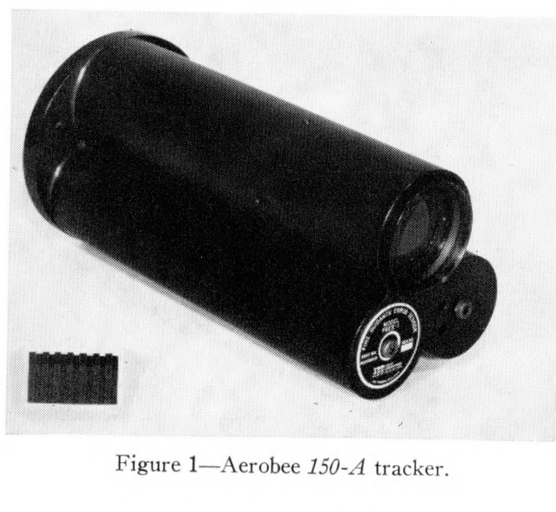

Figure 1—Aerobee *150-A* tracker.

*Presented at and published in the Proceedings of the Third Space Congress of the Canaveral Council of Technical Societies, Cocoa Beach, Florida; 7–10 March 1966.

swept across the limiting aperture, causing intensity modulation of the signal. Mode-control logic locks the tracker operation into the search mode at turn-on. An acquisition field is swept in 16-arc-minute segments at a rate of 6400 hertz. Line rate is 200 hertz and frame rate is 6.25 hertz. On receipt of a tracking signal from the control system, a 5-frame star-selection cycle is initiated. In this interval, star-selection circuits set a reference level which selects only the largest signal present in the field. At the end of this time, the acquisition scan stops when the brightest star enters the instantaneous field of view and the tracking mode of operation begins.

In the tracking mode, a cross-scan sweep is used that causes pulse position and pulse duration modulation of the electron beam. Demodulator circuits develop an analog error which is used to control the deflection-coil direct currents such that the cross scan is centered on the star image. The coil current magnitude is sampled and provides the output error voltages. As the vehicle control system responds to these errors, the tracking circuits constantly correct the coil direct currents to keep the cross scan centered on the star image.

The vehicle control system drives the vehicle so that the star is within the field of view of the experimental unit. After time for one experiment the inertial attitude control system slews the vehicle (and the tracker) to view another area. For correct star selection, the tracker is commanded to the search mode during the slewing operation. If not, since it had been tracking, it would continue to track the initial star until certain circuits saturated (up to possibly 6 degrees from the initial boresight axis). Therefore, if the new area were less than 6 degrees from the initial boresight axis, a selection would not be made and the initial star would still be tracked. System operation is such that star selection takes place only in the search mode. Once a star has been selected, it will be tracked even if a brighter target should move into the search field of view. However, the search mode can again be initiated on command to select and track the brighter star.

2. Principles of Operation

The fine-guidance error sensor provides two analog output error signals directly proportional to the angular displacement of the star, from each of two orthogonal planes whose intersection is the boresight or null axis of the sensor. Thus, when the star lies on this intersection, the output error signals are each zero.

Basically, the fine-guidance error sensor is composed of the following.

(A) The lens system for gathering and focusing radiant stellar energy on the detector.

(B) The detector, a multiplier phototube.

(C) Electronics.

In the following, each of these items is discussed. A block diagram is shown in Figure 2.

2.1 Lens System

The lens system plays a major role in determining the sensitivity and nulling accuracy of the fine-guidance error sensor. However, as this report is mainly concerned with electronic design, the lens system is only briefly touched on.

The lens aperture area determines the amount of radiant energy which is focused on the photocathode of the multiplier phototube, while the focal length of the lens system determines the angular instantaneous field of view.

2.1.1 *Sensitivity*

The photocathode current is determined by

$$I_{\text{photocathode}} = SPAT$$

where S = sensitivity of photocathode in amperes per watt

P = power density at objective lens in watts per square centimeter

A = clear aperture area in square centimeters

T = transmission efficiency of lens system.

2.1.2 *Angular Field of View*

The angular field of view is found by

$$\text{Angular Field of View} = 2 \text{ arc tan } \frac{d_p}{2f_l}$$

where d_p = diameter of instantaneous photocathode area

f_l = focal length of lens system.

2.2 Multiplier Phototube

The heart of the fine-guidance error sensor is the unique multiplier phototube that resulted from the marriage of our standard image tube and our standard secondary-emission multiplier stage. The multiplier phototube is constructed by replacing the phosphor in the image tube with a plate containing a small aperture, and positioning the multiplier stages behind this aperture.

Now, as shown in Figure 3, electrons leaving the photocathode only from the instantaneous photocathode area will pass through the limiting aperture. The diameter of this area is 1.4 times the diameter of the limiting aperture. For instance, if the limiting aperture is 0.100 inch, then the diameter of the instantaneous photocathode area is 0.140 inch.

If a star is imaged by means of a lens system on the photocathode within the instantaneous photocathode area, a very small stream of electrons will pass through the electron optics and through the limiting aperture. By placing deflection coils about the image section, it is possible to sweep this electron stream back and forth across the limiting aperture so that the stream of electrons is periodically interrupted, thus modulating the anode current.

2.3 Electronics

2.3.1 *Mode Control Logic*

A block diagram of the mode control logic is shown in Figure 4. Four logic levels are generated to control the tracker mode of operation. These are as follows:

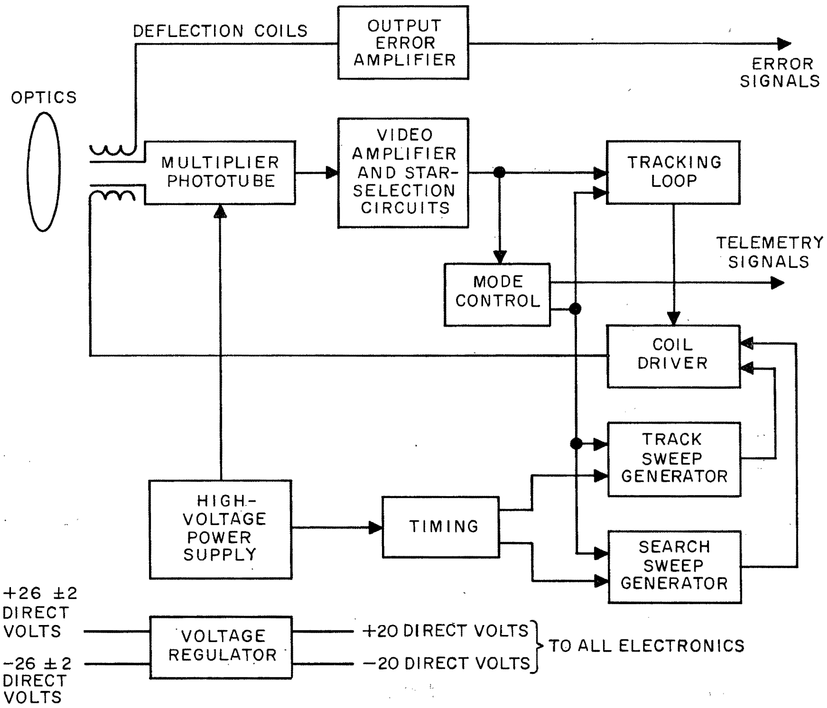

Figure 2—Block diagram of fine-guidance sensor.

$+S_A$ = positive voltage level in search mode, zero in track mode.

$-S_A$ = negative voltage level in search mode, zero in track mode.

$+S_T$ = positive voltage level in track mode, zero in search mode.

$-S_T$ = negative voltage level in track mode, zero in search mode.

The $-S_A$ and $-S_T$ levels are the two sides of a flip-flop using *p-n-p* transistors. Two logic-level inverter stages provide the $+S_A$ and $+S_T$ logic levels. The mode flip-flop is controlled by trigger pulses from two groups of logic gates. An input from the Aerobee control system can effectively lock the system in the search mode by blocking the gate that allows switching to the track mode.

Assuming a command to track (control input becomes zero), the following sequence occurs. As no star-presence signal is available, a clock pulse triggers a delay monostable multivibrator, closing the gate and preventing a switch to track for 4 raster scans. During this interval the video amplifier and star-selection circuits select the brightest star in the field of view. At the end of the delay multivibrator time interval, an acquire monostable multivibrator with a single-frame gate interval is triggered. This circuit prevents the tracker from returning to the

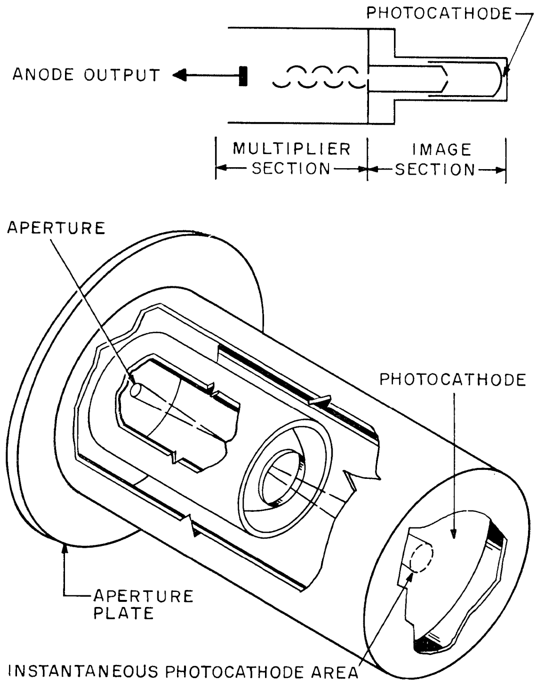

Figure 3—Multiplier phototube.

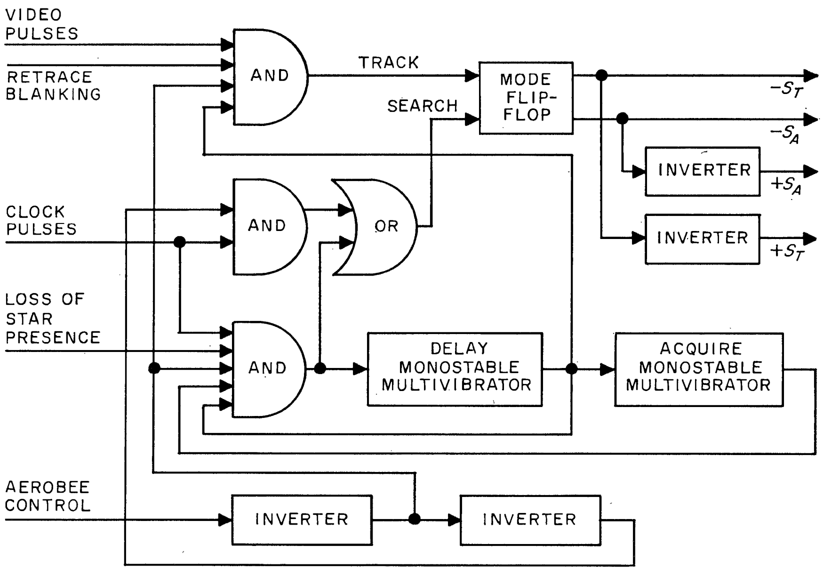

Figure 4—Block diagram of mode control circuits.

search mode until a star-presence signal has time to be generated after switchover to track. If no star video pulse has occurred during the acquire time interval, the entire cycle is started again.

Video pulses occurring during the acquire interval will cause the mode flip-flop to switch to the track mode. Any video occurring during sweep retrace is blocked by sweep retrace blanking. Should loss of signal occur during tracking, the loss of a star-presence signal opens an AND gate, allowing a clock pulse to return operation to the search mode.

2.3.2 *Search Scan Generator*

The raster scan of the search mode has 32 steps per line and 32 lines per frame. Figure 5 indicates the generator components. A digital-to-analog converter forms the sweep waveform from a 10-stage binary-counter chain. Clock pulses to the counter are fed through a diode AND gate which is closed, stopping the scan wherever switchover to track occurs. The digital-to-analog converter drives the input current summing mode of an operational amplifier.

2.3.3 *Track Scan Generator*

The track-mode cross-scan waveforms as shown in Figure 6 are generated by the circuits of the block diagram in Figure 7.

Three flip-flops count down the 3200-hertz pulses to provide timing gates. The 800- and 1600-hertz flip-flop outputs are combined in AND–OR gate circuits to provide an 800-hertz square wave shifted 90 degrees with respect to the flip-flop 800-hertz square wave.

This phase-shifted square wave drives a Miller integrator to generate an 800-hertz triangular sweep. This waveform drives two bridge switches, which are alternately gated on and off by the 400-hertz flip-flop outputs. The

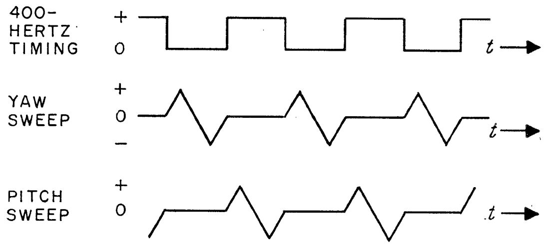

Figure 6—Track scan waveforms.

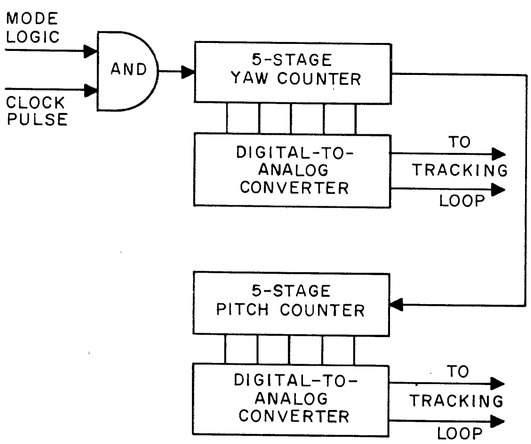

Figure 5—Search scan generator.

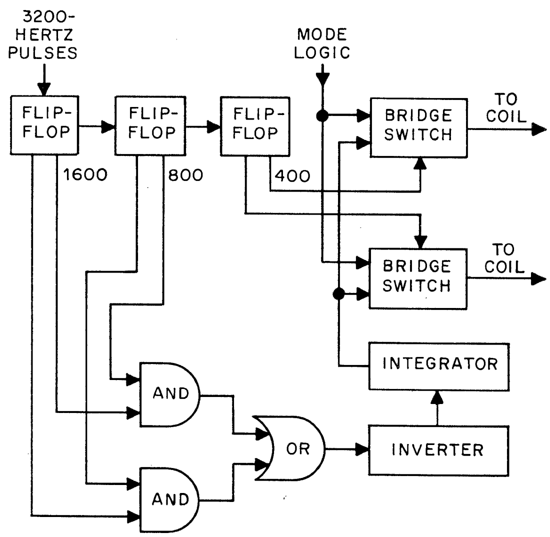

Figure 7—Track scan generator.

bridge switches are biased off by the mode logic during the search mode.

2.3.4 *Video Amplifier and Star-Selection Circuits*

The video amplifier basically consists of a variable-impedance input attenuator followed by a high-gain amplifier with a peak-detecting star-selection feedback network. The high-gain amplifier output is fed to two separate fixed-threshold output stages to develop the track and search mode outputs.

The input attenuator consists of a balanced diode attenuator network returned to the star selector. The attenuator, matched to the tube output through an emitter-follower, drives an integrated-circuit operational amplifier. A fixed clipping threshold is set by a zener diode network to allow only pulses exceeding a fixed amplitude to be amplified and used for star selection in the mode circuits. Discrimination of approximately one star magnitude is obtained.

2.3.5 *Tracking Loop Control Circuits*

A single channel of the tracking loop is shown in Figure 8. The error demodulators, which develop an analog error proportional to the star position from the center of the cross scan, function as follows. Diode AND gates use the 400-hertz timing flip-flop output to separate the video into pitch and yaw channel information. The 800-hertz flip-flop outputs separate the video into positive and negative scan information. Identical switches then drive a summing network to develop an error proportional to the difference between the positive and negative pulse widths.

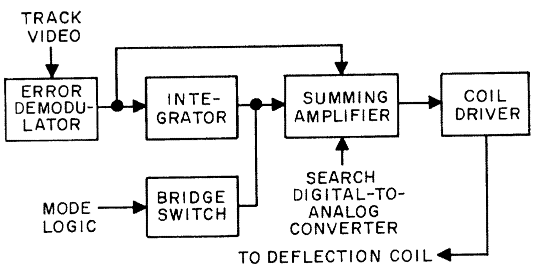

Figure 8—Single channel of tracking loop control circuits.

The tracking integrators consist of a differential input stage and a direct-current-coupled output stage. Capacitive feedback provides the integrating action. A shorting bridge on the output keeps the integrator from drifting during the search mode. The integrator output and the demodulator output are fed to opposite sides of the differential input of a summing amplifier along with the search scan. The amplifier is identical to the integrator design except that resistive feedback is employed. The summing-amplifier outputs directly drive high-impedance current drivers which are direct-coupled to the deflection coils.

2.3.6 *Output Error Amplifiers*

During tracking of a star, the coil currents consist of a direct-current component and cross-scan components. The error information required by the vehicle control system is proportional to the direct-current component only. A filter combining low-pass and notch characteristics controls the system bandwidth and removes the cross-scan current components.

The error amplifiers are operational amplifiers especially designed for stability, since they are outside the internal tracking loop and any drift at this point affects null accuracy directly. The error signal characteristics for either axis are shown in Figures 9 and 10.

The characteristics remain constant for all angles in the opposite axis within ±4 degrees of the boresight axis.

2.3.7 *Voltage Regulators and High-Voltage Power Supply*

Power for the sensors is tapped from the fine-attitude control system battery pack of +26 and −26 volts direct-current. Regulation to

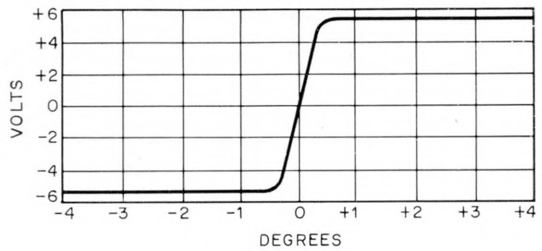

Figure 9—Error signal characteristics of single channel.

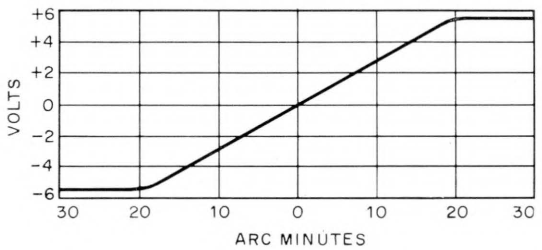

Figure 10—Error signal characteristics expanded at null.

+20 and −20 volts direct-current is provided by conventional voltage-regulation circuits.

The high voltage necessary for the multiplier phototube is supplied by a direct-current-to-direct-current converter operating at approximately 3200 hertz. This frequency provides synchronization for the complete system so that the effect of switching spikes is minimized.

3. Sensor Configuration

Since all tracker operation is accomplished by electronic gimbaling, there are no moving parts within the system. Other than the phototube, all electronics are solid state. The housing has 3 chambers. An in-line lens system is used that provides a minimum length of 10 inches. Module-type construction with high component density as shown in Figure 11 is used for the electronics. Several of these cordwood modules make up each subsystem and are subsequently encapsulated in sealed cylindrical metal cans.

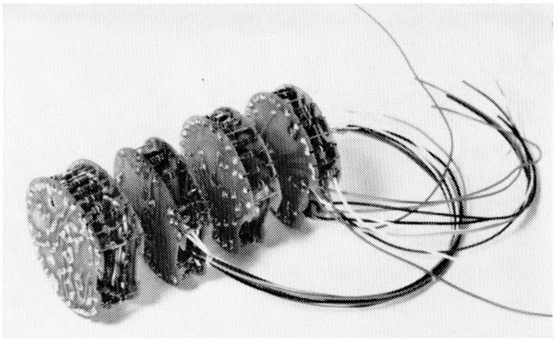

Figure 11—Cordwood modules.

The separate cans are required for signal isolation and ease of construction.

Mechanical adjustment of the tracker optical axis alignment with the mounting base is possible to within 15 arc-seconds. In addition, electrical adjustment of this alignment is possible to within 5 arc-seconds. The integral unit is sealed in such a way that it can be pressurized for the time of the experiment.

4. Acknowledgment

The star tracker described in this paper was developed on Contract NAS 2-1153 of the National Aeronautics and Space Administration under the technical direction of H. Paul Scherer of that Administration.

Richard A. Deters received the Bachelor of Arts degree in mathematics and physics from St. Joseph's College in 1959. In 1960 he received a Bachelor of Science degree and in 1961 a Master of Science degree, both in electrical engineering, from the University of Illinois, where he was an instructor in the rotating-machinery laboratories.

Mr. Deters joined the Guidance and Control Section of the Astrionics Laboratory of ITT Federal Laboratories in 1962. He worked on the advanced boresighted star and planet tracker and was responsible for construction and testing of the electro-optical sensing heads for the Orbiting Astronomical Observatory program. He participated in the design and final checkout of the fine-guidance error sensor and later became project manager for delivery of these units.

Dennis F. Eisenhut received the Bachelor of Science degree in electronic engineering from Indiana Institute of Technology in 1961.

He is a member of the Electro-Optical Systems Laboratory of ITT Federal Laboratories, where he has worked on solid-state circuits for various star sensing systems and on modulation techniques and error analysis of star sensors.

He contributed importantly to the dual-mode closed-loop star sensor for the Aerobee rocket and was the lead electronic design engineer for the Canopus star tracker for the lunar orbiter program.

R. F. Gates received the Bachelor of Science degree in 1948 and the Master of Science degree in 1954, both in electrical engineering, from Syracuse University. While attending the university he did research and development work on high-power ultra-high-frequency amplifiers and on transmitting and receiving antennas.

In 1954 he joined the Capehart-Farnsworth Corporation, where he worked on infrared equipment, guidance systems, and missiles. From 1957 to 1959 he returned to Syracuse University for graduate work including research on thermal resistance measurements for semiconductors.

He returned to ITT Federal Laboratories in 1959, where he has worked on interplanetary terminal guidance, doppler data reduction, electrostatic fuses, and electronic scanning star sensors.

Mr. Gates has been project manager for the electro-optical sensing head for the Orbiting Astronomical Observatory program, for a dual-mode tracker and a stellar pattern mapper for sounding-rocket studies, and for the Canopus star trackers for the lunar orbiter spacecraft.

At present, Mr. Gates is a staff engineer with TRW Systems in California.

Deltaphone

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1. Introduction

The past sixty years have seen many changes in the shape, materials, and performance of the familiar telephone set. The heavy candlestick instrument, with weighted base and separate wooden bell box, has given place through a succession of types to the modern set, with its streamlined plastic handset and body, designed on sound ergonomic* principles. Notable stages in the development of transmission performance have been the introduction of the anti-side-tone circuit; the improvement of transducer frequency response culminating in substantially non-resonant characteristics in both receiver and transmitter; and appreciable improvements in transducer sensitivity, particularly of the receiver. These transducer improvements demanded better side-tone reduction and equalization of the transmission to compensate for different lengths of line to the exchange. There has been less development on the signalling side. The ringer remains basically the same except in size, and the fundamental principle of low-frequency ringing has survived unchanged except in a few special systems which use harmonic ringing. Dialling, by making and breaking the direct-current loop, has remained the universal principle until recently, when multi-frequency or multiple direct-current signals have had limited use for pushbutton sets.

The aims of transmission performance development have been to give first louder, then clearer, speech over existing lines, and then to obtain acceptable performance over longer lines or lines with smaller conductors. Ergonomic developments have been directed to improving the efficiency and comfort in using the telephone, to extending the usefulness of the telephone service, and to increasing the attractiveness of the instrument. For instance, a handset instead of a separate receiver and transmitter enables the user to talk in a relaxed position with the transmitter close to the lips, with inevitable improvement in transmission.

Sets with the dial in the handset including standing handsets ease the subscriber's action still further by bringing the dial close. However, with such sets the subscriber must support unnecessary weight throughout every call; with standing handsets the lifting of the telephone seizes exchange apparatus whether a call is intended or not; some users have to change their grip between dialling and talking; and an attractive shape is difficult to achieve.

Some concurrent developments employing smaller but rather conventional telephones have met with some success. In these, a conventional handset rests centrally over a dial in a narrow oval or rectangular body. Special features include an illuminated dial and in some cases control of ringing volume.

The Deltaphone, with its very light revolutionary handset, introduces a new era in telephone set design, making a clean break from the traditional shape, yet incorporating the most up-to-date technical improvements and the best of modern features.

2. History of the Deltaphone

Nearly twenty years ago E. M. Deloraine forecast that the telephone of the future would be much smaller and lighter than the types then current and would depend in particular on the use of a very light handset. In pursuance of this several models of unusual lightweight handsets were made in London in 1948 by L. C. Pocock and A. C. Beadle. These required only a finger-hold instead of the usual handgrip to support them against the head, but the small lightweight transducers of adequate sensitivity needed to support this modelling activity were still several years away.

It was not until 1954 that the development of two small high-sensitivity transducers, namely the *4041*-type rocking-armature receiver and the *4039*-type carbon transmitter, enabled us to

*Application of biology and engineering to the man-machine interface.

provide the *4408* lightweight headset [1]. The possibility of using these two units in a handset arrangement had been contemplated, and when in 1959 the British Post Office invited the submission of designs for a small deluxe type of telephone, they were the obvious choice.

Engineers, convinced that a complete subscriber set in one piece was fundamentally unsound for the reasons given, decided to employ a handset having transmitter and receiver only. The alternatives of housing all remaining components in one body, or removing the bell and transmission circuit to a separate wall unit, were fully studied. In the latter arrangement, the body could be readily held in the hand for dialling, yet its very lightness made it unstable for dialling on a table. Further, a separate wall unit increases installation expense, and complicates the provision of a multi-point plug-in facility. Attention was therefore concentrated on a set with all remaining components in one body, the increase in size and weight being adequate to stabilize the set for dialling on a table.

It was realized that the achievement of aesthetic appeal, so essential in marketing, required the co-operation of an industrial designer, and the services of Martyn Rowlands were engaged. Then followed a combined exercise between the industrial designer and the electro-acoustic engineers to design a lightweight handset using the acoustic principles of the *4408* operator's headset so as to meet both functional and aesthetic aims. Initial studies proved the feasibility of adjusting the headset acoustic system to the modified shape required for a handset, and one of two early experimental designs survived, with only minor changes, to be the final design. The next step was to design a harmonizing telephone body, adequate to include all components. To minimize the table space occupied it was decided to make the long axis of the body coincident with that of the handset, placing the latter symmetrically over the dial. The shape of the new handset enabled this to be done with simple clean lines for the set, various designs of which led to today's Deltaphone.

The British Post Office version of the Deltaphone is known as the Trimphone. To obtain service experience quickly, an initial design was concluded, and a thousand sets were placed on field trial by the British Post Office from September 1965 [2]. Comments arising from the trial, both from users and from maintenance staff, indicated the changes desirable for the final design described below. Meanwhile, to get more extensive service experience, some easily introduced changes to the initial design have been made as an interim measure.

One of the 1966 Design Centre Awards was given to Martyn Rowlands and to Standard Telephones and Cables by the British Council of Industrial Design for the Deltaphone shown in Figure 1.

3. General Features

Apart from first-class transmission performance and aesthetic appeal, the Deltaphone introduces several radical improvements. An exceptionally light handset, weighing 4 ounces (115 grammes) without cord, is matched by a body which weighs only 23 ounces (650 grammes) and houses all components. The set can easily

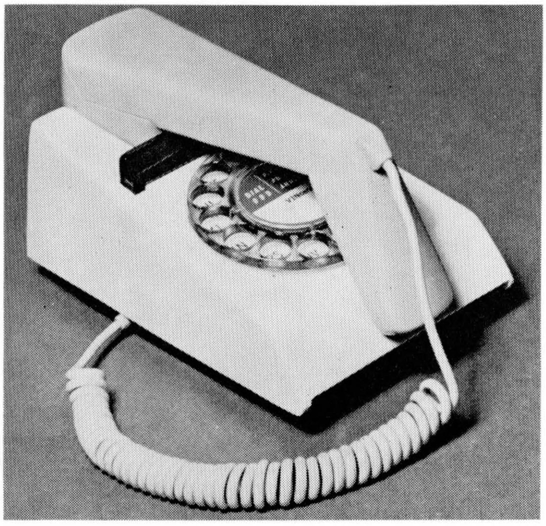

Figure 1—The Deltaphone.

be lifted in one hand by grasping it over the top of the handset and in the off-hook condition the prominent cradle bar is an excellent carrying handle. Low-intensity dial lighting requiring no external power and a novel electronic ringer giving a pleasant warbling note have also been incorporated.

The Deltaphone colours have been specially chosen to harmonize with all modern decors. Sets are currently available in three subdued two-tone combinations of grey, green, and blue, with lightly tinted smoke-grey cradle bar and dial finger plate. Retractable cords from a specially developed range of lightweight tinsel cordage fitted both to the handset and to the line terminal block allow maximum freedom of movement and prevent any drag on the set. The lightness and novel shape of the handset and the low overall height of the set necessitated special attention to the gravity switch mechanism. An extra-long travel of the cradle bar provides some gain in available effort, but actual switching must be confined to the last half of the movement to ensure the on-hook condition even if the user has failed to replace the handset correctly. The cradle bar restoring force also has a collapsing action which, associated with a lever-operated microswitch, reduces to the very minimum the chance of faulty operation of the gravity switch.

The requirements of modern easy maintenance have not been forgotten and have sometimes

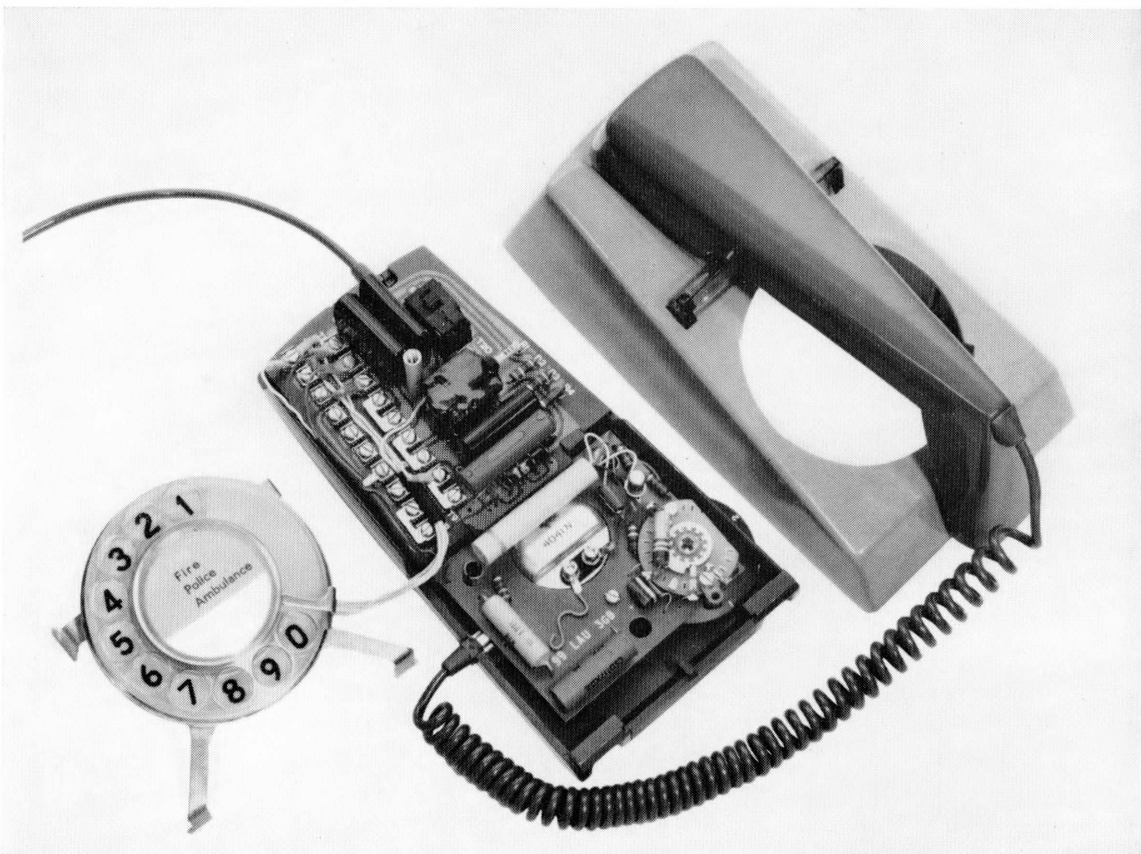

Figure 2—Internal view.

led to a compromise with the most desirable aesthetic design. All field maintenance can now be carried out with a screwdriver. Access to the inside of the set is obtained by releasing a single screw hidden by the handset when on-hook. The microswitch, which eliminates all spring-set adjustment, then automatically switches to the on-hook condition so that the set remains dead unless the microswitch button is depressed. The dial may be lifted out of its cover for inspection or its complete support sprung out of position to gain access to the tone caller, as may be seen in the general internal view of Figure 2. Cords may be changed without removing other assemblies, and both the transmission circuit board and the tone ringer may be removed separately by releasing a single screw.

As with other sets of the British Post Office, flexibility of installation is obtained both by a very generous supply of terminals (allowing circuit changes by simple strapping of internal and external connections) and by an extensive range of add-on units, such as press buttons for shared service or operator recall and additional gravity switches. Sets are available in both standard and tropical finish.

4. Handset

The acoustic design of the handset may be seen from the sectional view in Figure 3. The sound inlet to the carbon microphone follows the general form of a two-section conical horn. Behind the mouthpiece grid, the housing itself tapers inwards fairly sharply, but in the main handset body a separate and more gently tapering internal horn assembly leads to the small carbon microphone [1] mounted behind the receiver. Since the horn is necessarily short, some standing waves are inevitable, but the fundamental resonance is equalized by the absorption resonator formed by the sealed cavity and communicating damped hole at the top of the horn.

The receiver is a miniature version of the rocking-armature receiver [3] and is described in detail elsewhere [1]. A sealing gasket with flexible corrugations but solid periphery ensures the correct acoustic volume as well as providing the necessary seal between earcap and receiver.

The mechanical design of the handset, requiring a departure from simple circular parting lines, has made high-class moulding techniques essential. Since it is necessary to remove the

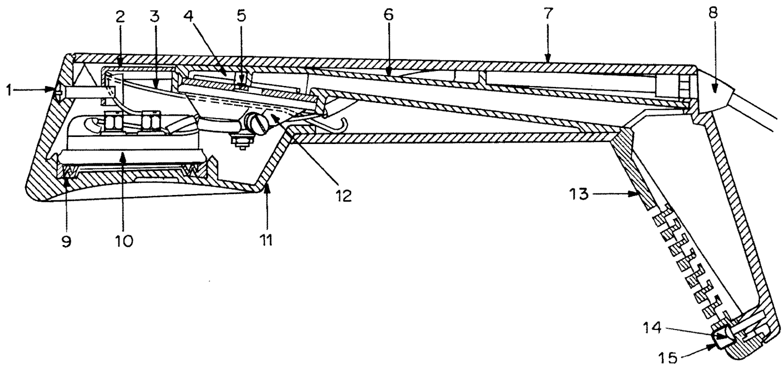

Figure 3—Sectional view of the handset.

1. Earcap nylon fixing screw
2. Plate
3. Spring clip
4. Sealed cavity
5. Damping silk
6. Internal horn assembly
7. Handset body
8. Cord
9. Sealing gasket
10. Receiver
11. Earcap
12. Microphone
13. Mouth piece
14. Screw
15. Cover

mouthpiece for only major cleansing or replacement, a polythene cover, which can readily be punctured with a screwdriver to gain access to the fixing screw, serves the dual purpose of covering the screw and forming a buffer to minimize scuffing between the handset and the telephone set cover. For easy maintenance the earcap is fixed to the handset body by a nylon screw threaded into a metal plate permanently secured in the body and forming an anchor point for the spring retaining the transmitter and horn assembly.

5. Transmission Circuit

Although the transmission circuit shown in Figure 4 is basically similar to the highly efficient and well-established network of the British Post Office *706*-type set [4] incorporating the most effective automatic line regulator in use anywhere in the world, slight changes have been made to improve the signalling circuits. A separate capacitor isolating the ringer circuit enables a simple dial spark-quench circuit of 39 ohms in series with 1·8 microfarads to be used, and eliminates unwetted cradle switch contacts from the speech circuit. All transmission circuit components and terminals are mounted on a single printed-circuit board secured to the base by overhanging lugs and a single screw. Of special interest are the enclosed microswitch units used as the gravity switches, and the new miniature induction coils with nickel-iron laminations.

6. Tone Ringer

The choice of an electronic tone ringer to replace the almost universal magneto bell of other telephone sets was governed both by market research, which indicated a distinct preference by the public for a less strident note, and the need to reduce the space within the set to an absolute minimum. An additional feature of the

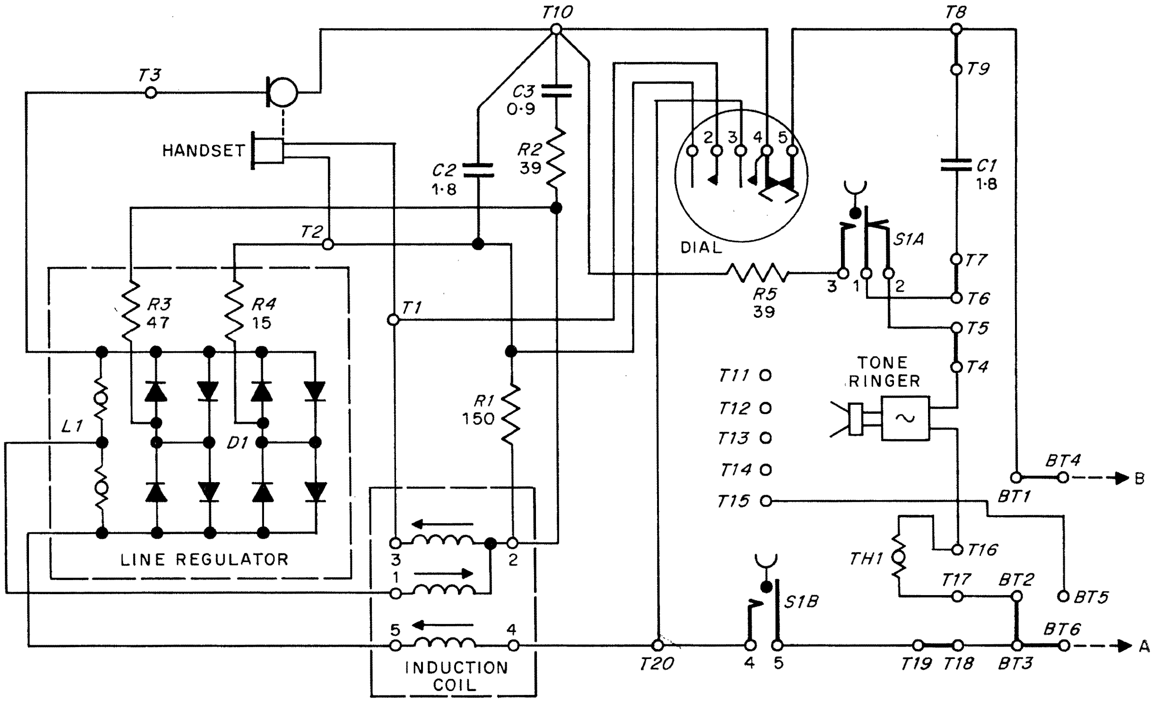

Figure 4—Transmission circuit. Values of resistance are in ohms and of capacitance in microfarads.

electronic circuit enables a slow build-up to be applied to the sound level so that only when the subscriber is at a distance need the sound attain its maximum intensity.

In the tone ringer circuit shown in Figure 5 the ringing voltage is applied across a diode chain *D2-D5* and thermistor *TH1* in series, the latter having a relatively short time constant but high triggering voltage which effectively prevents random pulses from activating the circuit. During the half-cycles when diodes *D4* and *D5* conduct, a voltage substantially independent of the applied input is developed across capacitor *C1,* thereby activating the oscillatory circuit. A switch controls the sound output volume by adding series resistance such as *R4.* The inclusion of thermistor *TH2* with a relatively long time constant in the intermediate switch position achieves a slow build-up to the calling note. To improve the stability of operation under varying circuit tolerances and ambient temperatures, *TH2* is also heated on the reverse cycle of the ringing voltage by the potential developed across diode *D3* and resistor *R1.* Because of widely varying ringing cadences and voltages in use throughout the world, it has not been found practical to provide slow build-up in all cases, and in some sets *TH2* is replaced by a fixed resistance to give a medium volume level.

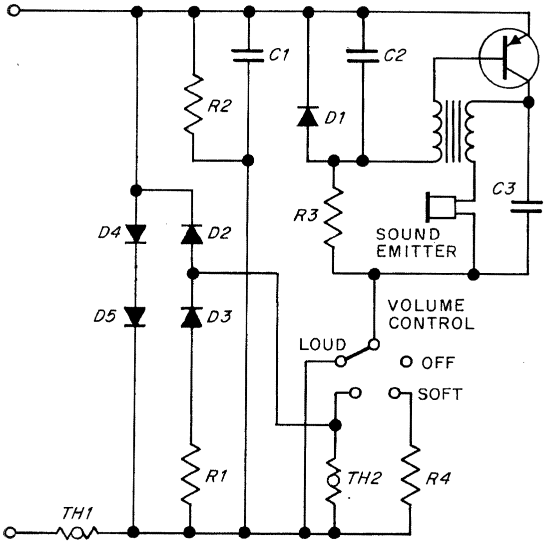

Figure 5—Tone ringer circuit.

The tone ringer circuit board is seen towards the front of the set in Figure 2 with the volume control on the right. The off position of the volume control may be rendered inaccessible to the user by adjusting a spacer during installation. The sound outlet from the tone caller is downwards through the base, a position which both protects the transducer from accidental damage and maintains smooth unbroken surfaces to the set cover. A fine grid prevents ingress of insects and accidental blockage of the sound outlet. Under normal conditions of use the tone ringer on the soft setting of the volume control will be audible only in the room containing the telephone. On the loud setting, it will be audible over greater distances and will penetrate greater obstacles (such as closed doors) than will a normal magneto bell. However, in large open offices some difficulty can be experienced in distinguishing between calls to adjacent telephones, and differentiation by frequency variation or other means is under consideration. Under normal operating ringing voltages at least four tone callers may be operated in series; only one thermistor *TH1* is needed in the series chain.

7. Dial

The dial has the same reliable mechanism of the trigger dial used in the standard instrument of the British Post Office, but is fitted with a special aluminized frame, which forms a reflector behind the number plate for a *C*-shaped "atomic" light source. This special tube, approved by all the United Kingdom authorities concerned, contains the hydrogen isotope tritium, radiation from which energizes a phosphor coating on the inner surface of the tube. Thus, without any external excitation or power, the dial glows sufficiently in the dark to enable the set to be located from a distance and for the numerals to be read for dialling.

As in some continental sets, the finger stop has been moved round to bring the figure 9 to the bottom. This greatly improves stability during dialling, and keeps the finger stop away from the region where it might damage the end of the mouthpiece of the handset.

The dial is mounted on a four-legged plastic cup which serves as dust cover and whose flexibility allows the dial to adjust itself to fit accurately into the set cover with the number ring flush with the top surface.

8. Transmission Performance

The internationally recognized transmission standard is the subjective loudness comparison relative to Nouveau Système Fondamental pour la détermination des Équivalents de Référence (NOSFER). The expected ratings of the Deltaphone shown in Figure 6 have been obtained partly from direct subjective loudness measurements against Système Étalon de Travail Électrodynamique (SETED) and partly by direct comparison with other British telephones of known performance.

Ratings by Nouveau Système Fondamental pour la détermination des Équivalents de Référence take no account of speech quality; they recognize only incidentally the facility with which carbon transmitters may change in sensitivity; and they are carried out at a fixed conversational level and a fixed talking distance. Consequently they can give, at best, only a guide to performance under free conversational use. Accordingly, in addition to user field trials, controlled free conversation opinion tests have been carried out [5]. In these tests untrained people were invited to talk over predetermined links without restriction on talking level or how they should hold the handset. At the end of each test the opinion, on a five-point scale, of each participant was obtained, and from the mean score under each condition of test a direct comparison of two telephone sets is possible. Preliminary tests indicate a performance certainly as good as the current *706*-type instrument.

9. Add-On Units

At the time of writing the following add-on units have been designed.

(A) A single press switch actuating a change-over microswitch. This slides into the front of the base in place of an apparatus blank and is suitable for shared service, operator recall, microphone muting, et cetera. It may be locking or non-locking.

(B) An extra gravity change-over switch fitted internally by a screw and bracket.

(C) A hook for a watch receiver which fits behind the set.

Other extra facilities such as twin press switches, neon calling indicators, and filament indicator lamps will also become available later.

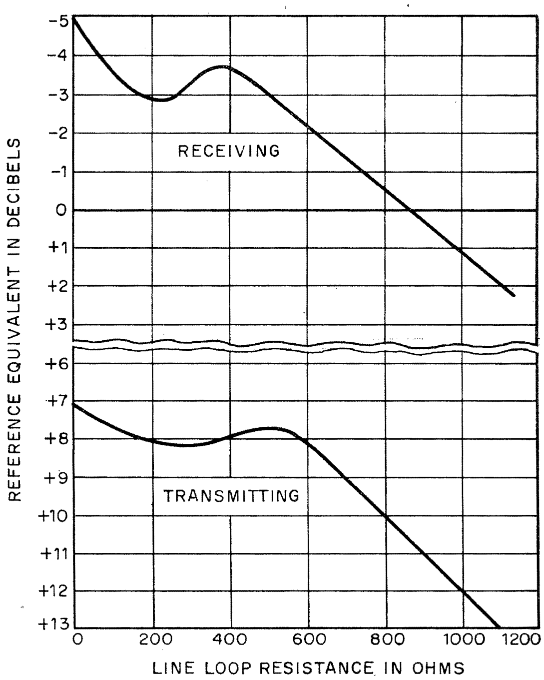

Figure 6—Volume rating of Deltaphone based on the Nouveau Système Fondamental pour la détermination des Équivalents de Référence. Operation is with 50 volts over a 200+200-ohm feed with cable of 24 American wire gauge.

10. Conclusions

Much has been learned from field trials made jointly with the British Post Office, whose collaboration at various stages of the project is gratefully acknowledged. As demand increases it will be possible to extend the colour range, to introduce wall mounting versions, and provide other variations to improve and extend the available facilities. The handset is already used on the Deltaline office intercommunication set, private automatic branch exchange attendant's cabinets, switchboards, and elsewhere.

Clearly the complete break with tradition that has been made with the Deltaphone has not been without its difficulties or criticisms. The link between design engineer and the eventual user is all too slender and it appears that operating instructions and advice do not always reach the subscriber. Nevertheless, it is apparent that the new design concept, elegant lines, and improved user comfort of the Deltaphone have met with acclaim not only among artistic circles but by the public at large.

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In 1925 he joined the Western Electric Company, later Standard Telephones and Cables, in London. Since 1932 he has worked at New Southgate on development of subscribers' apparatus, especially telephone receivers and transmitters, and since 1955 has been in charge of an Electro-Acoustic Apparatus Group.

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Sound-Reinforcing Systems

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1. Introduction

A number of points must be considered in the study of sound reinforcement [1]. For example, it is sometimes possible, by proper acoustic design, to avoid the need for electronic sound reinforcement in smaller halls. This means that unaided speech could be audible in many lecture rooms, conference chambers, et cetera. In larger halls, electronic sound reinforcement is invariably needed. The general criteria for a sound-reinforcement system are that at all locations the sound should be intelligible, natural, and of good quality. The system should also be both visually and aurally unobtrusive. Equipment with a high degree of robustness and reliability is needed, and in many large installations a time delay system is necessary to achieve naturalness and to avoid multi-source troubles such as echoes and confusion. The De Haas effect [2] is relevant here.

In the future, planners of large installations should consider the need for additional facilities such as radio microphones, recording, deaf aids, simultaneous translation, and closed-circuit television. It is also essential that a system give effective sound reinforcement with a good margin over the singing or feedback oscillation point. A number of proposals have been made for reducing feedback [3], most using circuits that continuously shift the frequency or phase of the signal by about 5 hertz to reduce the onset of oscillation. An increase of gain between 3 and 6 decibels may be obtained, but naturalness may be reduced by the flutter effect superimposed on the speech.

A great improvement in singing margin has recently been obtained, however, by the use of better designs of directional microphones and loudspeakers without any sacrifice of naturalness.

Newly developed systems of electronic-assisted resonance in concert halls also fall within the province of the sound engineer, but these systems use equipment of a special type consisting of a very large number of tuned microphone-amplifier-loudspeaker channels, each set to a particular room natural frequency. A careful survey of the acoustic sound patterns in the room may be necessary to ensure that the correct modes are reinforced. By this means a dramatic improvement in reverberant effect is possible [4].

2. Sound-Reinforcement Equipment

2.1 Microphones

The modern trend is towards the use of directional microphones. Unidirectional moving-coil,

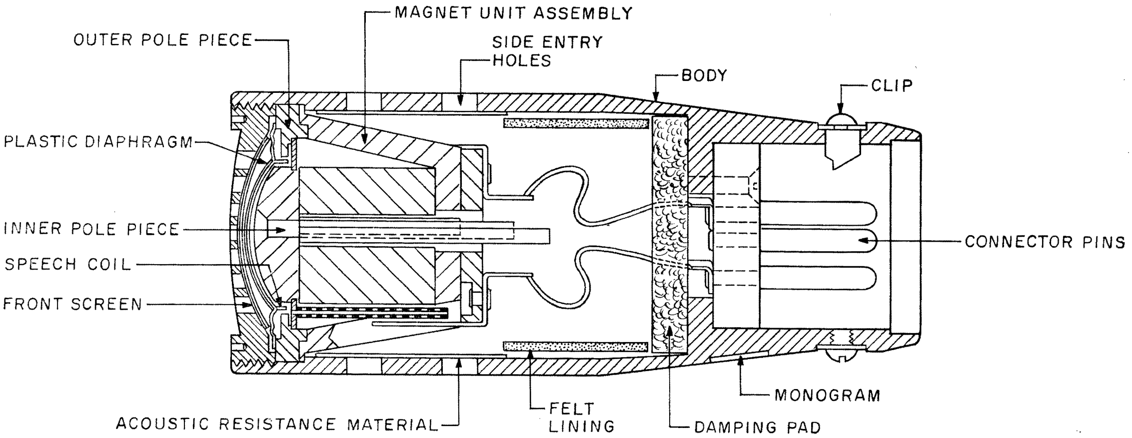

Figure 1.—Type *4105* unidirectional moving-coil microphone.

ribbon, and capacitor microphones with a cardioid or near-cardioid limaçon type of polar response pattern are now widely used. The frequency response is usually made substantially flat, and special precautions are often taken in construction and mounting to avoid breath and plosive consonant noises and to eliminate the effects of mechanical vibration and shocks. All these effects are minimized by ensuring firstly, that the moving systems are adequately acoustically damped; secondly, that wind-shielding gauze fronts and cases are fitted; and thirdly, that the stands or mountings incorporate a resilient section. In some cases, ultra-directional tubular or multi-unit line microphone arrays have been used.

The reduced size of most modern microphones permits them to be worn unobtrusively. The detailed design of these types [5–7] is briefly summarized here.

2.2 Commercial Types of Microphone

The *4105* is a unidirectional moving-coil microphone used for sound reinforcement. It has a good back-to-front ratio. Figure 1 shows the construction. The correct acoustical phase shift required to produce a unidirectional response is produced by the damped side entry holes acting in conjunction with the other acoustical elements inside the case. The response for various angles of incidence is shown in Figure 2. Figure 3 shows the new *4119* microphone, a directional ribbon unit with similar response to the *4105*. However, the frontal main pick-up lobe is slightly narrower, the polar curve being

Figure 3—Type *4119* tubular unidirectional microphone.

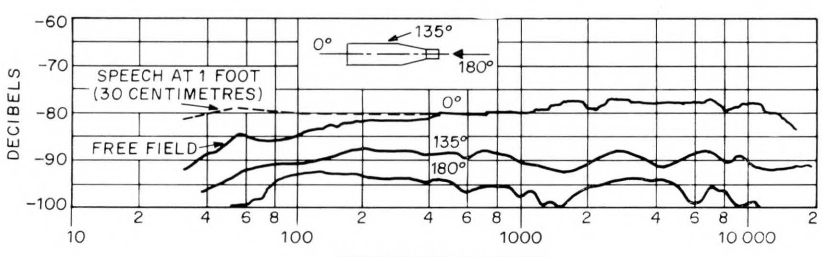

Figure 2—Response of *4105* directional microphone. 0 decibels = 1 volt per dyne per square centimetre.

a hyper-cardioid type of limaçon. The *4113* has a similar narrow-cardioid polar response.

For some applications, omnidirectional moving-coil microphones are more suitable than the directional pressure-gradient types. For severe climatic conditions and outdoor use, the *4035* moving-coil microphone (Figure 4) is widely used. It is of the pressure-operated type and is inherently resistant to the effects of wind and close-talking breath and plosive noises. Because of the cylindrical frontal shape, the response becomes semidirectional above 1 kilohertz. This helps to reduce the incidence of unwanted high-frequency background noises and the onset of "singing" due to acoustic feedback.

The *4037C* small tubular omnidirectional moving-coil microphone is useful where visually unobtrusive sound pick-up is required and also for applications where a hand-held interviewing microphone of good appearance is needed. Small plastic foam windshields (Figure 5) may be fitted for close talking or for outdoor applications.

The *4124* moving-coil microphone is an ultra-miniature neck or lavalier unit with a response designed to compensate for the known deficiencies of speech that is picked up at a point below the chin. Figures 6 and 7 show the construction and response of this microphone.

In some installations, speech must be relayed from areas having a very high ambient noise level. In other cases, several adjacent persons may be speaking simultaneously (for example, traffic controllers or simultaneous language translators). Noise-reducing microphones with directional properties such as the *4104* and *4115* are specially designed for this application. Unlike the communications type of noise-reducing microphone, they reduce background noise up to 30 decibels while holding speech quality to broadcasting standard. Figures 8 and 9 show the construction and response of the *4115*.

A much smaller type of noise-reducing unit, the *4121,* is suitable for mounting on a head-set boom, so that an operator wearing earphones has a microphone automatically placed at the correct talking distance. The speech quality of this miniature moving-coil noise-reducing microphone is not up to the full studio quality offered by the *4104* and *4115*.

The *4126* miniature all-transistor capacitor microphone is a new studio instrument. The microphone and the integral head amplifier are housed in a case 0·875 inch (2·2 centimetres)

Figure 4—Type *4035* omnidirectional moving-coil microphone.

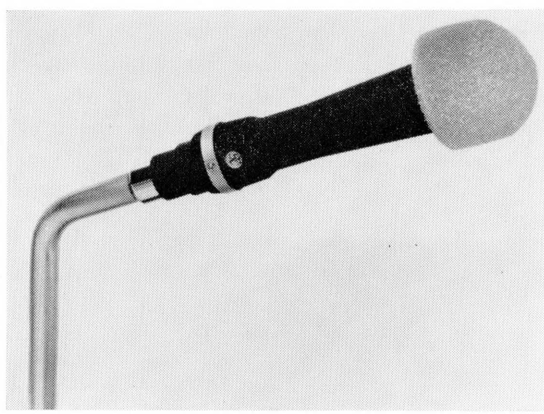

Figure 5—Type *4037* omnidirectional tubular moving-coil microphone and plastic foam windshield.

in diameter and 2 inches (5 centimetres) long. A battery or mains supply unit of small size may be 30 yards (27 metres) or more away, connected by a low-impedance cable circuit. The small unit (Figure 10) is suitable for stand, boom, or neck use and may also be equipped with a windshield for outdoor or close-talking use.

Radio microphones are now coming into use. These consist of a miniature frequency-modulated transmitter with a lavalier or lapel microphone. The elimination of a connecting cable allows the talker complete freedom of movement. The *4120* radio-microphone system is a frequency-modulation system consisting of a miniature radio transmitter measuring $3\frac{1}{2} \times 2\frac{1}{4} \times 1$ inches ($9 \times 5{\cdot}8 \times 2{\cdot}5$ centimetres) and weighing 3 ounces (80 grammes). It is compatible with any of our microphone types, including the *4126* small capacitor microphone,

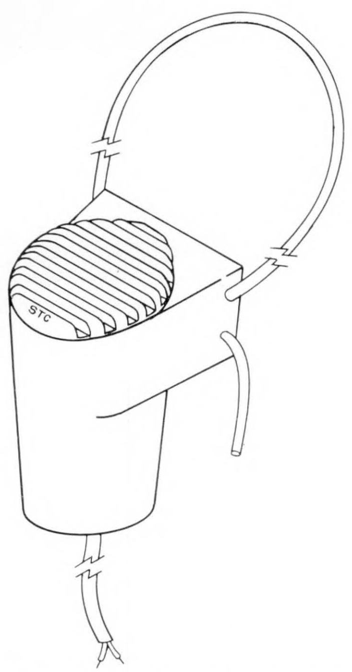

Figure 6—Type *4124* miniature lavalier moving-coil microphone.

Figure 8—Type *4115* noise-reducing close-talking microphone. The lip guard bar ensures that the correct talking distance is maintained.

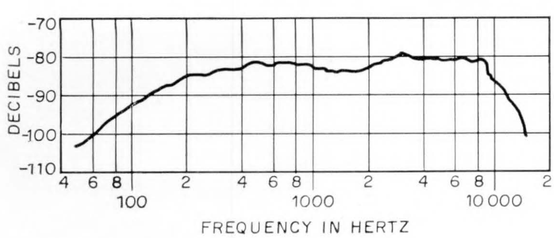

Figure 7—Response of the *4124* lavalier microphone. 0 decibels = 1 volt per dyne per square centimetre.

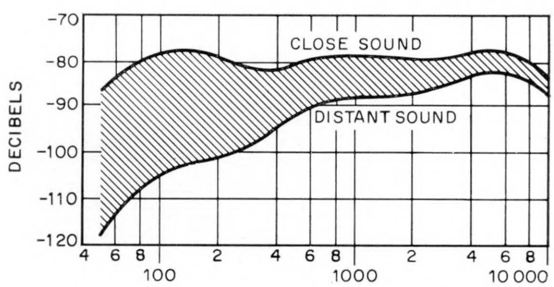

Figure 9—Response of the *4115* microphone to close and distant sound.

for which it provides the requisite power supplies, if a small additional battery is fitted for the polarization voltage required for the capacitor capsule. A compressor circuit on the transmitter prevents overloading and distortion, whilst diversity reception and squelch and limiter circuits prevent signal variations and noise at the receiver. A range of 50 yards (45 metres) or longer is obtained under most conditions and studio quality is achieved. The system conforms to the British Post Office regulations, and an operating licence is required for use in Great Britain in the 174-megahertz band.

It is seen from the above summary that a large variety of microphones and accessories are commercially available and able to suit almost any type of sound-reproduction system. The correct choice of microphone is important if a sound system is to give the best results.

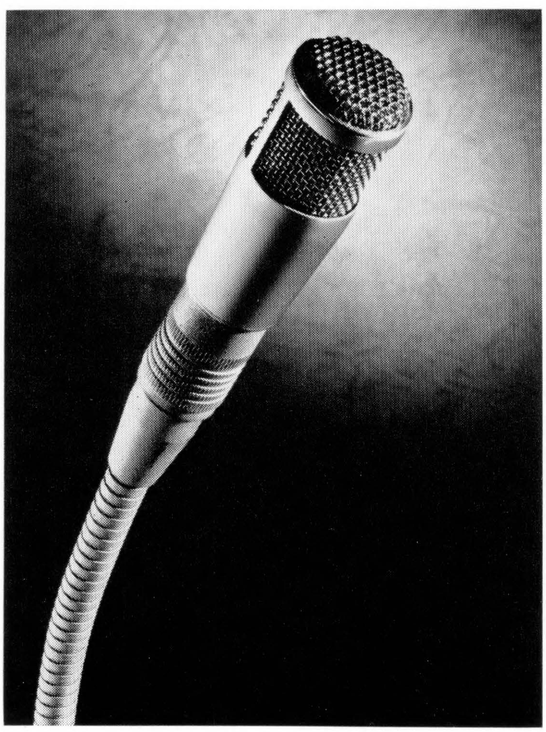

Figure 10—Miniature studio capacitor cardioid microphone mounted on a flexible stand adaptor.

2.3 Loudspeakers

Loudspeakers of many types are used in sound-reinforcement and sound-reproduction systems. In many cases, loudspeaker radiating surfaces are necessarily comparable to or larger than the wavelength of sound at middle and high frequencies. Wave effects are encountered and tend to give rise to an irregular polar response, causing unsatisfactory distribution of high-frequency sound. For normal enclosed-back loudspeakers the radiation of low frequencies is necessarily substantially omnidirectional, as the radiating surface is usually small compared with the wavelength, and the loudspeaker functions substantially as a point source for pressure.

In sound systems of the type being discussed in this article, loudspeakers with some degree of directionality are generally preferable to minimize acoustic feedback and to avoid the excitation of excessive reverberation. Hence they should be designed and mounted to give a directional middle- and low-frequency response, but the high-frequency polar response must be broadened to ensure even coverage and avoid undue focusing.

Thus, the design of loudspeakers for sound-reinforcement purposes in particular has been directed towards achieving a directional response at low frequencies and a well-spread response at high frequencies.

It is difficult to make loudspeakers directional at low frequencies without resorting to very large arrays. However, proper siting can be effective. For instance, if a normal cabinet loudspeaker with an omnidirectional response is mounted on the face of a substantial pillar or flank wall, the obstacle effect may be large enough to restrict the rearward radiation.

To avoid undue focusing of high frequencies, it is advantageous to restrict the size of the source opening. This normally means that multi-unit loudspeakers must be used with electrical cross-over networks to supply the smaller high-frequency tweeter units.

Alternatively, single-unit loudspeaker cabinets may be fitted with a narrow vertical slot as the radiating opening. This functions as a small source in the horizontal plane and hence distributes high frequencies widely where required. This narrow opening combined with the air volume enclosed in front of the loudspeaker diaphragm constitutes a Helmholtz resonator, which may have an adverse effect on the frequency response unless precautions are taken in the design to ensure that the resonator is well damped.

The conversion efficiency of loudspeakers is of considerable importance, as it is a factor which directly decides the power output required from the amplifiers. A fairly high efficiency is obtainable from horn-loaded units. These have the advantage that the horns also confer directional properties. Unfortunately, these arrays tend to be both bulky and expensive. They are also difficult to mount and are unlikely to blend with most forms of architecture and décor. The normal direct-radiator moving-coil loudspeaker is not very efficient even when fitted with good modern magnets. The efficiency is increased, however, when the units are mounted close together as in a line array. This type of array can also be made to have good directional properties.

Sound systems can generally be classed as high-level systems, where a few directional loudspeakers are sited to cover the area where sound distribution is required; or as low-level systems, where a relatively large number of smaller loudspeakers distributed about the area are each operated at a relatively low level to avoid mutual interference.

In modern indoor practice, high-power directional loudspeakers are nearly always of the column or line source type, whilst the low-power requirements are met by the use of small or medium size cabinet loudspeakers.

2.3.1 *Commercially Available Loudspeakers*

An integrated line of infinite-baffle cabinet loudspeakers are commercially available, equipped with moving-coil units whose low-frequency cone resonances are controlled and matched to the volume of the air enclosed in the associated cabinets. The larger cabinets are fitted with a vertical slot front opening to distribute widely the high frequencies. These cabinet loudspeakers cover the needs of most indoor low-level types of system. They are normally mounted on walls to give unidirectional radiation, but two-sided versions are available for bidirectional sound radiation.

It is imperative to use high-power directional loudspeakers for high-level systems where the sound must be concentrated on certain listening areas. The basic design features of these arrays have been described previously [5]. These may be summarized in the following way. A vertical row of direct-radiator loudspeaker units will produce a highly directional response in the plane containing the "line" of sources, and the radiating efficiency of the diaphragms is also increased. To avoid excessive directionality and side lobes, it is necessary to grade the inputs to the units by an electrical taper from the centre outwards, performed by a tapped transformer. Alternatively, the outer units may be phase-delayed by setting them back relative to the centre unit. This is done by curving the column in the vertical plane. A wide angle distribution in the horizontal plane is achieved by a slotted front. The low-frequency response is necessarily much less directional, as the length of the column is then no longer large compared with the sound wavelength. A unidirectional response of the cardioid type can, however, be maintained at low frequencies by allowing sound radiation from the rear of the cabinet via an acoustic labyrinth. The labyrinth is formed from a suitable layer of sound-permeable material acting in conjunction with the compliance of the air enclosed in the cabinet.

Figure 11 shows the directional response characteristics of our column loudspeakers. A number of their applications to large sound systems in theatres and churches are described in Section 4.

2.4 Amplifiers for Sound Reinforcement

A rapid transition towards all-transistor low-level and power amplifiers is now in evidence. These offer greater reliability, greater efficiency, and in most cases afford economy in the capital cost of an installation. Subsidiary benefits are reduced amplifier size and much lower heat dissipation.

We have developed a modular system of fully transistorized equipment consisting of preamplifiers, mixer units, equalizers, limiters, volume indicators, power amplifiers, power supply units, and so on.

The detailed design of high-quality audio preamplifiers, power amplifiers, and auxiliaries has been treated in other publications [8]. We note, however, that care is necessary in specifying and applying transistors because wide variations in the basic parameters may be encountered between makes, and a much wider production variation is likely than in the case of thermionic valves. The use of satisfactory components and the correct application of feedback enable a good signal-to-noise ratio and low nonlinear distortion to be obtained. The standard precautions are necessary to avoid damage to transistors, particularly when using constant-frequency inputs to check power output.

2.5 Equipment Standards

The engineering of any sound-reinforcement system must take into account the need to use equipment that may easily be mechanically and electrically assembled. These requirements can be met by the following conditions:—

(A) Equipment must be suitable for mounting in a portable case or in a 19-inch (48-centimetre) rack.

(B) Modules must be compact to keep overall equipment volume to a minimum.

(C) Modules must be readily inserted and withdrawn to facilitate replacement.

(D) Components must be readily accessible for servicing.

(E) Transistors should be used throughout to satisfy the requirements of size and reliability, and to achieve high-efficiency power amplifiers.

To make the equipment mountable in racks, it was decided to standardize the rack width at 19 inches (48 centimetres) as this remains a popular standard for sound equipment in Great Britain.

The minimum practical height that was likely to suit power amplifiers, mixers, and microphone amplifiers was $5\frac{1}{4}$ inches (13·34 centimetres), and the rack frames therefore had

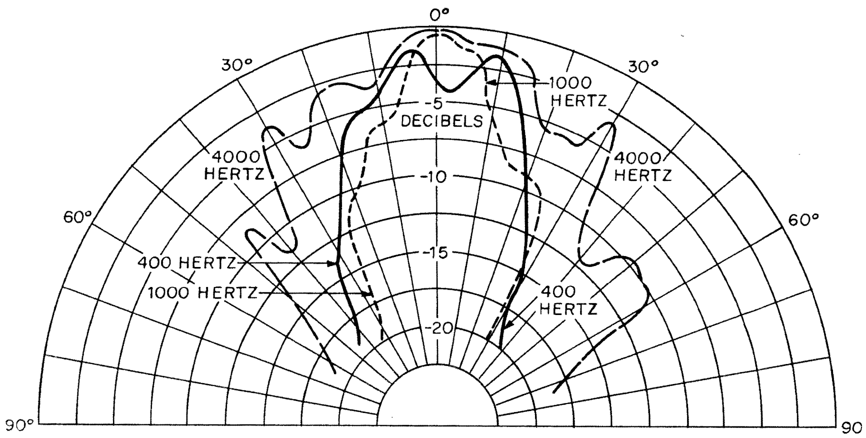

Figure 11—Polar response characteristics of column loudspeaker.

overall dimensions of 19 inches wide by $5\frac{7}{32}$ inches (13·2 centimetres) high.

The width between the rack or cabinet uprights determines the overall equipment width, and it has been decided to use 6 modules mounted side by side.

The mechanical construction of the modular system has been based on some of the component parts of the standard equipment practice for ITT Europe [9]. Figure 12, a single-board microphone amplifier, exemplifies this type of construction. The reverse side of the board mounts a printed circuit.

2.6 Use of Modular Equipment in a System

Figure 13 shows how some of the elements of the modular equipment may be used to fulfil the requirements of a relatively simple sound system.

The microphone switching unit provides selective switching from 5 push-button switches, mechanically interlocked to permit only 1 circuit to be connected at a time. A variation of this module is now being produced to give

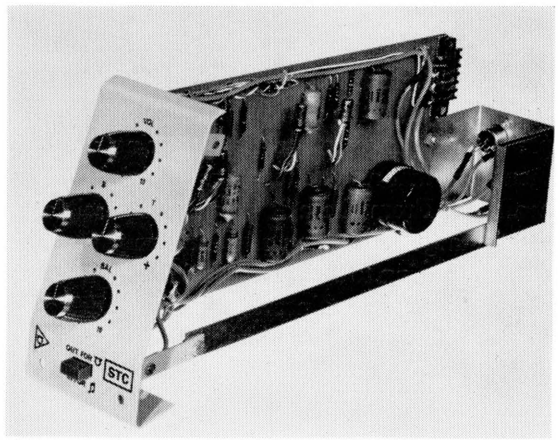

Figure 12—A microphone amplifier built into a single-width module unit. The method of construction combines adequate rigidity with ease of access for servicing.

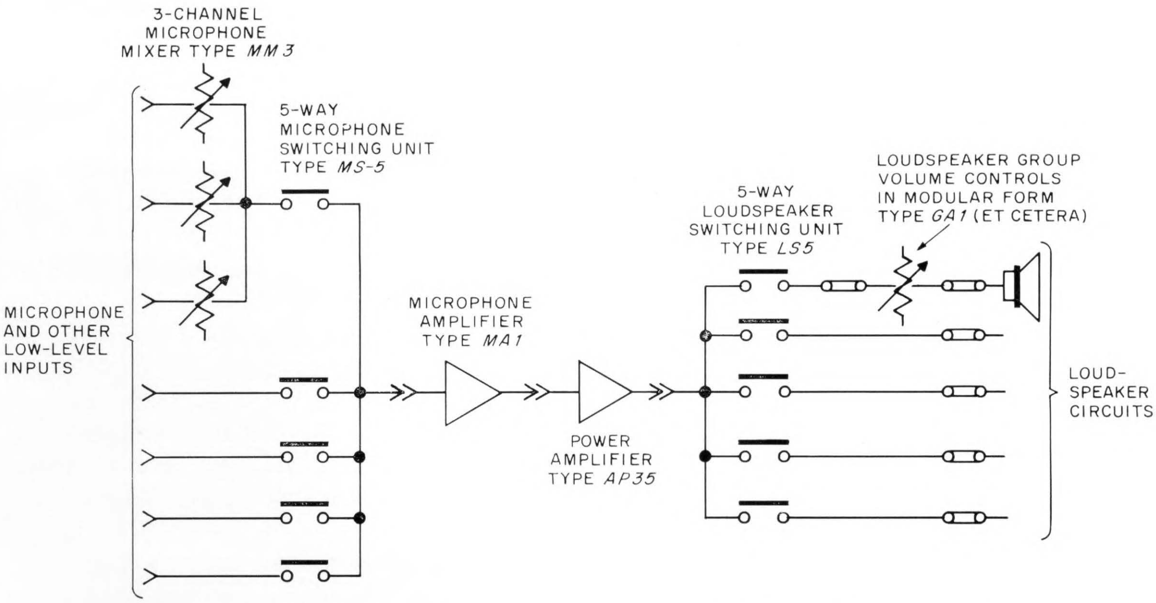

Figure 13—Diagram of a sound system engineered from standard elements of the modular public-address equipment.

collective switching so more than 1 microphone can be connected at a time. The loudspeakers may also be collectively switched by the module connected to the amplifier output; in this instance the switches have changeover contacts, and dummy load resistances can be connected if the necessity arises.

Many other modules have been designed and more will be created as the demand arises. It is thought that the system will continually expand and change to meet engineering requirements, so that a wide range of modules will be available. From these it should be possible to meet a large proportion of system requirements without having to resort to special design work. This type of pre-engineered equipment achieves economies in the overall system cost and reduces waiting time for the customer.

3. General Requirements and Tests for Systems

The acoustical requirements of a system may be summarized as follows:—

(A) The reproduced sound must be sufficiently loud with an adequate margin against feedback and adequate level above the prevailing ambient background noise in the auditory area.

(B) All the essential auditory components which make up a speech element such as a syllable should arrive within about 50 milliseconds. Any components arriving with a significantly longer delay are classed as reverberant components and should be suitably reduced in amplitude. The first 50 milliseconds includes the direct sound and early reflected sounds, and is the part of the auditory signal on which the intelligibility of the sound relies. The later reverberant components may contribute only to the aesthetic effect. Any large components with an excessive delay constitute echoes which may be deleterious in all respects.

The intelligibility of speech is akin to the quality of definition in music. Mathematically, intelligibility or definition can be expressed as the integral of the received sound energy at the listening point concerned, from 0 to 50 milliseconds, divided by the integral from 0 to infinity of the total energy received [10].

$$i_d = \frac{\int_0^{50 \text{ milliseconds}} p^2 dt}{\int_0^{\infty} p^2 dt} \tag{1}$$

where i_d = definition index
p = instantaneous sound pressure
t = time.

Intelligibility can be assessed subjectively by finding the percentage of correctly understood test syllables or phases obtained at given listening points in the auditorium. Lists of random speech components suitable for testing have been published by many authorities [11].

Objective tests may also be performed to obtain a measure of the definition index by using equipment such as two special ballistic galvanometers with thermocouples, one having a time constant such that the first 50 milliseconds of received energy is integrated, the other integrating the total energy received. A sharp pulse such as an electrical discharge has been used as a repeatable sound pulse for these tests.

Although both subjective and objective tests of the above types have been carried out by a number of workers in different places, no generally accepted numerical criteria have been evolved as an index of the performance of sound-reproducing systems, reliance still being placed on the experience of the experts responsible for planning and commissioning a system.

Correct microphone utilization technique is not always appreciated by users and some degree of guidance is often required. Many speakers do not appreciate the necessity of maintaining a correct natural talking level at a fixed distance, on the axis of a microphone. About 1 foot (0·3 metre) is normally adequate. Variations in voice level or distance make it difficult for an operator to maintain a satisfactory level of sound reinforcement. Too close an approach to gradient microphones may cause excessive low-frequency emphasis and "blasting" due to breath and plosive consonants. The use of lavalier or neck microphones with proper equalization of the response may give the talker more freedom, particularly if a radio microphone is used to eliminate the trailing cable connection.

4. Specialized Sound-Reproducing Systems

4.1 Theatre Sound Systems

The system for a large modern theatre must be planned to provide the various facilities needed whilst being sufficiently flexible to accommodate additional future requirements. Typical functions are:—

(A) A rear-of-house system for relaying stage sound and stage manager's instructions to stage and scenery operators, dressing rooms, et cetera.

(B) Reproduction of music and effects from tape or disc with suitable control and cueing facilities for use during performances.

(C) A front-of-house system for relaying interval music, announcements, and interval time signals to bars, foyers, et cetera.

(D) The sound-reinforcing system for the main auditorium stage.

(E) The producer's rehearsal system (plugged in as required at points in the auditorium). (See Figure 14.)

For **(A)** and **(E)** two-way communication may be necessary so that instructions can be confirmed and reports made. **(E)** may require special loudspeakers to convey instructions to the stage.

(A), **(B)**, and **(C)** are normally performed by low-level systems controlled from behind the stage, whilst the main auditorium loudspeakers are often high-power directional column units concealed in the proscenium arch. The position of these in relation to the audience is preferably chosen so that the distance lines slightly exceed (usually by 10 to 20 feet) the lines of direct sight between audience and stage. The De Haas precedence effect [2] then preserves the illusion that all the sound is coming from the stage. The directional polar patterns of these column loudspeakers are designed to be as wide as possible in the horizontal plane, but narrow vertically, thus concentrating sound on the audience and reducing unwanted reflections from the ceiling and other areas.

We have described refinements in design consisting of curving the column array or "tapering" the power input to the individual loudspeaker units which make up the column array, so that maximum power goes to the centre unit, the outer units being supplied from progressively reduced taps on the loudspeaker feed transformer. The effect in both cases is to reduce the normal tendency for the response to become excessively directional at high frequencies. Radiation from vertical slots in front of the loudspeaker cones gives a small virtual source width and prevents any tendency for the horizontal polar response to become narrowed at high frequencies. The properties of modern directional column loudspeakers are generally superior to those of the earlier horn-loaded "pressure" units. It is possible to project sound over distances exceeding 30 yards (27 metres)

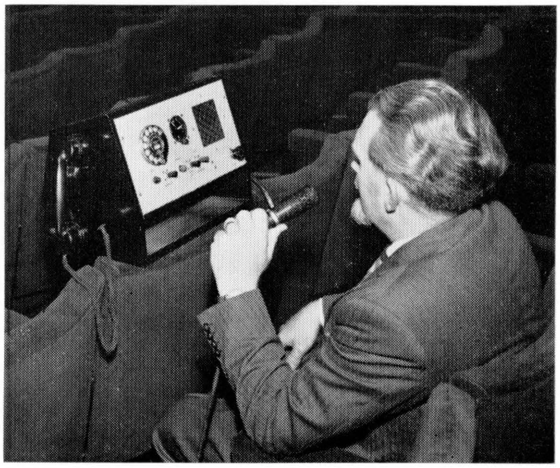

Figure 14—Producer's rehearsal control point in theatre stalls.

with properly sited column loudspeakers. The fall-off of sound with distance is also less marked with column units than with small sound sources.

Generally, column loudspeakers are essential when sound must be projected 50 feet (15 metres) or more. Some small low-level cabinet loudspeakers may have to be used locally to cover dead spots at the back of balconies, et cetera. There may then be some loss of realism, however, unless the signal to these speakers goes via a magnetic delay unit, giving the subjective impression that all sound emanates from the stage.

Directional microphones are generally used for fixed microphone positions. Cardioid unidirectional microphones are best for use in the footlight position to avoid excessive pick-up from the orchestra and audience. Three or five microphones may have to be spaced across the footlights. A good cardioid microphone has a back response similar to the front frequency response, but about 20 decibels reduced in gain. Small omnidirectional tubular "personal" or hand-held microphones, because of their unobtrusive appearance and the ease with which they are rendered "pop" proof by the addition of small woven windshields, are useful for soloists. On large stages, two to four stage microphones may be used from fly rails or rising from floor traps.

It is usual to have an operator's control position in the body of the house where he can adjust the sound volume and, when necessary, fade in and out the large number of microphones used in many modern stage productions. The sound operator should maintain the level about 4 decibels below the singing point to avoid any colouration of the sound reproduction. It is obviously much easier to exercise effective control from a point in the auditorium than from behind the stage.

Figure 15 shows how column loudspeakers have been built into the proscenium arch of a new theatre.

4.2 Sound Reinforcement in Cathedrals and Other Large Reverberant Buildings

Sound reinforcement may present special problems in commodious places because of the long distances between talkers and listeners and the extent to which reverberant sound may exceed the direct sound intensity. The problem was long considered insoluble in London's St. Paul's Cathedral (where the reverberation time exceeds 10 seconds) until the advent of directional column loudspeakers and magnetic delay systems [2].

The new installation at St. Paul's is diagrammed in Figure 16. The primary directional column loudspeakers are placed adjacent to the principal speaking positions at pulpit and lectern. These loudspeakers cover the congregation in the 100-foot (30-metre) diameter dome area. However, distances in the nave are also very large and the massive pillars cause dead areas as far as direct sound is concerned. Hence column loudspeakers were fixed to the far side

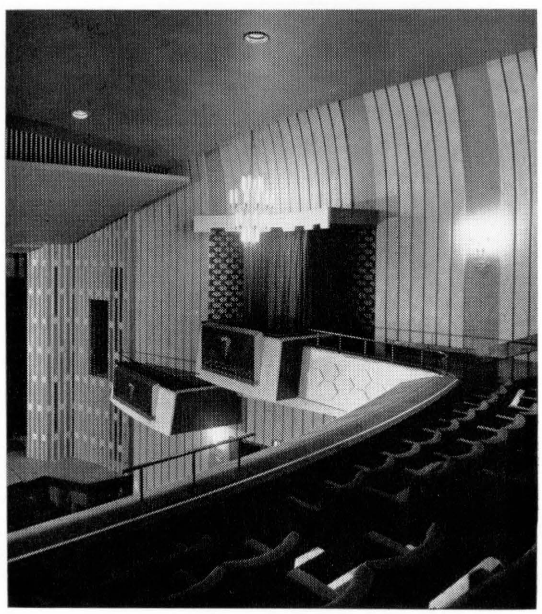

Figure 15—Column loudspeakers built into proscenium arch.

of the pillars, the area covered by each loudspeaker not being made too large in view of the predominance of the reverberant sound.

Starting from the microphone position in use at any given time, successive delays are applied to the various column-loudspeaker arrays, the actual amount of delay in each case being tailored to suit the particular set-up in use. The operation of the system is controlled from a desk position on the west side of the dome area. The amplifier and delay unit racks are housed in the crypt, all switching being performed by relays interlocked in such a way that the operator automatically selects the correct loudspeaker delay circuits when he switches in a given microphone. The control panel is laid out to a geographic plan to minimize operational errors. The volume is set with the aid of a peak programme meter monitoring the undelayed signal.

The column loudspeakers used are 11 feet (3·4 metres) high and retain a highly directional vertical polar response down to below 250 hertz. The narrowness of the source and the use of special tapered columns and small columns at high frequencies ensure a good horizontal sound distribution and a constant narrow vertical polar pattern free from side lobes. A bass cut is available to reduce the response below 250 hertz. Thus the extremely troublesome reverberation from the upper parts of the dome, et cetera, is not excited to any great extent and listening conditions are radically improved as a result.

Figure 17 shows diagrammatically the delay unit which is built into the main amplifier rack system. It basically consists of a magnetically loaded neoprene belt fixed to the face of a drum which revolves in precision bearings 80 times per minute. Record, playback, and erase heads are disposed around the periphery of the drum and are maintained in low-pressure contact (25 grammes) with the face of the loaded neoprene. This is continuously lubricated with a siliconized felt pressure pad. Head wear is claimed to be negligible for over 10 000 hours of operation and no adjustment is normally needed. The drum is driven at a constant speed by a synchronous motor via an idler wheel and flywheel arrangement.

Recording takes place at 30 inches (76 centimetres) per second with a wow and flutter

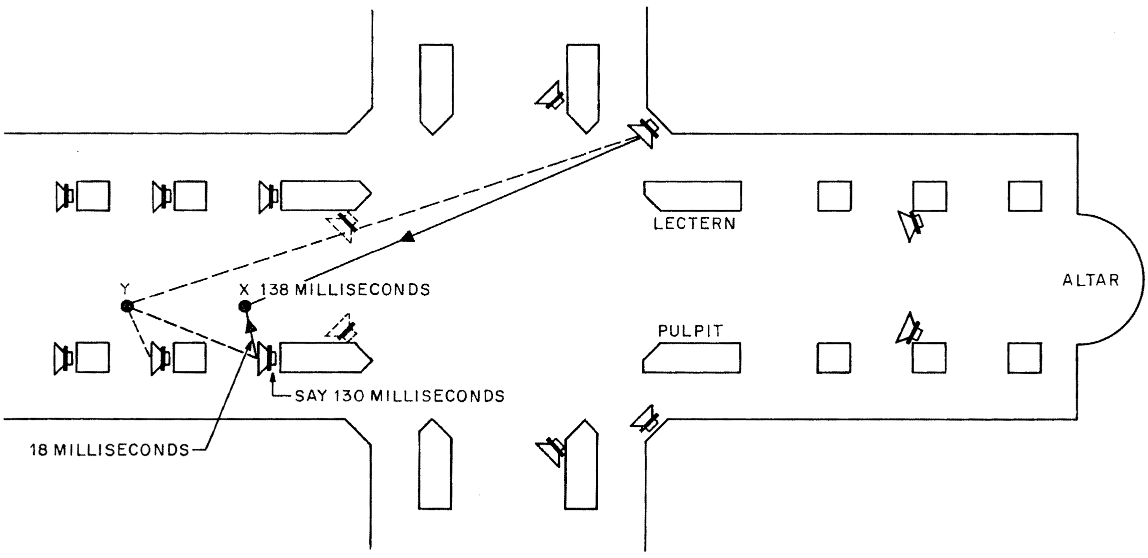

Figure 16—St. Paul's Cathedral system plan.

figure of 0·19 per cent. Delays between 25 milliseconds and 350 milliseconds can be obtained by setting the record and playback heads to appropriate positions around the periphery of the drum.

The thickness of the magnetic coating tends to reduce the high-frequency response, but it is equalized up to 7 kilohertz. The main rack equipment is shown in Figure 18 and includes 12 power amplifiers, the delay unit, transistor microphone amplifiers, and built-in test equipment to enable routine performance checks to be carried out at regular intervals.

Many of the above techniques are applicable to other large reverberant enclosures which may also have alcoves and other scattered subsidiary areas. Examples are railway stations, airports, terminals, and sports arenas. The use of correctly sited directional column loudspeakers can often be invaluable in providing clear announcements free from echo and confusion. Noise-sensing microphone systems can be used to operate automatic-gain-control systems to raise sound levels in railway stations and other places where periodic background noises exceed a certain level. Limiters and compressor circuits help to maintain constant speech output for various talking levels and help to avoid overloading [12].

5. Assisted Room Resonance Systems in Concert Halls

To make sense economically, a concert hall must be built to accommodate an audience of 2000 to 3000 persons and it must also be suitable for many other types of activity. From a design view-point, this means that the volume of a hall (one of the main factors governing its

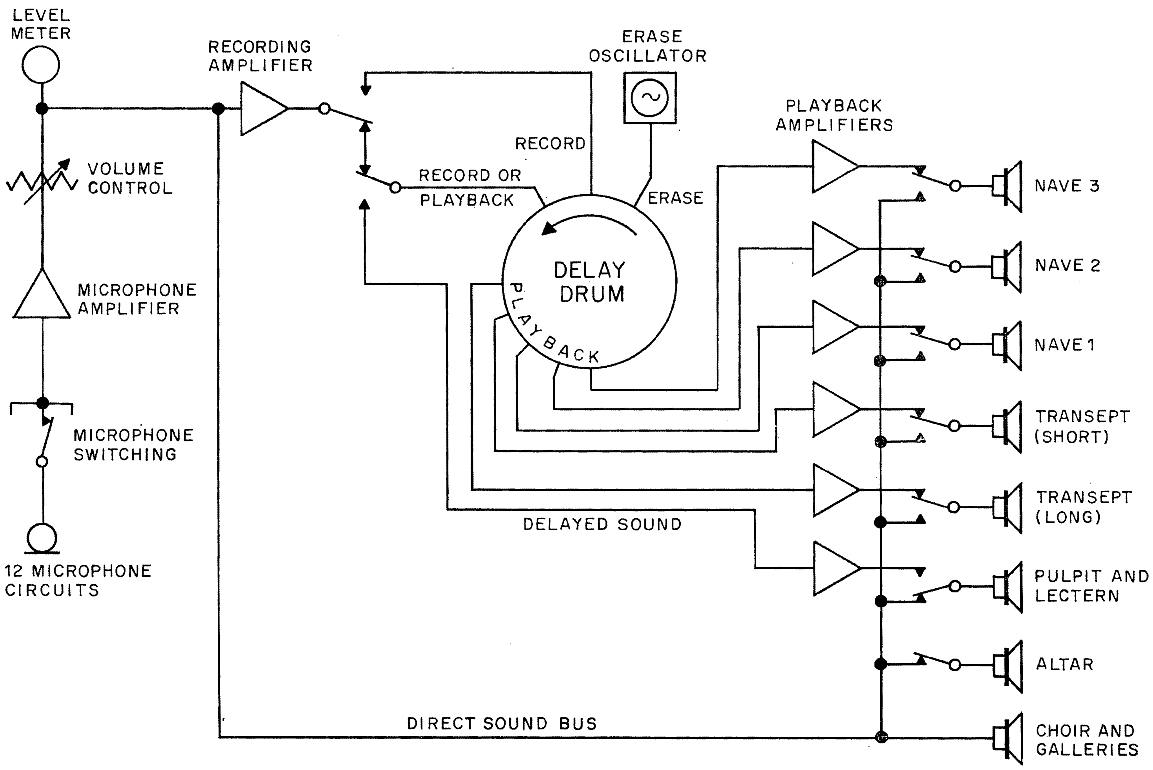

Figure 17—Layout of magnetic-drum delay unit.

reverberation time) has not increased at the same rate as the total acoustic absorption. The use of a higher ceiling level for a given audience capacity gives a greater volume, but it increases costs and also involves the risk of introducing interfering echoes due to long sound paths. The use of a hall for most activities other than orchestral work favours a fairly short reverberation time, and the extra absorption due to modern seating and carpeting helps to reduce the level of background noise in the hall.

Acoustic adjustments to a hall, such as moveable overhead reflectors, rotatable adjustable wall panels, et cetera, have been tried, but these expedients are apt to interfere with the architecture and are also extremely expensive.

In 1960 the Council for Scientific and Industrial Research of Great Britain and Mr. P. H. Parkin filed a patent on an electronic means of increasing the reverberation time of a hall by increasing the magnitude and duration of some hundreds of the normal room modes which actually constitute the main reverberant effect in the hall. Accurately tuned resonators containing microphones fed tuned amplifiers and loudspeakers. The non-uniform nature of the transmission characteristic of a hall can be improved by selective augmentation of weak modes. Optimum positions can be found for the microphones housed in their resonators and the associated separate loudspeakers by carrying out an acoustic survey of the sound pressure distribution in the hall at various frequencies.

Suitable mounting places can usually be found for the comparatively small units on the walls and ceilings. By correctly positioning a microphone and loudspeaker in the sound path of a mode, the output of the loudspeaker in question arrives at its microphone position in phase with the original sound pressure because of the room mode in question. By setting the phase and gain of the associated amplifier appropriately, the decay of that mode can be prolonged as desired, up to the point at which continuous oscillation occurs around the path. The artistic merit of the system lies in the fact that reverberant deficiencies at any given frequencies in the hall can be selectively made good. As the original excitation is entirely due to the musical performance, the naturalness of the system is not impaired [13].

The detailed theory and an account of the surveys, design work, and subjective appraisals of such a system have been given by Parkin and others [4].

6. Conclusion

It is readily seen that the design and application of a sound-reinforcement system to a new or existing building are engineering operations demanding experience and the application of special communications and acoustical techniques. A fairly full scientific survey and/or diagnosis is essential for many major contracts.

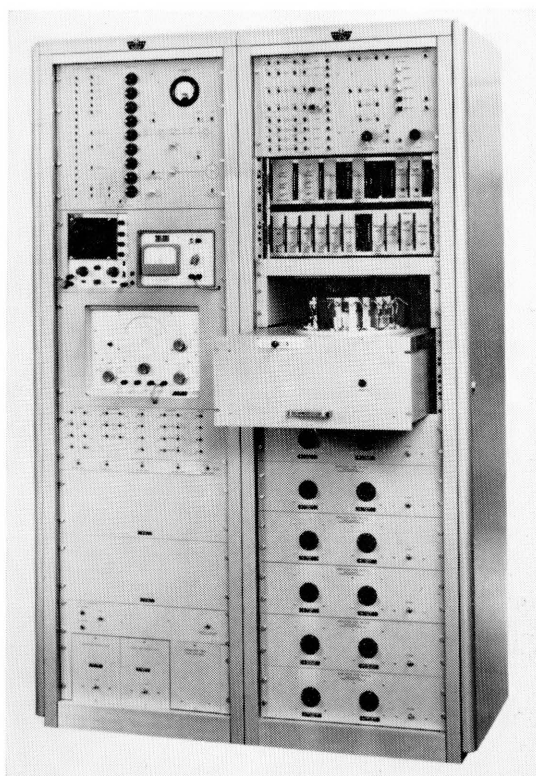

Figure 18—St. Paul's Cathedral rack and delay unit.

Modern systems can offer extensive special facilities and are necessarily fairly expensive. However, the system is often of such vital importance to the proper functioning of the building concerned that the cost of a properly designed and reliable system is a worthwhile capital expenditure.

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John L. Goodwin was born in January 1920 at Chigwell, Essex. He worked on underwater acoustics with the Admiralty for several years and studied electrical engineering at the Borough Polytechnic and Twickenham Technical College.

He joined the Standard Telephones and Cables Transmission Division in 1948 with responsibility for the engineering of the public-address department, and is now sound systems product-line manager with the department's reconstitution in the Private Communications Division. He is a member of the Institution of Electrical Engineers.

Behavior of Telephone Subscribers Using Push-Button Selection

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1. Introduction

Designers of telephone switching plants must adapt their equipment to meet the problems arising from human factors. Their willingness to do this is shown by both technological changes and by meetings such as the symposium "Human Factors in Telephony" [1–20]. Modern technology makes it increasingly possible to take into account the habits and wishes of telephone users. The versatility of telephone equipment has so increased that the designer must be fully informed about the behavior and reaction of people to be able to discriminate between economical and uneconomical system features from the standpoints of benefit and cost.

One of these new features in modern telephone switching systems that constitutes a true advance is push-button selection. In Germany, push-button selection has been introduced for the first time in a quasi-electronic experimental switching center of the Federal German Post Administration in Stuttgart. This switching center is called *HE-60* (*H* = Herkon-type reed relays, *E* = electronic, *60* = year) [21]. In the second half of 1963, some 50 push-button telephones were put in operation in the homes of public telephone subscribers. At present 200 more sets are being installed. The Administration applied no special principle in selecting those to receive the push-button set, although the subscribers had the right to refuse it.

Figure 1 shows the push-button telephone used in the *HE-60* switching center. The key arrangement is preferred by most of the administrations using push-button selection, and it is believed that this arrangement is the only one suitable for worldwide standardization [22].

Measurements were conducted in the Stuttgart experimental switching center to obtain information about subscriber behavior when using push-button telephones.

Investigations into the reactions of people to push-button selection had been made at an earlier time [8]. These investigations were conducted under more or less specific trial conditions, but not under true telephone operating conditions that would require the subscribers (among other things) to be unaware of the test. The first observations in the *HE-60* quasi-electronic switching center were made at the beginning of 1964, at a time when push-button selection was still new to the public. About 18 months later the measurements were repeated. The objective of the second measurement was to assess the possible effect of the subscribers becoming familiar with the new technique. The results obtained during the two test periods are described and compared with the results obtained from similar tests in conventional dial selection.

2. Performance of the Tests

2.1 Measured Times

The same sequence of operations was used in the quasi-electronic switching center with the push-button telephone and with the conventional dial telephone [21]. The subscriber removes the handset, waits for the dial tone, keys

Figure 1—Push-button telephone used in *HE-60* telephone exchange in Stuttgart.

in the desired subscriber number, and begins the conversation after the called subscriber answers. On completion of the conversation he replaces the handset.

The time intervals observed in the above operations are as follows.

(A) Selection delay t_b [1, 2] is the time that elapses from the instant of lifting the handset until selection of the first digit of the subscriber number.

(B) Inactive holding time t_A is the time the subscriber holds the line until he replaces the handset without having tried to select a digit.

(C) Key actuation time t_i may be defined as the time during which the subscriber holds a key fully depressed (the time it takes to send a complete push-button digit signal).

(D) Interdigit pause t_p is the interval between two key operations.

(E) Selection time t_w is defined as the period consisting of the key actuation times $(n \cdot t_i)$ and the interdigit pauses $(n\text{-}1)$ multiplied by t_p. It defines the time the subscriber takes to select an n-digit subscriber number.

2.2 Test Setup

The selection delay t_b and the inactive holding time t_A may total several seconds on the average. For this reason, the test setup shown in Figure 2 was chosen: A timer continuously

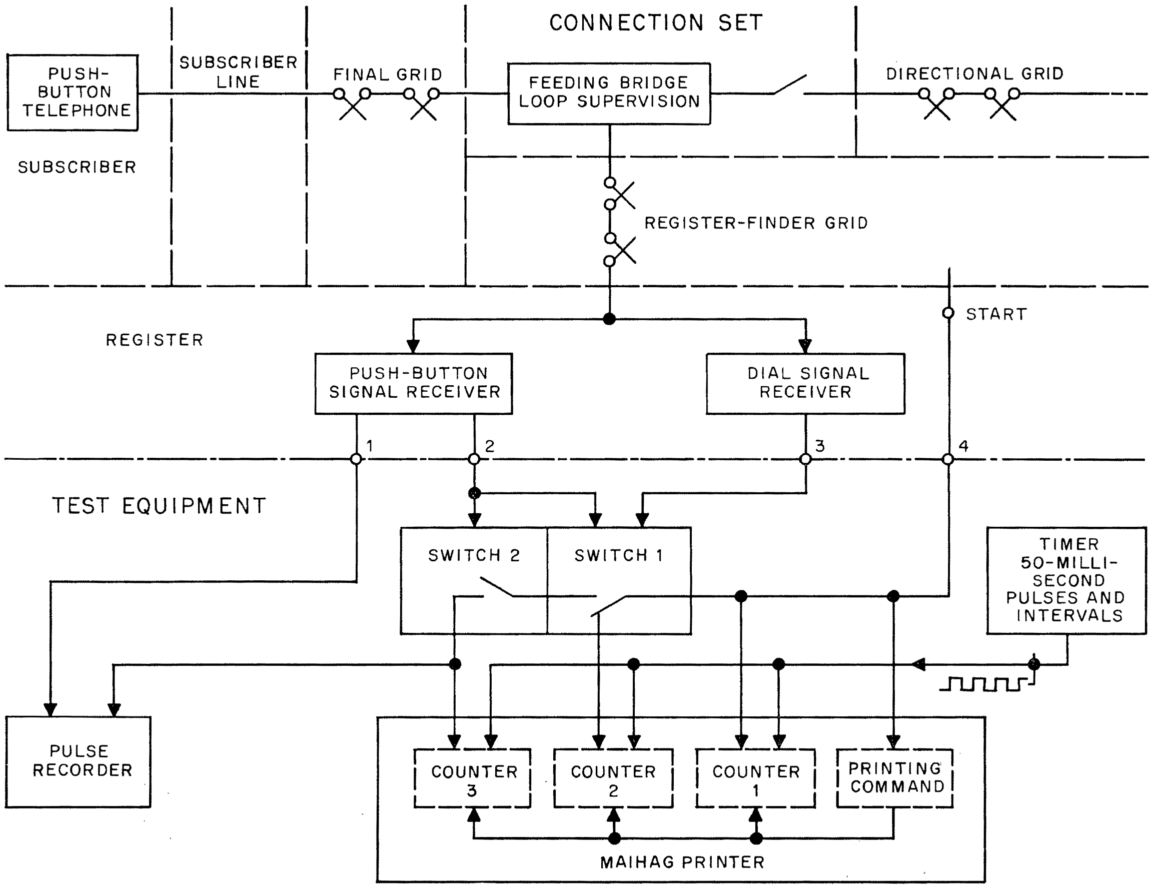

Figure 2—Block diagram of the test setup.

supplies a basic pulse rate of 50 milliseconds with intervals of 50 milliseconds to 3 counters of a Maihag printer.*

Counters 1 and 2 are started simultaneously at the instant of occupancy, but counter 2 is stopped at the instant the beginning of the first digit is recognized and operates switch 1 regardless of whether dial or push-button selection is used. This counter thus indicates the selection delay t_b. If counters 1 and 2 stop simultaneously, this indicates that a subscriber has seized a line and then replaced the handset without dialing.

To permit separate evaluation of the selection delay for push-button selection and for dial selection, the values for the former were provided with special marks during printing. At the instant counter 2 stops, a start signal is passed over switch 2 from the push-button signal receiver to counter 3, which counts the tenths of seconds from the beginning of the push-button selection process until the register disconnects. Thus 3 values per seizing operation were recorded with push-button selection, and only 2 with dial selection. This arrangement was necessary since any subscriber line may optionally be equipped with a push-button or a dial telephone, and therefore it is not known from the outset which type of telephone the calling subscriber has.

With push-button selection, the key actuation time t_i and the interdigit pauses t_p are as short as 10 milliseconds but only in extreme cases. While resolution to a tenth of a second was quite adequate and the detection time of the receivers could be neglected for dialing, a higher degree of accuracy was necessary in the assessment of t_i and t_p for push-button operation. Therefore, pulse recorders† having errors smaller than ± 2 milliseconds were used in these cases. Because of the response delays and release times of the push-button signal receivers and of the measuring equipment, differences occurred between the measured and the actual key actuation times t_i and the interdigit pauses t_p. With the aid of pulses and intervals of known duration, it was possible to assess these differences, so that the measured values could be corrected correspondingly.

The observation period for the 1964 test series covered 4 weeks, and for the 1965 test series 7 weeks. Measurements were carried out on working days from 8 a.m. to 4 p.m.

3. Measurement Results

The measured values were punched into tape and evaluated on our *ER 56* computer.

In the following, the percentage distributions and the cumulative percentage distributions of the more interesting measurements are dealt with. Since the physiological action generally obeys a logarithmic law [2], a logarithmic time scale was chosen as the abscissa (for example, key actuation time t_i). In the evaluation a relative class width of some 12 percent has been used for all curves (20 classes per decade).

Each of the obtained distribution curves reflects a different reaction and is composed in principle of the distribution curves of the individual subscribers. As the number of observed push-button subscribers was not very large, individual subscriber distributions can still be recognized in parts of the distribution curves.

3.1 Selection Delay t_b

Figure 3 shows that the selection delay t_b of the

*The Maihag printer contains counters that can be operated independently of each other (similar to message registers in telephone exchanges) and which are employed here for time measurement under the control of defined 50-millisecond pulses and 50-millisecond intervals. The counters can be started and stopped by control signals. Subsequently, the counter settings are recorded under the control of a print command and the counters are reset to zero.

†The pulse recorder, under the control of a start signal, passes a paper tape at constant speed under a writing pencil. An electromagnet inside the recorder shifts the pencil from the rest position to a second position. It thus records pulses which are applied to the control input. The pulses can be read from the paper tape by means of a rule calibrated in milliseconds.

1964 measurements is virtually the same for both push-button and dial selection. The arithmetic mean of t_b with push-button selection is only 250 milliseconds less than with dial selection. The time difference may be considered the mean duration required to spin the dial.

The 1965 measurements clearly show a reduction of the selection delay t_b with push-button selection. This may be due to greater familiarity of the subscribers with the new technique.

3.2 Inactive Holding Time t_A

In about 10 percent of all cases observed, the line was seized and the handset replaced without any calling action. The distribution of these inactive holding times t_A is shown in Figure 4.

In about 34 percent of these cases (that is, about 3 percent of all seizures) the inactive holding time was shorter than 0.4 second. It is assumed that a certain proportion of these short seizures is caused when the telephone set is cleaned. A further cause may be the habit of some subscribers (calling and called) to depress the cradle by hand at the end of the conversation before replacing the handset. As a result the cradle may momentarily rise again, causing a short seizure.

A maximum in the distribution is observed at about 2 seconds (Figure 4), while a second maximum at about 20 seconds is caused by the register providing for the automatic forced release of calling subscribers who fail to select (about 1 percent of all seizures).

3.3 Key Actuation Time t_i

The designer is particularly interested in the

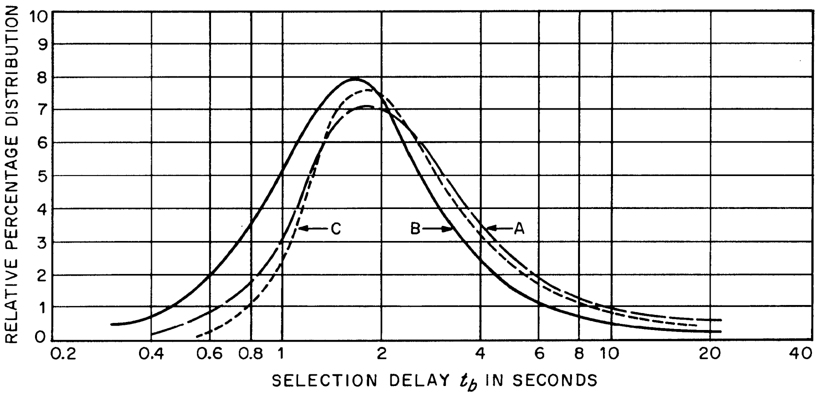

Figure 3—Percentage distribution of selection delay t_b. Class width = 12 percent.

	Curve *A*	Curve *B*	Curve *C*
Selection	push-button, 1964	push-button, 1965	dial
Arithmetic mean time in seconds	2.86	2.524	3.11
Median time in seconds	2.027	1.68	2.2
Number of seizures	2442	4762	18 380

shortest key actuation times t_i that are likely to occur. These figures give him valuable information about the required operating speed of the telephone sets.

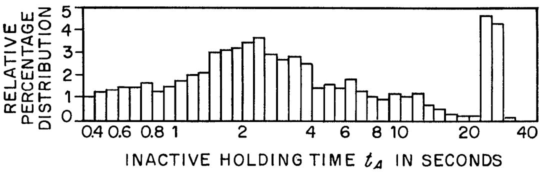

Figure 4—Percentage distribution of inactive holding times (failure to call after lifting handset) for 2977 seizures. There were 34.4 percent under 0.4 second and the 9.1 percent above 20 seconds corresponds to automatic forced release of the register for failure to call. Class width = 12 percent.

Figures 5 and 6 show how long the digit recognition time must be so that lost signals do not exceed a specified percentage. If, for instance, the push-button receiver needs 30 milliseconds to accept a signal, about 0.1 percent of all signals could not be detected (Figure 6). Assuming 6-digit subscriber numbers, it is estimated that some 0.6 percent of all seizures would result in wrong connections.

Similarly, if the push-button receiver needs 40 milliseconds to accept a signal, the corresponding estimates of signal loss are 0.5 and 3 percent, while for 50 milliseconds they are 2 and 12 percent.

In practice, short key actuation times can essentially be attributed to some few quickly

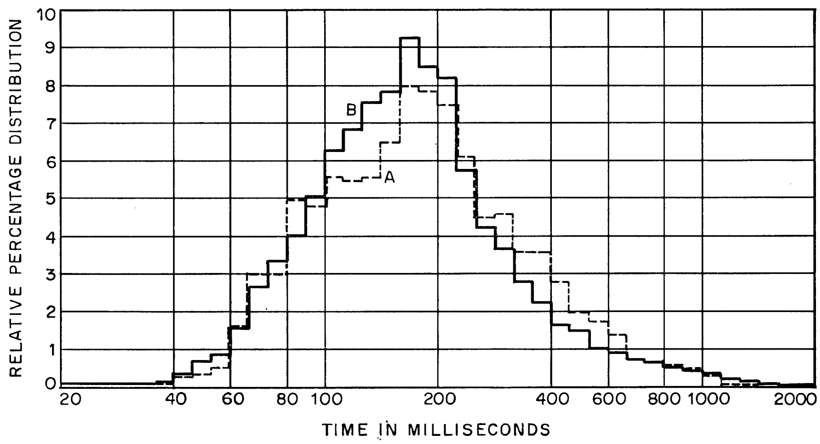

Figure 5—Relative percentage distribution of all key actuation times t_i. Class width = 12 percent.

	Curve *A*	Curve *B*
Selection	push-button, 1964	push-button, 1965
Arithmetic mean time in milliseconds	230.1	210.5
Median time in milliseconds	200	170
Key depressions	11 168	20 929
Number of seizures	1843	3462

reacting subscribers. If, as demanded in [23], only actuation times $\geqq 50$ milliseconds are evaluated, the percentage of wrong selections attributable to these fast keyers—who certainly are subscribers with high calling rates—would be considerably higher than 12 percent (which is already unacceptably high). If the telephone user is required to deliberately press each key for some prolonged period, this would contradict the philosophy of adapting the switching equipment to human behavior.

On the other hand, since artificial prolongation of the key actuation time by mechanical or electrical means would unduly increase the cost of the push-button station and possibly make it less reliable, the best solution is to design the push-button signal receivers for a signal recognition time of 30 milliseconds.

In general, the curves in Figures 5 and 6 show an insignificant reduction in key actuation times at the end of the 1-year trial period.

The effect of greater familiarity with the new technique becomes evident by comparing the arithmetic mean values of the key actuation times as shown in Figure 7. Curves A and C (subscriber numbers $\leqq 6$ digits; local calls) are approximately parallel. They show that reduction of the key actuation times as a result of greater familiarity with the new technique may amount to some 5 to 10 percent. Curves B and D (subscriber numbers $\geqq 7$ digits) do not show this tendency so clearly.

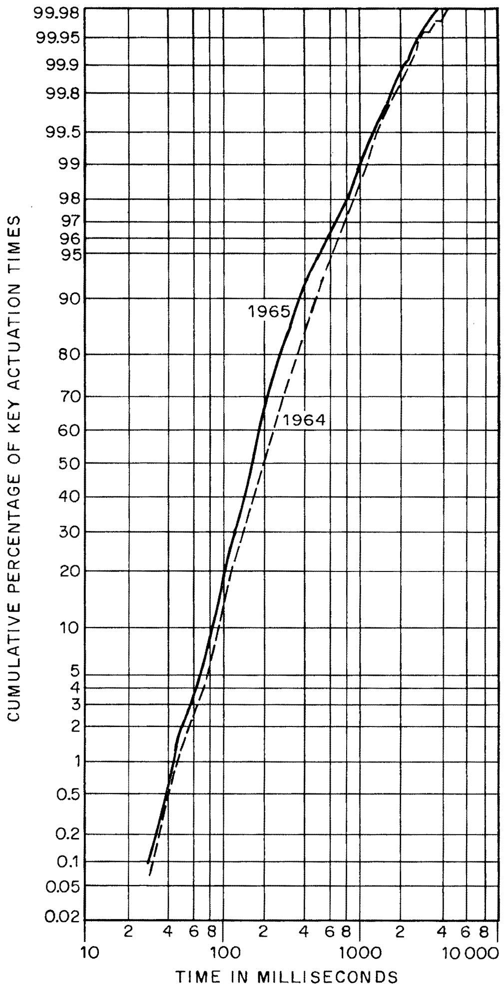

Figure 6—Cumulative percentage distribution of all key actuation times t_i.

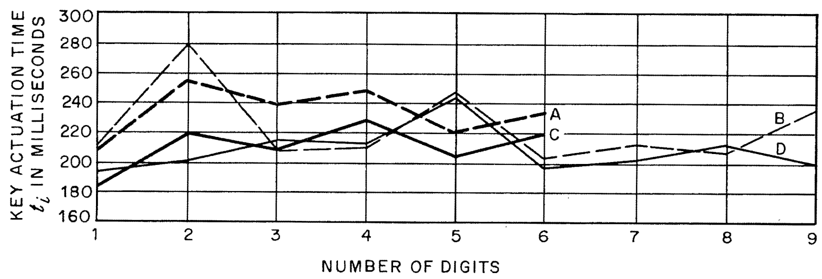

Figure 7—Arithmetic mean values of the key actuation times. Curves A and B were measured in 1964; they represent 7259 and 3188 key depressions, respectively. Curves C and D were measured in 1965 and represent 13 670 and 7259 key depressions.

3.4 Interdigit Pause t_p

In push-button selection, the interdigit pause is needed to find the next digit, while with dial selection the next digit is found by most telephone users during the spin-back of the dial. For a fast subscriber, the dial spin-back is forced inactivity. Most subscribers will therefore dial the next digit as soon as the dial has come to a stop. Hence, with dial selection, the interdigit pause essentially consists of the time required to wind up the dial, plus the spin-back allowance (constant for all digits) of 200 milli-

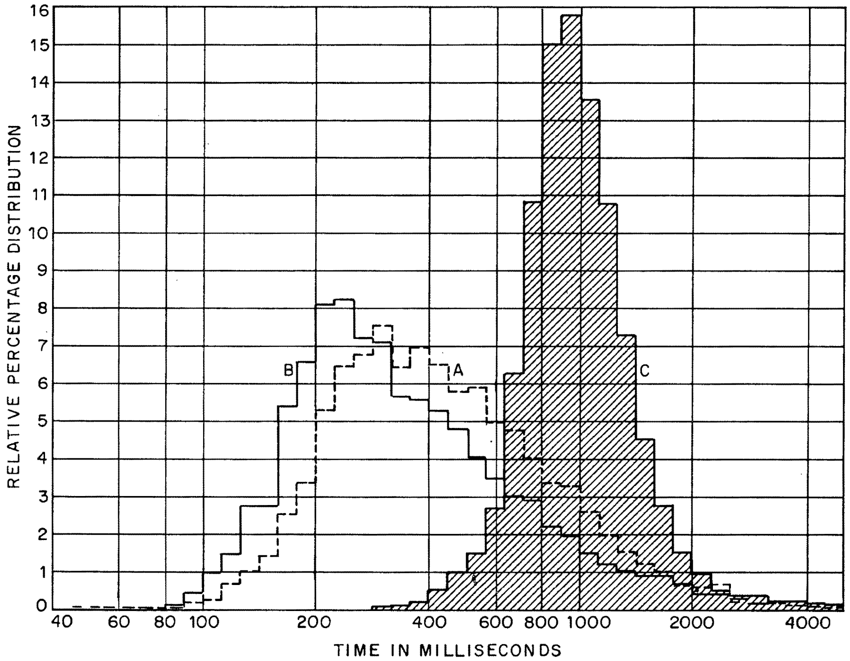

Figure 8—Percentage distribution of interdigit pauses $t_p \leqq 6$ digits (local calls). Class width = 12 percent.

	Curve *A*	Curve *B*	Curve *C*
Selection	push-button, 1964	push-button, 1965	dial [1,2]
Arithmetic mean time in milli-seconds	559.8	472.3	1190
Median time in milli-seconds	370	270	700
Number of pauses	6524	11 076	11 025
Number of seizures	1452	2594	—

seconds. The interdigit pause is thus considerably influenced by the mechanical construction of the dial; this is also expressed by a displacement of the cumulative time distribution toward the higher values.

The influence of the mechanical construction diminishes as the subscriber selects more slowly, so that the extremely long interdigit pauses occur with approximately the same frequency in push-button selection and in dial selection. This may also be seen from the distribution curves for push-button and dial selection in Figure 8.

Figure 9 shows the mean interdigit pauses of 6-digit and 7-digit subscriber numbers. The alternating short and long interdigit pauses reveal the dialing rhythm, which in local calls is similar for both push-button and dial selection. This rhythm comes from the notation of the subscriber numbers in the telephone directory (XX XX XX), which has been confirmed by the investigations of Deininger [10]. In the United States, the numbers are grouped in the telephone directory as follows: ABX-XXXX.

The result is a prolonged third interdigit pause as indicated by the 7-digit curve in Figure 9.

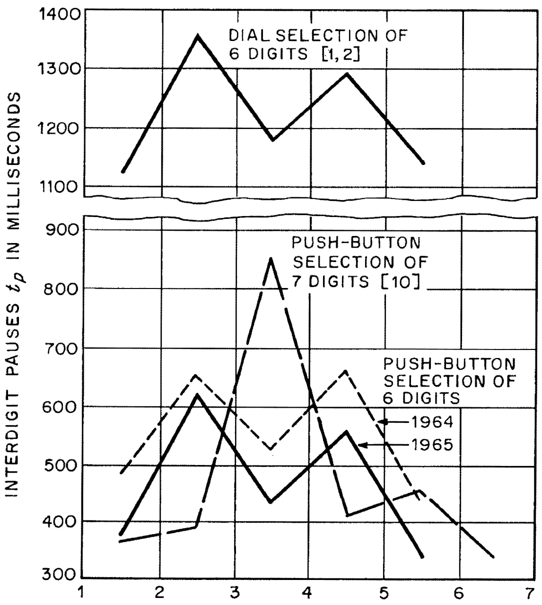

Figure 9—Arithmetic mean values of interdigit pauses t_p.

Comparison of the measurement results of 1964 and 1965 (Figure 9) shows a reduction of the mean interdigit times t_p by some 10 to 20 percent. This confirms the effect of greater subscriber familiarity with push-button selection after the 1-year trial period.

Analysis showed that less than 0.05 percent of all intervals (key actuation time t_i plus interdigit pause t_p) are shorter than 100 milliseconds. Intervals of up to 150 milliseconds occur at a rate of 0.5 percent. The claim made on several occasions that push-button signal receivers need be designed to handle minimum intervals of 100 milliseconds [17, 23] is therefore amply justified.

3.5 Selection Time t_w

The selection time t_w is the average time required to select a complete n-digit subscriber number. The values obtained during the experimental period from subscribers of the public telephone network show a mean selection speed of 1.6 digits per second, which is about three times that achieved with dial selection (Figure 10). The influence of familiarization can also

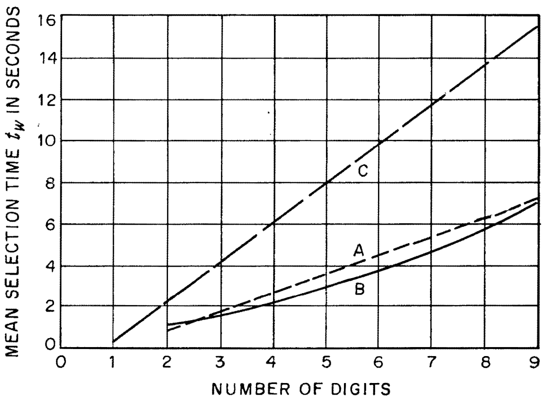

Figure 10—Mean selection times t_w. Curves A (1964) and B (1965) are for push-button selection, while curve C is for dial selection.

be seen by comparing the measurements of 1964 and 1965. For local calls with 6-digit subscriber numbers (about half of all pulse trains observed), an increase of 10 percent in the selection speed was observed; there was no noticeable variation for long-distance calls.

4. Conclusion and Recommendations

Table 1 summarizes the significant measurements of the subscriber observations of 1964 and 1965.

It was surprising to learn that in about 10 percent of all seizures the handset was replaced without the subscriber proceeding to select. One-third of these ineffective seizures are momentary ($\leqq 0.4$ second) while 10 percent $\geqq 30$ seconds.

With 6-digit subscriber numbers, which represent more than 50 percent of all subscriber

TABLE 1

BEHAVIOR OF SUBSCRIBERS IN PUSH-BUTTON AND DIAL SELECTION

Time Measurements	Push-Button Selection		Dial Selection	
	HE-60, 1964	*HE-60*, 1965	*HE-60*, 1964	G. Rothert 1961
Inactive holding time t_A:				
$\leq$ 0.4 second	34.4 percent		34.4 percent	
0.4 to 4 seconds	51.6 percent		42.5 percent	
4 to 19 seconds	4.9 percent		14.0 percent	
$\geq$ 20 seconds	9.1 percent		9.1 percent	
Number of measurements	2977*			
Selection delay t_b in seconds:				
Mean	2.86	2.52	3.11	2.88
Median	2.03	1.68	2.2	2.24
Number of measurements	2442	4762	18 380	9235
Key actuation time t_i in milliseconds:				
Mean	230.1	210.5		
Median	200	170		
$\leq$ 50 milliseconds	1.72 percent	2.16 percent		
$\leq$ 40 milliseconds	0.57 percent	0.58 percent		
$\leq$ 30 milliseconds	0.07 percent	0.1 percent		
Number of measurements	11 168	20 929		
Interdigit pause t_p in milliseconds:				
For $\leq$ 6 digits:				
Mean	559.8	472.3		1190
Median	370	270		700
Number of measurements	6528	11 076		11 025
For $\geq$ 7 digits:				
Mean	552.5	581.4		1490
Median	350	316		1190
Number of measurements	2777	6391		3554
After area code in long-distance calls:				
Mean	735	1038		2950
Median	390	400		2300
Number of measurements	391	868		8145
Selection time t_w for 6 digits in seconds:				
Mean	4.15	3.62		10.1
Median	3.4	3.1		10.4
Number of measurements	968	1741		

* 10.4 percent of all seizures.

numbers, nearly 2 digits are selected per second on the average. This means that push buttons increase the selection speed by a factor of 3 compared with dial selection.

At the end of the 1-year trial period, a 10-percent reduction was observed in both selection delay and key actuation time of push-button operation. Interdigit time for subscriber numbers $\leqq 6$ digits (local calls) was reduced by 20 percent, and selection time by more than 10 percent. These reductions all resulted from subscriber familiarization with push buttons.

From the measurements, the following recommendations can be derived for the equipment design.

The push-button signal receiver should be able to handle key actuation times $\geqq 30$ milliseconds and interdigit pauses $\geqq 70$ milliseconds. In both cases the probability of occurrence of shorter times is $\leqq 0.1$ percent. The probability that intervals (consisting of key actuation time plus succeeding interdigit pause) are shorter than 100 milliseconds is only 0.036 percent.

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Optical Subcarrier Communications

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1. Introduction

There is currently considerable enthusiasm over the application of the laser in optical radar and communications systems. Undoubtedly, optical frequencies will have increasingly greater importance in communications as more powerful and coherent sources become available. The basic advantage of optical-frequency communications over microwaves is the combination of narrow beamwidths with potentially large information bandwidth. Both of these properties are due to the high frequencies associated with optical radiation. It is significant that these advantages should also lead to the primary disadvantages. In particular, narrow beamwidth means that the target must be located and tracked with extraordinarily high accuracy. A further hindrance to communications at optical frequencies is the atmospheric effect on the light beam. This limitation is particularly severe on systems which require the preservation of the spatial coherence of the beam for certain information processing functions.

One of the simplest ways to exploit the large information bandwidth of an optical carrier is to place radio-frequency subcarriers on the optical beam which can, in turn, be modulated.

The subcarrier approach to optical communications permits the use of a variety of established data processing techniques and may assume many levels of sophistication, depending on the particular mission to be performed. With appropriate post-detection electronic processing, the following missions may be accomplished:

(A) Distance and velocity measurement.
(B) Angle measurement and tracking.
(C) Phase-locked receiver tracking.
(D) Multichannel telemetry.
(E) Television.

The use of optical beams in these missions requires a careful consideration of the optical-electronic interface. In particular, the modulation of the beam and its effect on photodetection devices must be examined.

First, it is necessary to consider the optical beam as a carrier. Although the laser oscillator may be considered quite coherent optically, it is not coherent in the absolute sense and, indeed, has a spectral width of several kilohertz under ordinary conditions. It is evident that an optical beam must be treated as a noisy carrier for communication purposes. In addition, further analysis must be given to generation of shot noise by a photodetector excited by a modulated laser beam.

This laboratory investigated the effects of a noisy carrier on conventional techniques of synchronous detection by phase-locking to a microwave subcarrier placed on an optical beam having a spectral width of approximately 10^4 gigahertz [1]. The outcome of this investigation demonstrated that the self-noise associated with a wideband optical carrier does not require drastic modification of conventional synchronous detection techniques. This suggests the possibility of synchronous detection of radio-frequency subcarriers on noisy optical beams, thereby gaining most of the advantages afforded by synchronous detection.

In the presentation which follows, the modulation process and the derivation of a generalized signal-to-noise ratio equation are discussed. In addition, three subcarrier systems developed at our laboratory are described. These are range and angle tracking systems and a prototype optical receiver.

2. Modulation

A necessary task in synthesizing an optical communication system is the placing of the information on the light beam. The current need for wideband communications has resulted in a critical requirement for microwave light modulators to fully exploit the bandwidth potential of lasers. Although there are numerous methods of modulating light beams at low frequencies, few are practical at radio frequencies.

The most generally useful of the optical modulator techniques employ the linear electro-optic effect in certain crystals. The electro-optic effect refers to the alteration of refractive properties of an optical medium by the application of an electric field. As a result of this effect, an electrically variable phase retardation may be produced in a light beam on its transit through the electro-optic medium. All electro-optic modulators using transparent media are basically phase modulators in that the modulating fields act directly to change the optical phase velocity of the medium.

Electro-optic materials fall into two classes. The first comprises materials which exhibit a linear electro-optic effect, and the second includes materials which possess a quadratic electro-optic effect. The specific materials considered in the first class are either crystals of cubic symmetry, such as cuprous chloride and zinc sulfide, or crystals of the tetragonal scalenohedral symmetry, such as potassium dihydrogen phosphate (KDP) and its isomorphs. Considerable progress is being made in the development of new materials. However, it is difficult to obtain sufficiently strain-free optical-quality samples. This discussion is concerned with the application of the tetragonal materials and, specifically, with potassium dihydrogen phosphate because of the availability of large high-quality samples.

The scope of this paper does not permit a detailed treatment of the electro-optic effect. However, a brief qualitative explanation is in order so that the basic design considerations may be appreciated. Those who are interested in a more detailed discussion are referred to a previous paper by the author [2] or to the original work of Billings [3].

In the absence of an electric field, a crystal of the tetragonal class, such as potassium dihydrogen phosphate, is uniaxial. When an electric field is applied, the crystal becomes biaxial, having induced axes which are not generally coincident with the normal crystallographic axes. The results of an electric field applied along the optical axis (the z axis) are of special interest. In this case, the z and z' axes are coincident, and the induced x' and y' axes are rotated 45 degrees from the x and y crystallographic axes. The magnitude of the axes rotation angle is independent of the magnitude of the applied field for this case. Figure 1 shows a prism of potassium dihydrogen phosphate having faces respectively perpendicular to the induced x', y', z' axes. It can be shown that the refractive indices for polarization vectors along the induced axes are given by (1), (2), and (3).

$$n_{x'} = n_o + \tfrac{1}{2} n_o^3 r_{63} E_z(t) \tag{1}$$

$$n_{y'} = n_o - \tfrac{1}{2} n_o^3 r_{63} E_z(t) \tag{2}$$

$$n_{z'} = n_e \tag{3}$$

where n_o and n_e denote the ordinary and extraordinary index of refraction, r_{63} is the electro-optic coefficient having dimensions of centimeters per volt, and $E_z(t)$ is the value of the electric field applied in the z direction. It is obvious that the induced birefringence is greatest for light propagating in the z direction parallel to the electric field, and that natural birefringence does not occur for this case. The phase difference in radians for the two normal polarization directions is given by

$$\Delta\varphi = \frac{2\pi n_o^3 r_{63} d E_z(t)}{\lambda} \tag{4}$$

where d is the thickness of the crystal in the direction of propagation and λ is the wavelength of the light.

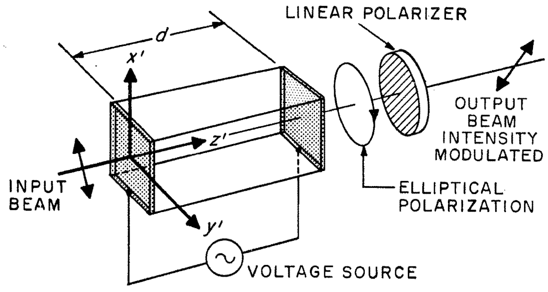

Figure 1—Electro-optical modulator using longitudinal field.

Equation (4) can be written in terms of the applied voltage V as

$$\Delta\varphi = \frac{2\pi n_o{}^3 r_{63} V(t)}{\lambda}. \tag{5}$$

The phase difference is, therefore, directly proportional to the potential difference and is independent of the crystal thickness for the longitudinal field case. The form of the modulation depends on the input beam polarization state. If the input beam is circularly polarized or linearily polarized having an orientation at 45 degrees to the x' and y' axes, the output beam will be elliptically polarized in general, because of the relative retardation produced between the two normal components of polarization. The ellipticity of the output beam polarization is dependent on the applied electric field. This polarization modulation can be converted to an intensity modulation by passing the output through a properly oriented polarizer.

If light is propagated normal to the electric field in the y' direction, as illustrated in Figure 2, the relative retardation for polarization components in the z' and x' directions is given by

$$\Delta\varphi = \frac{2\pi(n_o - n_e)}{\lambda} + \frac{\pi n_o{}^3 r_{63} S V_z(t)}{\lambda d} \tag{6}$$

where S is the length of the crystal in the propagation direction and d is the thickness of the crystal in the direction of the applied field. In the transverse field case, the retardation is directly proportional to the path length in the crystal and to the magnitude of the applied voltage. The first term in the transverse field equation represents the natural birefringence and the second term indicates the field-dependent retardation. Because of the natural birefringence associated with this direction of propagation, it is necessary to use monochromatic light of low divergence. One of the more serious problems is associated with the field-independent term, since it is very sensitive to environmental changes. It is possible to construct a modulator which is thermally compensated by using two matched crystals of the proper orientation, as suggested by Peters [4].

By confining the polarization vector of the input beam to the x' direction for light propagating in the y' direction, it is possible to accomplish a pure phase modulation of the light beam. This form of modulation is least susceptible to random strains in the crystal structures. It has been determined experimentally, however, that the maximum power which can be dissipated in the crystal is approximately 1 watt, because of thermally induced strains.

Figure 3 shows an experimental model of a

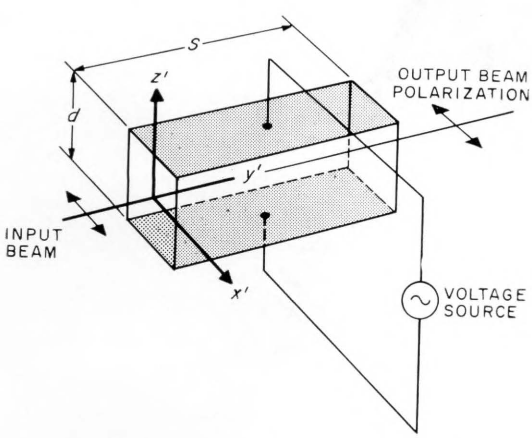

Figure 2—Electro-optical modulator using transverse field.

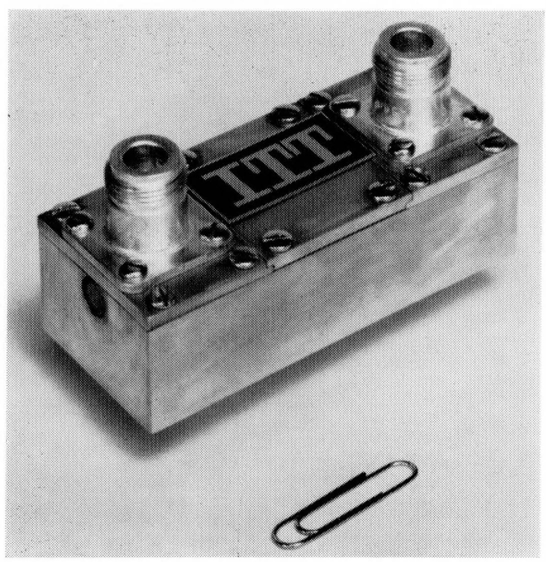

Figure 3—Transverse-field modulator.

modulator of the transverse-field type. The modulator is of the partially dielectric loaded coaxial type with input and output connectors for matched operation. The coaxial package illustrated in Figure 4 is designed to match the modulating field phase velocity with the optical group velocity in the electro-optic crystal. Figure 5 shows the performance of a modulator having a crystal length of 6 centimeters, matched to a current driver through a simple parallel-tuned circuit resonating at 100 megahertz. The variation of modulation depth with frequency is shown for two matching circuits dissipating 5 watts and having different Q's.

Truly efficient broadband performance can be achieved by a continuous interaction in a structure where both the modulating and optical signals can propagate as transverse-electromagnetic-field waves having equal phase velocities. Such conditions permit the use of long crystals with a concomitant increase in modulation efficiency. Modulators of this type have been constructed which are capable of efficient modulation over gigahertz bandwidths. Such bandwidths can best be utilized, under the present state-of-the-art limitations in electronic systems, through optical subcarrier multiplexing.

3. Signal-to-Noise Power Ratio

The performance of an optical communication system is usually determined through a consideration of the signal-to-noise power ratio at the output of a photodetector. Expressions for the signal-to-noise power ratio up to this time have been based on very simple and restrictive models for the input optical beam. Such signal-to-noise expressions may be inadequate for

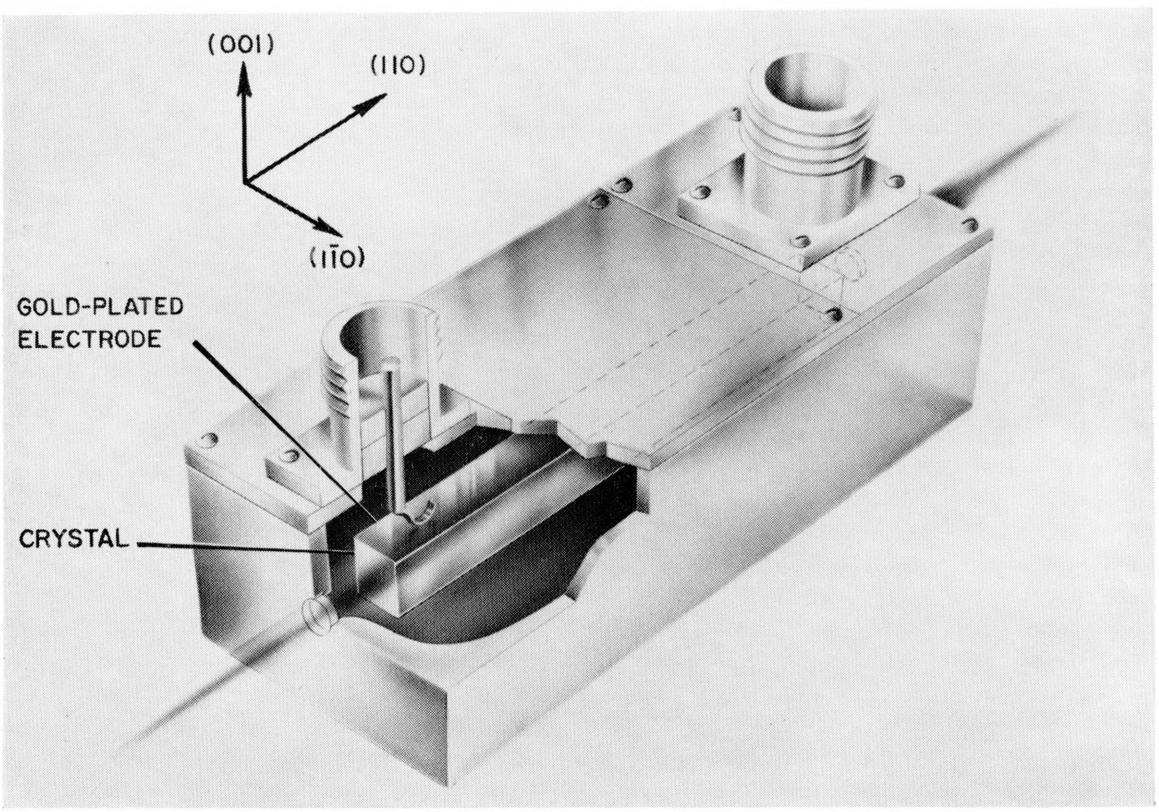

Figure 4—Internal arrangement of transverse-field modulator.

handling the laser beam or, more specifically, the modulated laser beam. A completely general expression for the power density spectrum at the photodetector output has been developed [5] at this laboratory which predicts system performance for any input optical beam characteristics.

The approach leading to the development of the signal-to-noise power ratio expression was to compute the power density spectrum at the output of a photodetector in a completely general fashion. Figure 6 illustrates the various components and mechanisms considered in the derivation. Thermal noise, which appears as an additive term, is not considered in the derivation. This omission does not seriously affect the generality of the power density expression. No

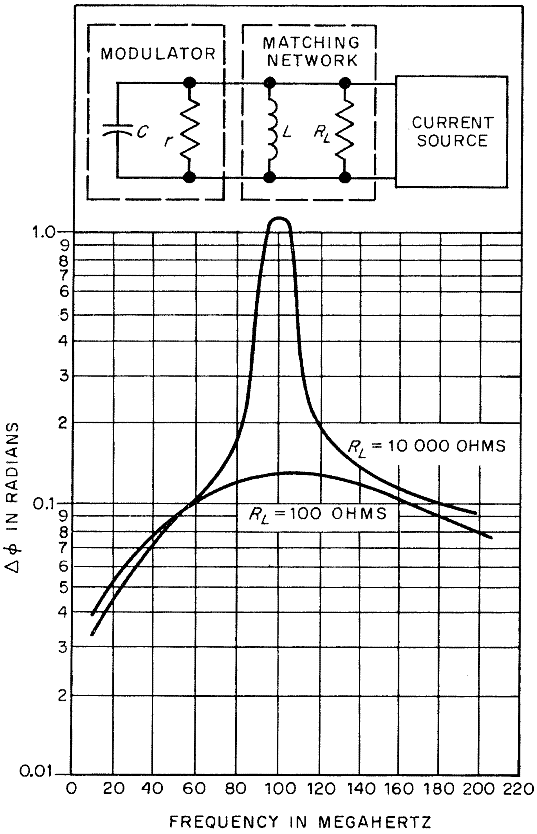

Figure 5—Performance characteristics of transverse-field modulator. $L = 0.12$ microhenry and $P_T = 5$ watts.

restrictions are imposed on the nature of the light source; that is, it may have any beam statistics. The forms of modulation are equally nonrestrictive and may be of the amplitude or angle type, providing the proper demodulation scheme is used. External Gaussian noise inputs shaped by the optical prefilter are considered. The optical prefilter may be a simple narrow-band filter or some more-complex arrangement, such as an interferometric comb filter, described in a later section. The photodetector is considered a square-law device followed by a Poisson mechanism with filtering. The latter filter represents the spectral response of the photodetector or the post-detection electronics. In addition to the effects of optical inputs, the shot noise associated with the direct-current potential or dark current is considered.

The development of this expression utilizes the basic assumption of Poisson statistics for photoemission and considers the noise generation as a result of driving one probabilistic process, which is the shot effect, with another probabilistic process, which is the input optical beam. The power density spectrum of the output of the detector has contributions which may

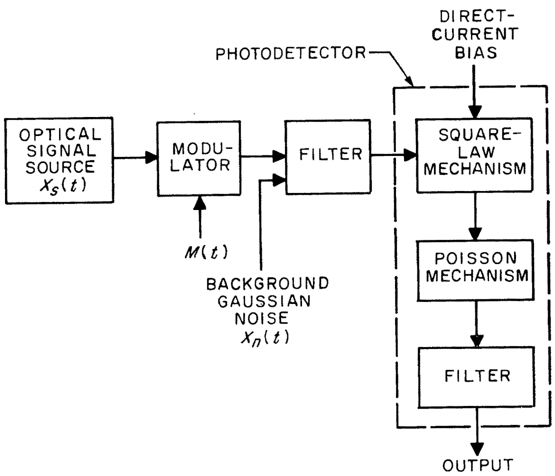

Figure 6—Model for deriving signal-to-noise ratio. The output power density spectrum includes signal × signal, signal × noise, noise × noise, and shot noise caused by optical inputs and direct-current potentials.

be classified as signal cross signal, noise cross noise, signal cross noise, and shot noise.

The scope of this paper does not permit a detailed derivation of the general output power density spectrum. However, the amplitude-modulated case is presented as a specific and useful example. Assuming a signal bandwidth such that spectral shaping by the photodetector response can be neglected, the signal and noise terms can be collected and written in the form of (7).

Signal-to-noise power ratio =

$$\frac{\left(\frac{\eta}{\Delta E}\right)^2 (P_S)^2 \left(\frac{k}{1+\frac{k^2}{2}}\right)^2}{\Delta f \left\{\left(\frac{\eta}{\Delta E}\right)^2 (2\pi) \left(\frac{1}{\Delta \nu}\right) \left[P_N^2 + \tfrac{1}{2} P_S P_N \left(\frac{k^2}{1+\frac{k^2}{2}}\right)\right] + \left(\frac{\eta}{\Delta E}\right)(P_S + P_N) + N_o\right\}} \tag{7}$$

where η = photodetector quantum efficiency
ΔE = energy per photon in the optical bandpass
k = amplitude-modulation index
$\Delta \nu$ = optical prefilter bandwidth in hertz
Δf = electronic post-detection bandwidth
P_S = total power in signal beam on detector
P_N = total power in background on detector
N_o = dark current parameter or average number of photoelectrons per unit time emitted from photocathode.

The noise portion of the equation consists of three distinct terms. The first is the higher-order correlation term which arises from the quadratic detection process and consists of a noise-cross-noise term and a noise-cross-signal term. The second and third terms are shot noise due to the total power in the optical beams and the direct-current potential or dark current, respectively. It is significant to note that the higher-order correlation terms, which in the past have been neglected in predicting optical system performance, become significant under conditions of narrow optical prefilter bandwidth and in the presence of high optical power levels, such as might be experienced in optical heterodyning. As an example, a prefilter bandwidth of 1 angstrom, which is not uncommon in the present state of the art, produces a quadratic noise equivalent in magnitude to the shot noise for a power level of 10^{-7} watt on the photodetector. Although this power level is not generally encountered in practice, the quadratic noise term becomes more significant with narrower optical prefilters. The future use of optical prefilters of less than 1 angstrom bandwidth is feasible through the application of electro-optical networks.

4. Prototype Optical Subcarrier Systems

Three systems are now presented which incorporate the techniques discussed above. These are a ranging system, a space rendezvous system, and a multiplex optical receiver.

4.1 Electro-Optical Direction and Ranging Systems

A natural adjunct to the development of optical subcarrier methods is the combination of narrow optical beams and precision phase measurement techniques. These two complementary techniques have been combined in a concept of EODARS—an acronym for Electro-Optical Direction And Ranging Systems. The breadboard configuration for the ranging section is shown in Figure 7. This system is illustrated by the simplified block diagram in Figure 8. Distance measurement is accomplished through a comparison of the phase of a transmitted radio-frequency subcarrier placed on the optical beam with that same signal returned from a target. The advantage of using continuous-wave subcarrier techniques over pulse operation for ranging is that range measurements can be made to zero distance. Accurate short-range measurements are necessary for such missions as space rendezvous and docking and low-level altimetry.

The prototype is a single-channel system with an unambiguous range of approximately 100 feet (30 meters). A system is under development which is capable of ambiguity resolution over greater distances through the use of multiple channels. The prototype system utilizes digital phase-comparison techniques to achieve relative phase-angle measurements to an accuracy of 1/4000, under conditions of good signal-to-noise ratio. An absolute accuracy of 0.1 inch (2.5 millimeters) has been demonstrated in the single-channel breadboard system over the full range down to zero.

The transmitter portion of the system consists of a gallium arsenide injection source, directly modulated at 5 megahertz, and refractive beam-forming optics which direct the beam onto the target whose range is to be determined. A portion of the light reflected by the target is collected by the receiving lens and is directed by a beamsplitter onto a photomultiplier detector after passing through an optical prefilter and a background limiting field stop. The transmitting and receiving optical systems are made coaxial for use with both diffuse and cooperative targets.

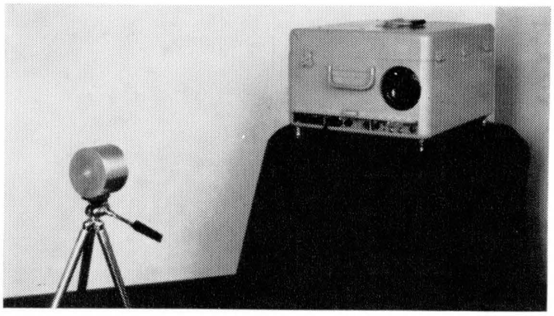

Figure 7—Breadboard arrangement for electro-optical direction and ranging system (EODAR).

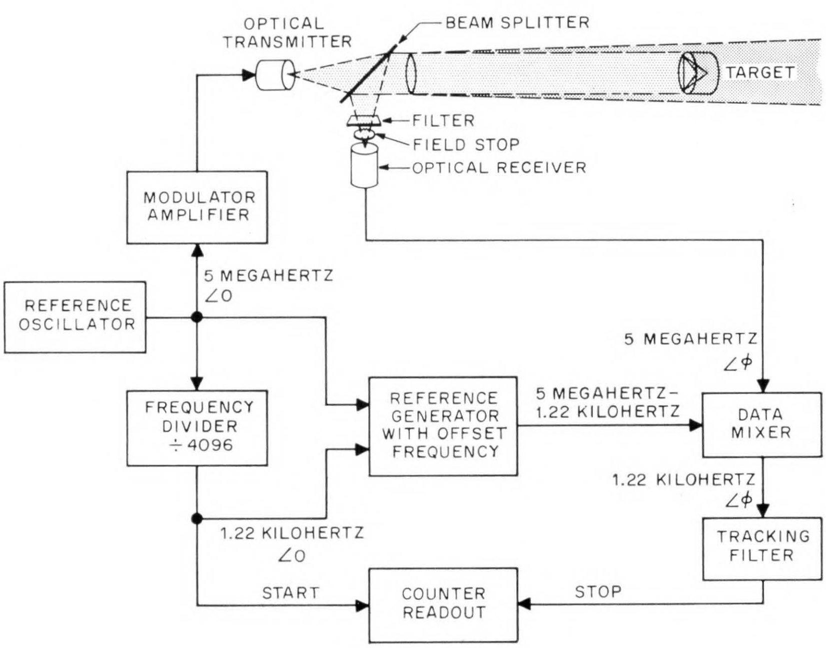

Figure 8—Simplified diagram of electro-optical direction and ranging system (EODAR).

The reference oscillator produces the basic modulation tone of 5 megahertz and establishes the zero phase reference. The amplified 5-megahertz signal directly modulates the optical source. The modulated light traverses the distance between the optical transmitter and the target and then returns to the optical receiver, producing a second 5-megahertz signal with a phase shift which is proportional to the total distance traveled. The purpose of the data mixer is to translate this phase shift of the 5-megahertz signal to a lower frequency, nominally 1.22 kilohertz, to facilitate phase measurement. The second input to the data mixer is a 5-megahertz signal offset phase coherently by 1.22 kilohertz. This signal is generated in the offset reference generator which is a phase-locked loop utilizing two inputs. One of the inputs is the 5-megahertz reference, and the other is a phase coherent 1.22-kilohertz signal. The phase shift between these inputs represents the distance traveled by the light beam which is twice the distance between the target and the receiver. The system readout is a simple counter which is started by the leading edge of the reference signal and stopped by the leading edge of the data signal. The phase angle readout is calibrated to give a direct measure of the distance between a reference on the transceiver and the target. The accuracy of the readout is related to the signal-to-noise ratio according to (8).

$$\sigma = \frac{1}{\pi^2}\left[\frac{1}{2(S/N)}\right]^{1/2} \text{hertz.} \tag{8}$$

Figure 9 shows this relationship for a 1σ accuracy in parts of a hertz for a single-channel system. The experimental performance of the breadboard system was 12 decibels below that initially predicted by the previously described S/N equation. The discrepancy was found to be caused by a lower optical power output from the source than that suggested by the manufacturer. Measurements indicate that the rise times quoted for pulsed operation by diode manufacturers are associated with higher current densities than can be realized in continuous operation and, consequently, do not permit the expected higher-frequency operation. The diode output seems to follow a 6-decibel-per-octave fall-off above 1 megahertz. Making the proper correction for optical efficiency at the source, the analytical and experimental performances are in good agreement, as shown in Figure 10.

In static measurements, the range accuracy can be improved by performing a time integration or an averaging over many cycles of data. By using multiple channels and higher subcarrier frequencies, measurements in range to one part in several million are feasible. These same optical subcarrier digital processing techniques can be used with more-powerful laser sources and more-sophisticated electro-optical "front ends" to achieve high-accuracy measurements over great distances.

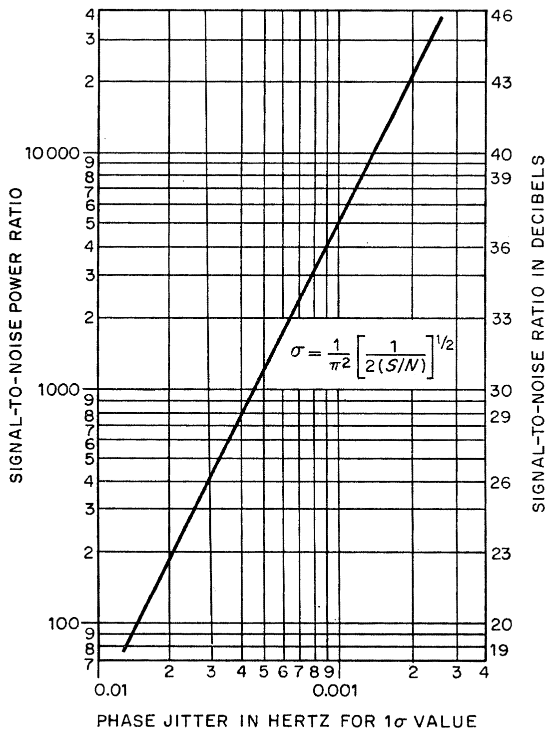

Figure 9—Phase jitter versus signal-to-noise ratio.

4.2 OPTICAL RENDEZVOUS

Some of these optical subcarrier data processing techniques have been employed in the prototype optical rendezvous guidance system shown in Figure 11. This system was developed under the direction of the Marshall Space Flight Center of the National Aeronautics and Space Administration. It measures range, range rate of change, x and y angles, and angle rate of change. It will range and track to 120 kilometers (75 miles) with an accuracy of 0.5 percent for distances exceeding 3 kilometers (2 miles) and within 10 centimeters (4 inches) from 3 kilometers (2 miles) to docking. Angle accuracy is within 10 seconds of arc. Volume is 0.025 cubic meter (1 cubic foot), weight 16 kilograms (35 pounds), and power requirement 15 watts.

Figure 12 is a block diagram of a prototype optical guidance system, including assemblies for both the target vehicle and for the chaser vehicle. The system operates in both an acquisition and a tracking mode.

A wide-angle telescope and sensor on the chaser vehicle detects the relatively wide-beam acquisition light source on the target vehicle. The sensor is a multiplier phototube, which is capable of electronically scanning an acquisition field of view.

When the beacon comes into the acquisition field of the chaser, this system locates the target beacon by means of a raster scan, and acquisition occurs. The sensor automatically switches to the tracking mode and generates angular information to cause the chaser vehicle to align itself with the beacon located on the target vehicle. The long-range laser light source of the chaser vehicle illuminates the target vehicle. This allows the tracking system on the vehicle to acquire the chaser vehicle light source. The target vehicle then aligns itself with the chaser vehicle. In the aligned position, the chaser vehicle tracking system operates with a passive reflector on the target vehicle.

The receiving optics on the chaser vehicle consist of a wide-angle system for acquisition and a narrow-angle long-focal-length system for accurate tracking. The two are coaxial and use the same tracking error sensor to generate the tracking signals.

The long-range system is designed for operation to 120 kilometers (75 miles) and uses a gallium arsenide laser transmitter operated in a pulsed mode. Range is determined by measuring the time for a light pulse to travel from the source to the reflector and return. For short

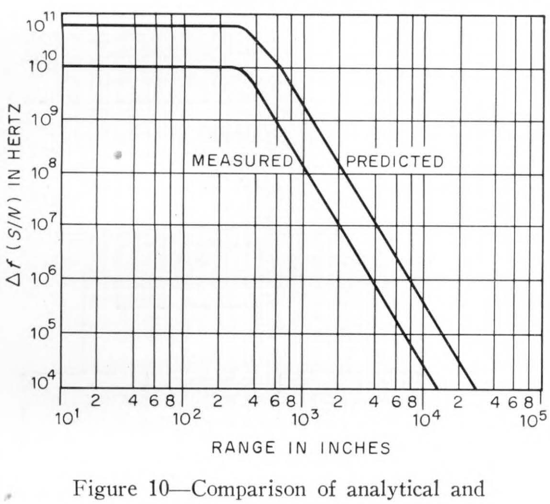

Figure 10—Comparison of analytical and experimental performances.

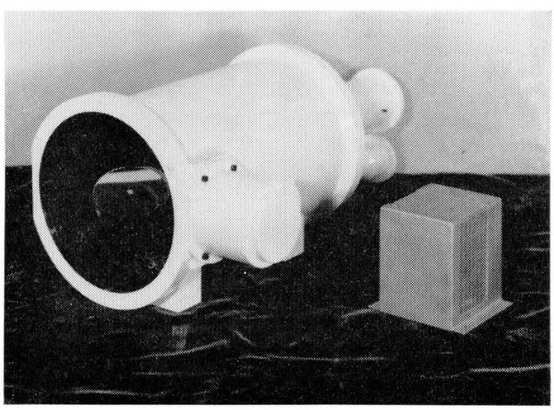

Figure 11—Prototype optical rendezvous guidance system.

ranges, the continuous-wave subcarrier approach is utilized to obtain accurate measurements of range and range rate. This mode begins at 3 kilometers (2 miles) and continues until docking is completed. The range measurements are made by phase comparison between the modulation of the transmitted signal and the modulation received from the retroreflector. The accuracy of this measurement is approximately 10 centimeters.

4.3 Homodyne Receiver

A more-sophisticated approach to optical subcarrier processing is embodied in the optical homodyne system. This system is capable of accomplishing various missions, including voice and television multiplexing and telemetry, electronic phase-locking, and electronic phase comparison through the use of optical frequency mixing and advanced electronic processing techniques.

The optical section of the receiver is a type of time-delayed autocorrelator which is a familiar technique used at radio frequencies for demodulation of phase-modulated signals. The optical autocorrelator is shown schematically in Figure 13 in which an entering optical beam denoted by $x(t)$ is split into two beams. The amplitudes of the optical beam which impinge on the side channel photodetectors are denoted by $x(t)$ and $x(t+\tau)$ for the nondelayed and delayed beams, respectively. A portion of the two side channel beams are combined, giving rise to an input of $x(t)+x(t+\tau)$ to the central photodetector. Photodetection produces an output proportional to the intensities of the input beams yielding an $x(t)^2$ and an $x(t+\tau)^2$ output in the respective side channels and an $x(t)^2 + 2x(t)x(t+\tau) + x(t+\tau)^2$ output in the central channel. The signals from the photodetectors in the side channels are subtracted from the output of the central channel photodetector to remove unwanted correlated contributions in the central channel, leaving only the autocorrelation term. It should be pointed out that the

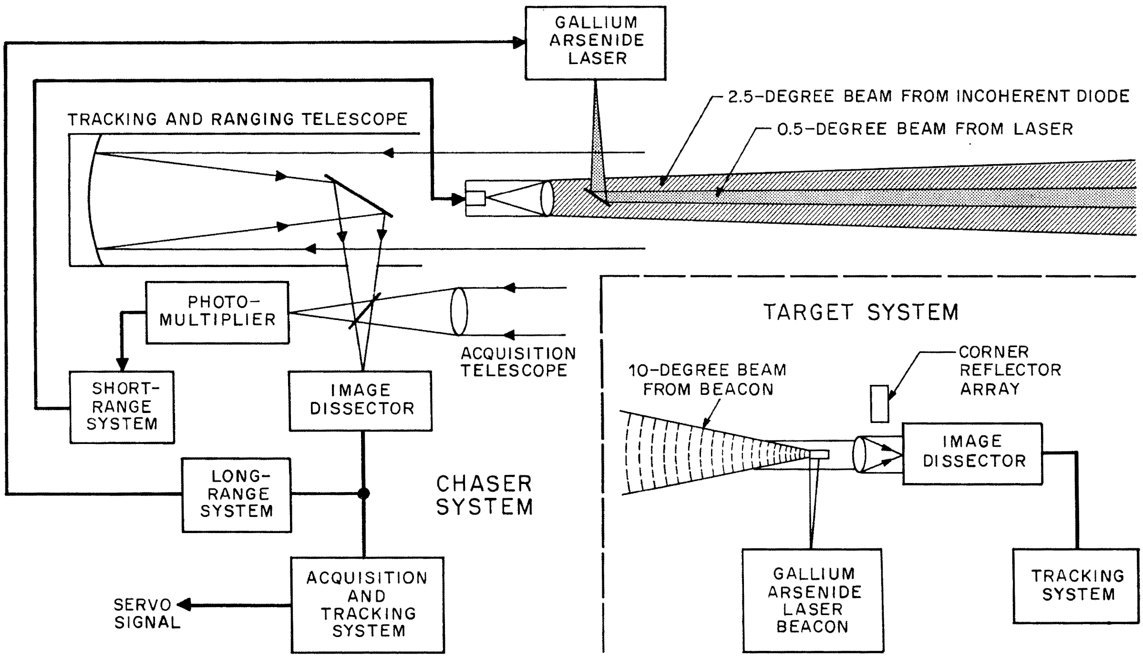

Figure 12—Diagram of rendezvous guidance system.

side channel contributions are significant only when the so-called radio-frequency or quadratic noise predominates. As mentioned earlier, this might be the case under conditions of high total optical power and/or very narrow optical bandwidths. This arrangement of a split beam interferometer with three photodetectors and addition-subtraction circuits is an electro-optical autocorrelator.

It is possible to "mix in" a locally generated subcarrier with the incoming optical beam by the addition of an electro-optical modulator in one arm of the interferometer, as illustrated in Figure 14. The addition of the local modulator may be considered qualitatively as producing a shift in the central-channel interference pattern which is proportional to the phase shift induced in the local modulator by an electric field. This fringe intensity variation is superimposed on the original incoming beam, and is mixed with the incoming beam in the square-law photodetection process. By placing the local electro-optical modulator in one arm of the interferometric arrangement, a phase-to-amplitude conversion for this related modulation is not required. The interferometric time delay may, therefore, be set so as to optimize the phase-to-amplitude conversion of the modulation placed on the beam at the transmitter. In practice, the optical path length difference of the interferometric arrangement should be of the order of one-half wavelength corresponding to the transmitter subcarrier frequency.

It can be shown that the frequency-translated output signal is proportional to the Bessel function product shown in (9).

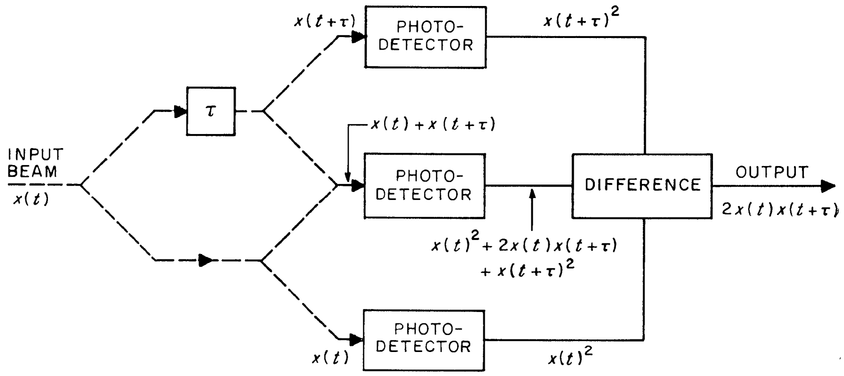

Figure 13—Optical autocorrelator.

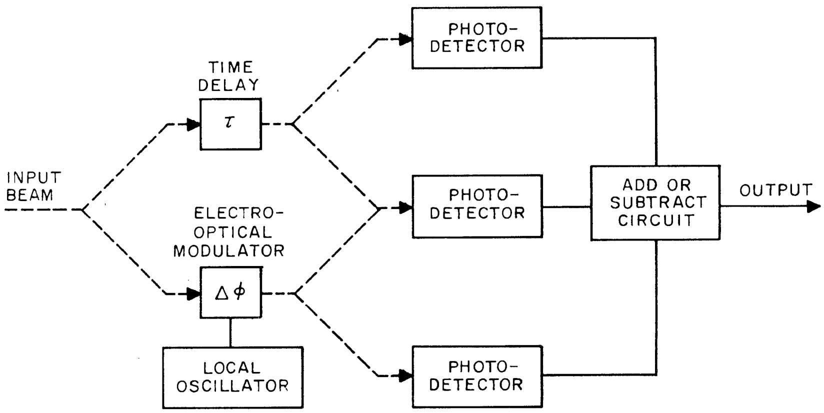

Figure 14—Optical autocorrelator with local modulator.

$$J_1(k_r)^2 J_1\left(2k_t \sin\frac{\nu\tau}{2}\right)^2 \qquad (9)$$

where k_r = modulation index of the local receiver modulator

k_t = modulation index of the transmitter modulator

ν = transmitted subcarrier frequency

τ = interferometric time delay.

This function is optimized for a phase-modulation index corresponding to the first Bessel zone maximum of approximately 1.8 radians.

Figure 15 shows the breadboard electro-optical "front end" with local modulator, as described above. This unit is an optical-frequency mixer-demodulator for phase-modulated light. A breadboard system of this type has been demonstrated in the laboratory by phase-locking to the optical subcarrier difference frequency appearing at the output of the central channel photodetector. In this experiment, a 105-megahertz subcarrier placed on the transmitter beam was

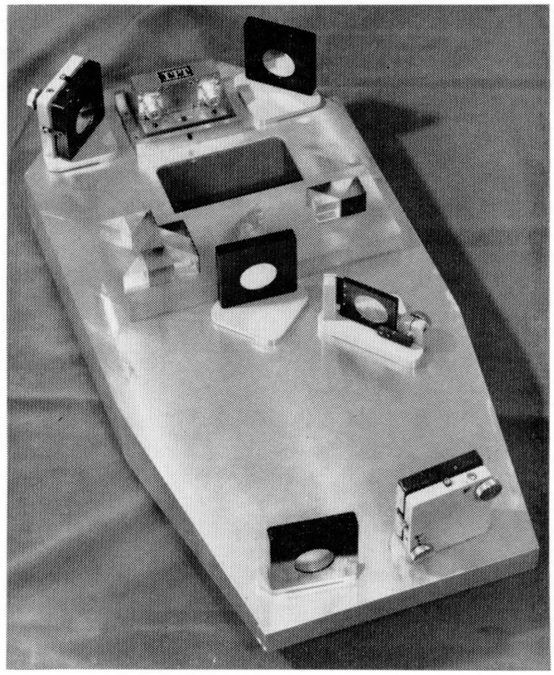

Figure 15—Electro-optical front end.

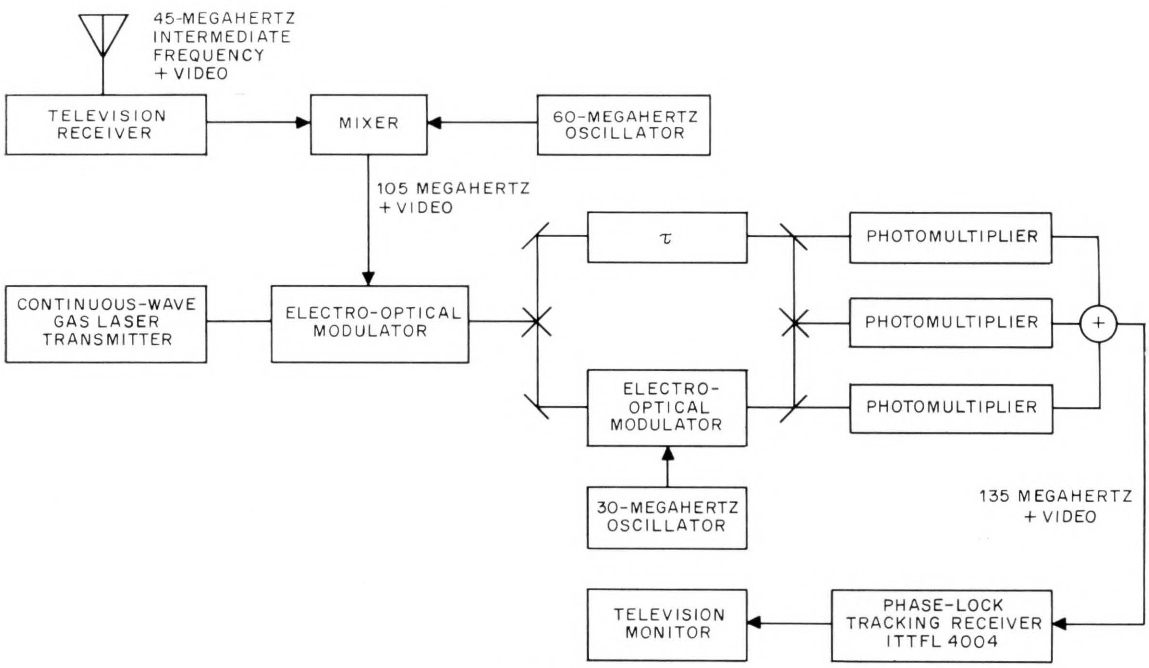

Figure 16—Television experiment.

mixed in the receiver with a 30-megahertz optical subcarrier introduced by the receiver local modulator. The expected mixing components were observed at the central channel output, and the 135-megahertz sum component was phase-locked by means of the *ITTFL 4004* phase-locked tracking receiver.

A video communication experiment is illustrated in Figure 16. In this experiment a gas laser beam is phase modulated with a 105-megahertz subcarrier containing video information. A portion of the modulated transmitter beam is collected by the receiving optics and enters the "front end" interferometer. The local electro-optical phase modulator superimposes a spectrally pure 30-megahertz subcarrier which mixes with the incoming 105-megahertz subcarrier containing the video information. The 135-megahertz sum component at the central channel is inserted into the *ITTFL 4004* phase-locked tracking receiver, which phase-locks to the subcarrier tone and translates the video to a 45-megahertz intermediate frequency for processing and display in a conventional television monitor.

Preparations are in progress for field testing the optical communication link over a 3-mile (5-kilometer) distance between the laboratory and a nearby mountain range.

Figure 17 shows the electro-optical transmitter consisting of a helium-neon laser source, transverse-field phase modulator, and beam-forming telescope. A bore-sighted spotting scope is included to facilitate pointing. The front-end section of the optical receiver is shown mounted on a 24-inch (600-millimeter) diameter collecting aperture in Figure 18.

5. Conclusion

The preceding material has presented some of the basic techniques for optical subcarrier communications, as well as a discussion of three systems utilizing these techniques. The main thought that we would like to leave with you is that the use of subcarriers on an optical beam provides a great measure of versatility. It has advantages for a number of space-oriented missions, including long-range wideband communication, spacecraft tracking and rendezvous, and spacecraft altimetry and landing aids. It also allows the use *today* of well-developed radio-frequency techniques combined with the

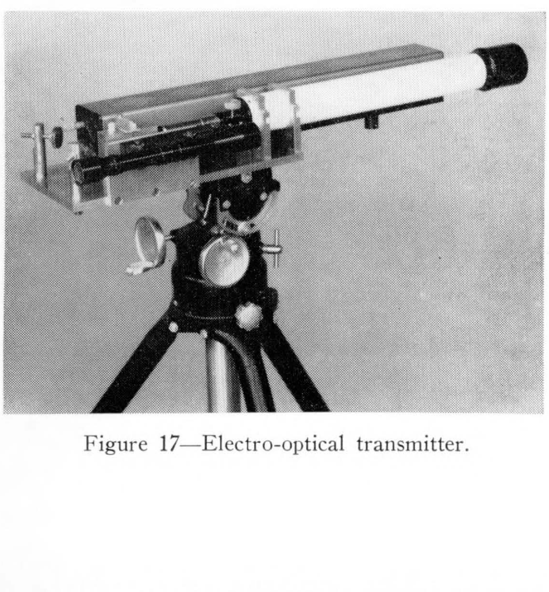

Figure 17—Electro-optical transmitter.

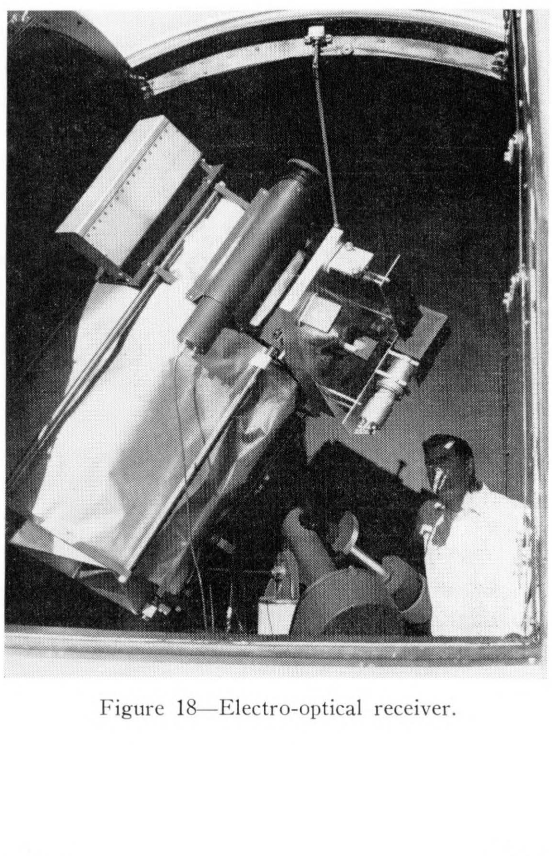

Figure 18—Electro-optical receiver.

advantages of the newer electro-optical technologies.

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Transitions in the Occupation Condition of a Group of Switches

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1. Introduction

For routing calls in a communication network, the trend is now to use what might be called "dynamic" strategies, that is, strategies or policies which take the occupation state of the network into account, in contrast with "static" strategies. For instance, if several paths are available to route a given call from a given point to another one through a communication network, a static strategy gives, for instance by means of routing tables, the order in which the possible paths must be hunted, whereas a dynamic strategy allows choice of an optimal path, for instance that corresponding to the least loaded route.

Knowledge of the occupation state of a group of trunks can be obtained by sampling at regular intervals to determine the number of busy trunks. Another means is to provide each group of trunks with a measuring device which transmits the information about every change of state to a routing control unit. If a change of state is understood to be any change in the exact number of busy trunks, the corresponding information traffic would certainly be prohibitive and moreover useless because exact knowledge of the occupation level is not necessary at all for routing purpose.

An approximate knowledge of the occupation level is certainly sufficient for an efficient routing process. This approximate knowledge can be, for instance, that the number of busy trunks in a group of N trunks is smaller than α or at least equal to β, where β can be equal to α (two disjoint classes) or smaller than α (two overlapping classes). The value of using overlapping classes is evident since this leads to a decrease in the information traffic as will be seen later on. The acquisition of such an approximate knowledge can be implemented by means of a simple measuring device based on a kind of hysteresis effect. The present paper is devoted to the study of the corresponding average transition frequency, that is, the reciprocal of the average time interval between two changes of class.

2. Study of the Transient State

Consider a group of N junctions and let $x(t)$ be the number of junctions busy at time t.

Let two integers X and Y be such that

$$0 < X \leqslant X + Y < N.$$

(Later it will be seen that the equations established are in fact valid for $Y = -1$).

The state of occupancy of the group is entirely characterized by the value of x but two classes for the different possible states of occupancy will be defined as follows (see Figure 1).

Suppose that at a given instant of time t_0, $x(t_0) \leqslant X + Y$ is satisfied; by definition the state of occupation is then said to belong to class 1, at time t_0.

If, for values of t such that

$$t_0 \leqslant t < t_1$$

one always has

$$x(t) \leqslant X + Y$$

then it will be said that in the time interval (t_0, t_1) the state of occupancy has remained in class 1.

If, moreover, $x(t_1) > X + Y$, it will be said that at time t_1 there is a change of class from class 1 to class 2 (in abbreviated form $(1 \rightarrow 2)$ change).

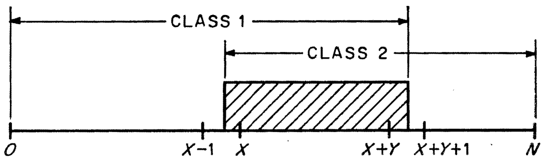

Figure 1—Overlapping classes.

Furthermore, if

$$x(t) \geqslant X \quad \text{for} \quad t_1 \leqslant t < t_2$$

it will be said that, in the time interval (t_1, t_2) the state of occupancy has remained in class 2, and if then $x(t_2) < X$, that there is a change of class from class 2 to class 1, $(2 \rightarrow 1)$ change, and so on.

In other words, if, at time t, x becomes greater than $X + Y$, whereas the earlier state of occupancy belonged to class 1, there will be a $(1 \rightarrow 2)$ change at t; there will be a $(2 \rightarrow 1)$ change at t', if at that instant, x becomes smaller than X, whereas the system was previously in class 2.

The above reasoning started with $x(t_0) \leqslant X + Y$ (class 1) but could also have started with the inequality $x(t_0) \geqslant X$ (class 2). The fact that there is an ambiguity for $X \leqslant x(t_0) \leqslant X + Y$ is of no importance, for the class in which x is at time t_0 can be arbitrarily chosen.

It will be seen, moreover, that the probability that the state of occupancy x be in class 1 or in class 2 when $X \leqslant x \leqslant X + Y$ can be computed for steady-state conditions.

At moments such as t_1, $(1 \rightarrow 2)$ change, the state of occupancy is given by $x(t_1) = X + Y + 1$; it can be said that at the time of a $(1 \rightarrow 2)$ change, the state is almost certainly $X + Y + 1$, since this change can only be due to one or several new calls and since the probability of having two or more calls simultaneously is zero. Likewise, at moments like t_2, $(2 \rightarrow 1)$ change, the number of lines occupied is $X - 1$.

Let us assume that at moment $t = 0$, there is a $(2 \rightarrow 1)$ change; a trial will be made to compute the time during which the system remains in class 1.

Let $P_{X-1}{}^{i}(t)$ be the probability of being in state i at the end of time t, *without having passed through states* $x > X + Y$, knowing that at time $t = 0$, the state was $x = X - 1$. The probability of there being a change of class between t and $t + dt$ (without change of class between 0 and t) will then be given by

$$P_{X-1}{}^{X+Y}(t) \cdot \frac{a}{h}\, dt \cdot \left(1 - \frac{X + Y}{h}\, dt\right)$$

or, neglecting second-order terms, by

$$P_{X-1}{}^{X+Y}(t) \cdot \frac{a}{h}\, dt$$

where a is the traffic offered (in erlangs) and h is the average holding time (in seconds).

The following recurrence relations between the transition probabilities $P_{X-1}{}^{i}(t)$ can now be written

$$\begin{cases} P_{X-1}{}^{X+Y}(t+dt) = P_{X-1}{}^{X+Y}(t)\left[1 - \dfrac{a+X+Y}{h}\, dt\right] + P_{X-1}{}^{X+Y-1}(t)\, \dfrac{adt}{h} \\ \qquad \cdots \\ P_{X-1}{}^{i}(t+dt) = P_{X-1}{}^{i+1}(t)\, \dfrac{i+1}{h}\, dt + P_{X-1}{}^{i}(t)\left[1 - \dfrac{a+i}{h}\, dt\right] + P_{X-1}{}^{i-1}(t)\, \dfrac{adt}{h} \\ \qquad \cdots \\ P_{X-1}{}^{0}(t+dt) = P_{X-1}{}^{1}(t)\, \dfrac{1}{h}\, dt + P_{X-1}{}^{0}(t)\left[1 - \dfrac{a}{h}\, dt\right] \end{cases}$$

where $i = 1, 2, \cdots, X + Y - 1$.

The set of differential equations linking the $P_{X-1}{}^{i}(t)$ is then given by

$$\begin{cases} \dfrac{dP_{X-1}{}^0}{dt} = & -\dfrac{a}{h}P_{X-1}{}^0 & +\dfrac{1}{h}P_{X-1}{}^1 \\ & \cdots & \\ \dfrac{dP_{X-1}{}^i}{dt} = \dfrac{a}{h}P_{X-1}{}^{i-1} & -\dfrac{a+i}{h}P_{X-1}{}^i & +\dfrac{i+1}{h}P_{X-1}{}^{i+1} \\ & \cdots & \\ \dfrac{dP_{X-1}{}^{X+Y}}{dt} = \dfrac{a}{h}P_{X-1}{}^{X+Y-1} & -\dfrac{a+X+Y}{h}P_{X-1}{}^{X+Y} & \end{cases} \tag{1}$$

$i = 1, 2, \cdots, X + Y - 1.$

This set can be written in matricial form

$$\left[\frac{dP}{dt}\right] = \frac{1}{h}[A]\cdot[P] \tag{2}$$

$[P]$and $\left[\dfrac{dP}{dt}\right]$ being two matrices with $X + Y + 1$ rows and one column, the square matrix $[A]$ having $X + Y + 1$ rows and $X + Y + 1$ columns.

2.1 Remarks

(A) The square matrix $[A]$ does not have the usual property of the corresponding operator of the Markov processes, in which the sum of all the elements of any column is zero; in fact, the sum of the terms of the last column is not zero: this is due to the fact that the set of states of class 1 is not a closed set. All the probabilities $P_{x-1}{}^i(t)$ tend toward zero when $t \to \infty$, for the matrix $[A]$ does not have zero as an eigenvalue.

(B) For $[P]$ a column matrix was chosen and not a square matrix for here all the probabilities of transition need not be considered; only the probabilities of passage from state $x - 1$ to state i of class 1 are of interest.

$$[A] = \begin{bmatrix} -a & 1 & 0 & 0 & \cdots & & & & & & \\ a & -(a+1) & 2 & 0 & \cdots & & & & & & \\ 0 & a & -(a+2) & 3 & \cdots & & & & & & \\ & & & \cdots & & & & & & & \\ & & \cdots & 0 & a & -(a+i) & i+1 & 0 & \cdots & & \\ & & \cdots & & & & \cdots & & \cdots & & \\ & & & & & & \cdots & a & -(a+X+Y-2) & X+Y-1 & 0 \\ & & & & & & \cdots & 0 & a & -(a+X+Y-1) & X+Y \\ & & & & & & \cdots & 0 & 0 & a & -(a+X+Y) \end{bmatrix}$$

$$[P] = \begin{bmatrix} P_{X-1}{}^0 \\ P_{X-1}{}^1 \\ \vdots \\ P_{X-1}{}^i \\ \vdots \\ P_{X-1}{}^{X+Y} \end{bmatrix} \qquad \left[\frac{dP}{dt}\right] = \begin{bmatrix} \dfrac{dP_{X-1}{}^0}{dt} \\ \dfrac{dP_{X-1}{}^1}{dt} \\ \vdots \\ \dfrac{dP_{X-1}{}^i}{dt} \\ \vdots \\ \dfrac{dP_{X-1}{}^{X+Y}}{dt} \end{bmatrix}.$$

The formal solution of (2) is given by

$$[P(t)] = e^{[A]t/h}\cdot[P(0)] \tag{3}$$

$[P(0)]$ being the matrix $[P]$ in which all the elements are zero except

$$P_{X-1}{}^{X-1}(0) = 1.$$

Equation (3) can be expanded in series

$$P_{X-1}{}^{X+Y}(t) = [A]_{X+Y}{}^{X-1}\frac{t}{h} + [A]_{X+Y}{}^{(2)X-1} \times \frac{t^2}{2!h^2} + \cdots + [A]_{X+Y}{}^{(n)X-1}\frac{t^n}{n!h^n} + \cdots$$

But if not only very short times t have to be considered, a great number of terms of this expansion becomes necessary to give sufficient precision.

It was shown above that the probability of having a change from class 1 to class 2 is given by

$$P_{X-1}{}^{X+Y}(t)\cdot\frac{a}{h}\,dt.$$

The average time interval τ_{12} between a $(2 \to 1)$ change and a $(1 \to 2)$ change is given by

$$\tau_{12} = \int_0^\infty P_{X-1}{}^{X+Y}(t)\cdot\frac{a}{h}\cdot t\,dt.$$

The time interval τ_{21} between a $(1 \to 2)$ change and a $(2 \to 1)$ change is obtained in the same way.

$$\tau_{21} = \int_0^\infty P_{X+Y+1}{}^{X}(t)\,\frac{X}{h}\cdot t\,dt$$

with

$$P_{X+Y+1}{}^{X}(t) = [e^{[B]t/h}]_X{}^{X+Y+1}$$

and

$$[B] = \begin{bmatrix} -(a+X) & X+1 & 0 & 0 & \cdots & & & \\ a & -(a+X+1) & X+2 & 0 & \cdots & & & \\ & & & & \cdots & & & \\ & & & \cdots & 0 & a & -(a+N-1) & N \\ & & & \cdots & 0 & 0 & a & -N \end{bmatrix}.$$

To solve system (1) directly, the roots of the characteristic equation have to be computed, that is, the eigenvalues of matrix $[A]$.

3. Study of the Steady State: Computation of the Transition Frequency

The previous chapter shows that the transient state study is very complex; in the steady state however the computation of the transition frequency is straightforward.

3.1 Case of Two Disjoint Classes

The transition frequency will, first of all, be computed for the case that the first class includes the states $x \leqslant X - 1$ and the other class the states $x \geqslant X$ (see Figure 2).

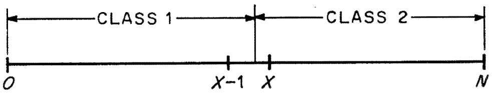

Figure 2—Disjoint classes.

Let ${}_aE_N(x)$ be the probability of being in state x (Erlang's Law)

$${}_aE_N(x) = \frac{a^x}{x!\left(1 + a + \frac{a^2}{2!} + \cdots + \frac{a^N}{N!}\right)}.$$

The probability of having a $(2 \to 1)$ change between time t and time $t + dt$ is given by

$$\frac{X}{h}\cdot{}_aE_N(X)\cdot dt.$$

The probability of a $(1 \to 2)$ change is given by

$$\frac{a}{h}\,{}_aE_N(X-1)dt = \frac{X}{h}\,{}_aE_N(X)dt.$$

As was evident a priori, the frequency of the $(2 \to 1)$ changes is equal to the frequency of the $(1 \to 2)$ changes, that is,

$$\frac{X}{h}\,{}_aE_N(X).$$

The transition frequency will then be given by

$$F_0 = 2\frac{X}{h}\,{}_aE_N(X). \qquad (4)$$

3.2 Case of Two Overlapping Classes

When the number of busy junctions x is smaller than X or larger than $X + Y$ (see Figure 1), there is no ambiguity as to whether the system is in a state belonging to class 1 or class 2. But if x is in the closed interval $(X, X + Y)$, there is a certain probability of being in either one of two classes. Let $\prod_2{}^x$ be the probability of being in state x and in class 2, and $\varpi_2{}^x$ the conditional probability of being in class 2, knowing that one is in state x; then

$$\textstyle\prod_2{}^x = \varpi_2{}^x \cdot {}_aE_N(x) \qquad (5)$$

$(X \leqslant x \leqslant X + Y)$.

The average number of transitions per unit of time leading, in class 2, to state x, is given by

$$\textstyle\prod_2{}^{x-1}\frac{a}{h} + \prod_2{}^{x+1}\frac{x+1}{h}.$$

The average number of transitions per time unit leading from state x, class 2, to nearby states is given by

$$\textstyle\prod_2{}^x\frac{a+x}{h}.$$

Steady-state conditions give

$$\frac{a+x}{h}\textstyle\prod_2{}^x = \frac{a}{h}\prod_2{}^{x-1} + \frac{x+1}{h}\prod_2{}^{x+1} \qquad (6)$$

or, according to (5)

$$\frac{a+x}{h}\,\varpi_2{}^x\cdot{}_aE_N(x) = \frac{a}{h}\,\varpi_2{}^{x-1}\cdot{}_aE_N(x-1) + \frac{x+1}{h}\,\varpi_2{}^{x+1}\cdot{}_aE_N(x+1).$$

By means of the recurrence relations of the Erlang function, this becomes

$$\frac{a+x}{h}\,\varpi_2{}^x\cdot{}_aE_N(x) = \frac{x}{h}\,\varpi_2{}^{x-1}\cdot{}_aE_N(x) + \frac{a}{h}\,\varpi_2{}^{x+1}\cdot{}_aE_N(x)$$

or, finally

$$(a+x)\varpi_2{}^x = x\varpi_2{}^{x-1} + a\varpi_2{}^{x+1}. \qquad (7)$$

The relation (7), valid for $X \leqslant x \leqslant X + Y$, can be written as follows

$$a(\varpi_2{}^{x+1} - \varpi_2{}^x) = x(\varpi_2{}^x - \varpi_2{}^{x-1})$$

or

$$\left\{\begin{aligned} \varpi_2{}^{X-1} &= 0\\ a(\varpi_2{}^{X+1} - \varpi_2{}^X) &= X\varpi_2{}^X\\ a(\varpi_2{}^{X+2} - \varpi_2{}^{X+1}) &= (X+1)(\varpi_2{}^{X+1} - \varpi_2{}^X)\\ &\cdots\\ a(\varpi_2{}^{X+Y} - \varpi_2{}^{X+Y-1}) &= (X+Y-1)(\varpi_2{}^{X+Y-1} - \varpi_2{}^{X+Y-2})\\ a(\varpi_2{}^{X+Y+1} - \varpi_2{}^{X+Y}) &= (X+Y)(\varpi_2{}^{X+Y} - \varpi_2{}^{X+Y-1})\\ \varpi_2{}^{X+Y+1} &= 1. \end{aligned}\right. \qquad (8)$$

If the following symbols are introduced

$$\begin{aligned}\sigma_p &= \varpi_2{}^{X+p} - \varpi_2{}^{X+p-1}\\ \sigma_0 &= \varpi_2{}^X\\ \sigma_{Y+1} &= 1 - \varpi_2{}^{X+Y}\end{aligned}$$

the relations (8) become

$$\begin{cases} a\sigma_1 = X\sigma_0 \\ a\sigma_2 = (X+1)\sigma_1 \\ \cdots \\ a\sigma_p = (X+p-1)\sigma_{p-1} \\ \cdots \\ a\sigma_{Y+1} = (X+Y)\sigma_Y. \end{cases} \tag{9}$$

System (9) is equivalent to the $Y+1$ equations obtained by multiplying the first p equations ($p = 1, 2, \cdots, Y+1$) member by member, or

$$\begin{cases} \sigma_0 = \sigma_0 \\ a\sigma_1 = X\sigma_0 \\ a^2\sigma_2 = X(X+1)\sigma_0 \\ \cdots \\ a^p\sigma_p = X(X+1)\cdots(X+p-1)\sigma_0 \\ \cdots \\ a^{Y+1}\sigma_{Y+1} = X(X+1)\cdots(X+Y)\sigma_0. \end{cases} \tag{10}$$

To find σ_0, notice that $\sum_{p=0}^{Y+1} \sigma_p = \varpi_2^{X+Y+1} = 1$ and add all the equations (10) after having divided them by a^p.

$$1 = \sigma_0 \left[1 + \frac{X}{a} + \frac{X(X+1)}{a^2} + \cdots + \frac{X(X+1)\cdots(X+Y)}{a^{Y+1}} \right].$$

Finally, since $\varpi_2^X = \sigma_0$

$$\varpi_2^X = \frac{1}{1 + \dfrac{X}{a} + \dfrac{X(X+1)}{a^2} + \cdots + \dfrac{(X+Y)!}{(X-1)!a^{Y+1}}}. \tag{11}$$

The frequency of class changes from class 2 to class 1 will be

$$F_{2,1} = \prod{}_2^X \cdot \frac{X}{h} = {}_aE_N(X) \cdot \varpi_2^X \cdot \frac{X}{h}.$$

As the frequency of class changes from class 1 to class 2 is given by $F_{1,2} = F_{2,1}$, the pursued frequency of transition will be given by $F_{Y+1} = F_{1,2} + F_{2,1} = 2F_{2,1}$ (the index $Y+1$ is chosen to recall that there are $Y+1$ junctions common to the two classes).

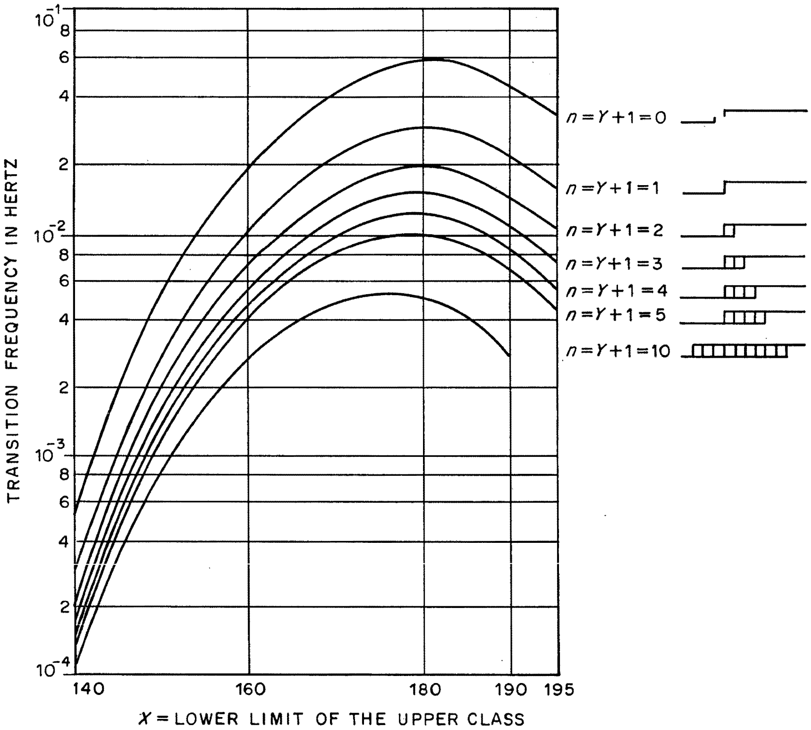

Figure 3—Average transition frequency versus occupation class limits. $N = 200$, $a = 179.74$ erlangs, $B = 0.01$, and $h = 180$ seconds.

$$F_{Y+1} = 2\frac{X}{h} \times \frac{{}_aE_N(X)}{1+\frac{X}{a}+\frac{X(X+1)}{a^2}+\cdots+\frac{(X+Y)!}{(X-1)!a^{Y+1}}}. \quad (12)$$

3.3 REMARKS

(**A**) For $Y + 1 = 0(Y = -1)$, (12) results in (4) for disjoint classes.

(**B**) Not too far from the maximum of $E_X(X \simeq a)$, the denominator of (12) is of the order of $Y + 2$: by putting $n = Y + 1$ junctions common to the two classes, the transition frequency is divided by $n + 1$.

(**C**) The group can be divided into several classes; if there are no lines common to more than two classes, the transition frequency will be the sum of the frequencies computed as above for each group of two classes.

3.4 RESULTS

The frequency given by (12) has been computed for the case of a group of $N = 200$ junctions with a traffic $a = 179.74$ erlangs corresponding to a loss of $B = 0.01$; the results are shown in Figure 3 for several values of $X(X = 140, 160, 180, 190, 195)$ and of $n = Y + 1(n = 0, 1, 2, 3, 4, 5, \cdots, 10)$.

Figure 4 gives the ratio F_0/F_{Y+1}, that is, the gain obtained by dividing the group into overlapping classes.

Figures 5, 6, and 7 give the ratio F_0/F_{Y+1} for groups of 150, 100, and 50 junctions.

4. Conclusion

Formula (12) of the present paper, giving the average transition frequency of the process

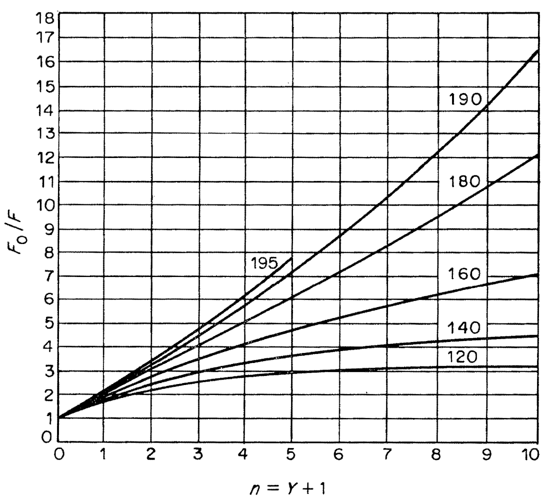

Figure 4—Transition frequency ratio versus class overlapping for values of X indicated on the curves. F = transition frequency, F_0 = transition frequency for $n = 0$ (disjoint classes), $N = 200$, $a = 179.74$ erlangs, $B = 0.01$, and $h = 180$ seconds.

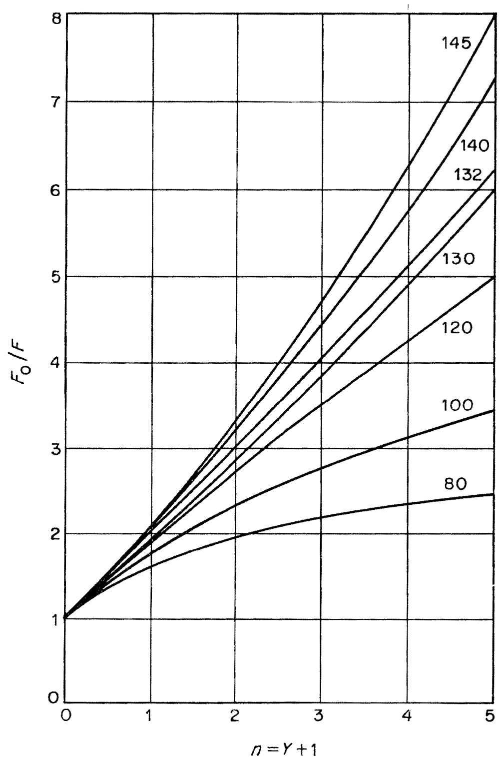

Figure 5—Transition frequency ratio versus class overlapping for values of X indicated on the curves. F = transition frequency, F_0 = transition frequency for $n = 0$ (disjoint classes), $N = 150$, $a = 131.58$ erlangs, $B = 0.01$, and $h = 180$ seconds.

under study, is very easy to calculate by means of a computer because it involves the Erlang formula for the calculation of which a well-known recursive formula can be used.

The interest of overlapping classes is to divide the transition frequency by approximately the overlapping number of trunks, at least in the vicinity of the most probable occupation state. A mathematical generalization of the present study has been published recently [1].

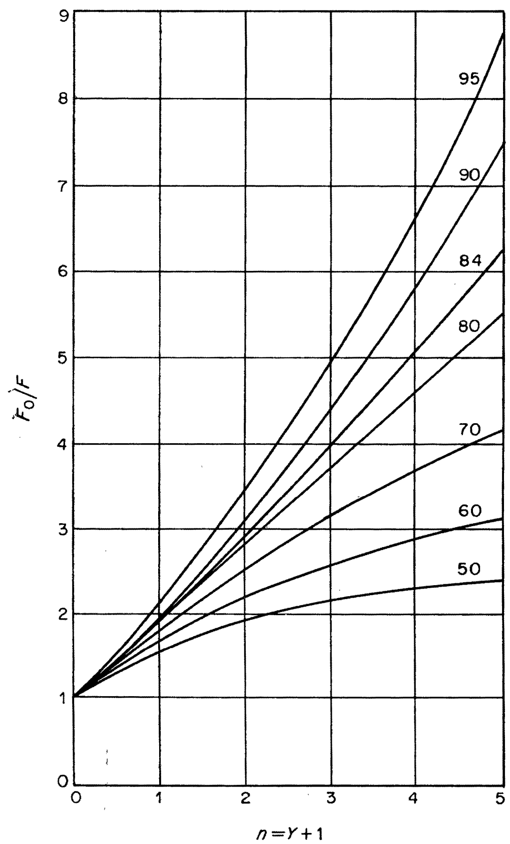

Figure 6—Transition frequency ratio versus class overlapping for values of X indicated on the curves. F = transition frequency, F_0 = transition frequency for $n = 0$ (disjoint classes), $N = 100$, $a = 84.06$ erlangs, $B = 0.01$, and $h = 180$ seconds.

5. Bibliography

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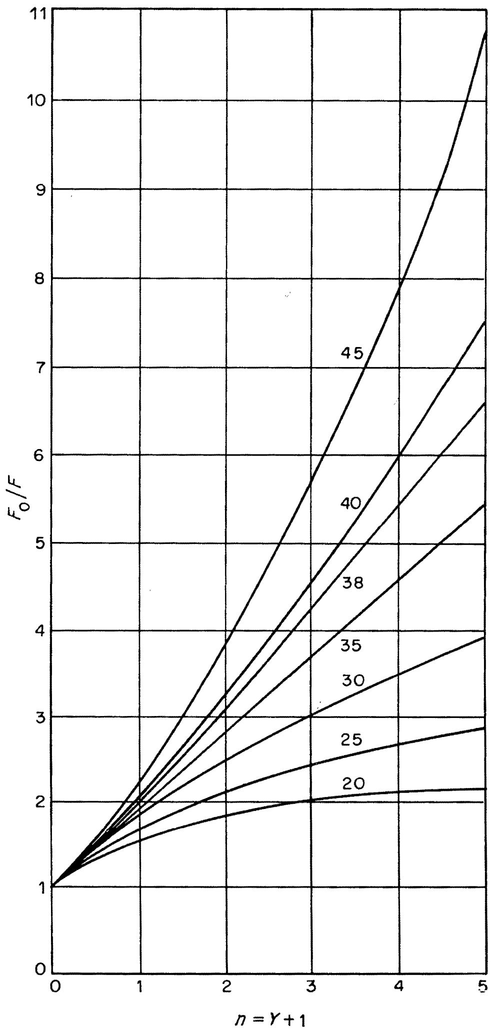

Figure 7—Transition frequency ratio versus class overlapping for values of X indicated on the curves. F = transition frequency, F_0 = transition frequency for $n = 0$ (disjoint classes), $N = 50$, $a = 37.90$ erlangs, $B = 0.01$, and $h = 180$ seconds.

Jacques Déjean was born near Paris on 14 May 1927. "Licencié ès Sciences Physiques" of the Faculty of Sciences of Paris in 1949, he was a member of the electronics laboratory of the same Faculty, where he was concerned with the application of high-power xenon flash tubes.

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After a few years of similar activity in the research laboratories of the Office National d'Études et de Recherches de l'Aéronautique and the Philips Group, he came to Laboratoire Central de Télécommunications in 1960, where he at present supervises a department in charge of studies relating to traffic theory, telecommunication networks organization, and application of simulation methods.

World's Telephones—1966 *

On 1 January 1966, the total number of telephones in the world stood at 195.3 million. This was an increase from a year earlier of 12.8 million, or 7 percent, which is the largest numerical gain ever recorded in a single year. Moreover, the world's 200-millionth telephone is estimated to have gone into service sometime in mid-1966.

As the number of people around the world who can be reached by telephone grows steadily larger, overseas telephone calling increases. There were 8.1 million calls between the United States and overseas points during the year ending 1 January 1966, a total 26 percent greater than for the previous year.

New conveniences and speedier call-handling are important factors in this growth. The telephone user in the United States can now reach 188 million telephones, which is 96 percent of the world's total. Operator dialing, which greatly reduces calling time, is available in many cases, and even faster connections are just over the horizon. For example, in September 1966 the first overseas call dialed directly by a customer was made between the United States and the Virgin Islands. Earlier in the year, customer dialing of calls to Europe was demonstrated, and it was announced that the introduction of direct overseas dialing between points in the United States and Europe would begin in 1970.

Cable capacity has been markedly enlarged in the ten years since the first transatlantic cable was placed along the ocean floor. The 1956 cable had an initial capacity of 36 simultaneous conversations; improved terminal equipment now enables it to carry 48 conversations at one time. Newer types of cables in service across the Atlantic and Pacific are capable of handling as many as 138 conversations at one

* Abridgement from the 1966 issue of a booklet, "The World's Telephones," published yearly by the chief statistician's office of the American Telephone and Telegraph Company, New York, New York.

TABLE 1

TELEPHONES IN CONTINENTAL AREAS—1 JANUARY 1966

Area	Number in Service			Privately Operated (1)		Automatic	
	Number	Percent of World	Per 100 Population	Number	Percent of Total	Number	Percent of Total
North America	100 789 000	51.6	46.9	99 489 000	98.7	100 123 000	99.3
Middle America	1 641 000	0.8	2.1	1 195 000	72.8	1 485 000	90.5
South America	4 232 000	2.2	2.5	2 075 000	49.0	3 741 000	88.4
Europe	61 887 000	31.7	9.8	10 953 000	17.7	55 954 000	90.4
Africa	2 474 000	1.3	0.8	23 000	0.9	1 922 000	77.7
Asia (2)	20 006 000	10.2	1.1	13 321 000	66.6	14 230 000	71.1
Oceania	4 271 000	2.2	23.5	324 000	7.6	3 594 000	84.1
World	195 300 000	100.0	5.9	127 380 000	65.2	181 049 000	92.7

(1) Necessarily the distinction in this classification is with respect to operation rather than ownership. In particular it is to be noted that systems that are government owned in whole or in part may be privately operated, as in Italy and Japan. The word "government" refers to nations, states, or municipalities.

(2) These data include allowances for the Asiatic parts of Turkey and the Union of Soviet Socialist Republics.

time, and future types will handle even more. Current plans call for laying a transistorized cable between the United States mainland and the Virgin Islands capable of handling 720 simultaneous conversations.

Additions to the existing network of underseas telephone cables in 1966 made possible all-cable telephone connections to South America and Southeast Asia. In addition, more than 65 circuits in Comsat's Early Bird satellite were in use for public telephone service between the continental United States and Europe, and plans call for the use of increasing numbers of satellite circuits across both the Atlantic and the Pacific as they become available.

The number of countries having more than one-half million telephones has reached 30. This is 7 more than there were 10 years ago. In the meantime, the number of telephones in the world has nearly doubled. The United States, with 93.7 million, has more than the other 29 countries combined, and has nearly half of the world total. Japan, with 14 million telephones, is second, followed by: the United Kingdom, 10.7 million; West Germany, 8.8 million; the Union of the Soviet Socialist Republics, 7.9 million (estimated); and Canada, 7.5 million.

In terms of telephones per 100 population, the United States is also first, with almost 48 telephones per 100 persons. On this basis, Sweden ranks second among the principal countries with 46 per 100, followed by New Zealand, 38; Switzerland, 37.8; and Canada, 37.7.

During 1965, North America became the first continental area to have more than 100 million telephones, reaching 100 789 000 on 1 January 1966. North America's percentage of the world total, however, dropped to 51.6 from 52.3 a year earlier. Europe and Asia, meanwhile, increased their share of the world's total to 31.7 percent and 10.2 percent, respectively.

The cooperation of telephone administrations and telephone operating companies throughout the world makes this report possible, and grateful acknowledgment is made of their assistance.

TABLE 2

TOTAL NUMBER OF TELEPHONES IN SERVICE AT START OF YEAR INDICATED

Area	1965	1964	1963	1962	1961	1956
North America	95 509 000	90 824 000	87 028 000	83 180 000	79 830 000	60 423 000
Middle America	1 500 000	1 389 000	1 276 000	1 167 000	1 076 000	733 000
South America	4 072 000	3 873 000	3 733 000	3 476 000	3 338 000	2 568 000
Europe	57 418 000	53 378 000	49 735 000	46 377 000	43 173 000	29 990 000
Africa	2 360 000	2 242 000	2 155 000	2 082 000	2 005 000	1 411 000
Asia (1)	17 595 000	15 482 000	13 578 000	11 909 000	10 353 000	4 709 000
Oceania	4 046 000	3 812 000	3 595 000	3 409 000	3 225 000	2 366 000
World	182 500 000	171 000 000	161 100 000	151 600 000	143 000 000	102 200 000

(1) These data include allowance for the Asiatic parts of Turkey and the Union of Soviet Socialist Republics.

TABLE 3

TELEPHONES BY COUNTRIES AS OF 1 JANUARY 1966

Area		Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation (1)	
					Private	Government
NORTH AMERICA						
Canada		7 455 660	37.68	95.6	6 234 400	1 221 260
Greenland		1 120	2.80	100.0	0	1 120
St. Pierre and Miquelon		684	13.68	0.0	0	684
United States	(2)	93 332 000	47.82	99.6	93 255 000	77 000
MIDDLE AMERICA						
Bahama Islands		21 624	15.02	100.0	4 426	17 198
Barbados		15 628	6.35	100.0	15 628	0
Bermuda	(3)	21 623	44.13	100.0	21 623	0
British Honduras		1 525	1.43	86.4	1 312	213
Canal Zone	(3, 4)	9 820	22.94	100.0	0	9 820
Cayman Islands		32	0.36	0.0	0	32
Costa Rica		21 805	1.49	85.7	700	21 105
Cuba*		231 000	2.99	93.0	0	231 000
Dominican Republic		31 290	0.85	97.4	30 840	450
El Salvador		19 882	0.67	78.4	0	19 882
Guadeloupe		7 020	2.19	31.9	0	7 020
Guatemala*		25 000	0.55	93.0	0	25 000
Haiti		4 400	0.09	86.0	0	4 400
Honduras		8 852	0.38	94.0	0	8 852
Jamaica		49 293	2.72	100.0	49 293	0
Leeward Islands:						
Antigua		1 250	2.02	0.0	0	1 250
Montserrat		275	1.96	0.0	0	275
St. Kitts		765	1.28	75.8	0	765
Total		2 290	1.68	25.3	0	2 290
Martinique		11 039	3.39	75.4	0	11 039
México		823 064	1.98	87.4	821 640	1 424
Netherlands Antilles		21 789	10.48	100.0	4 544	17 245
Nicaragua		12 322	0.73	76.1	0	12 322
Panamá		46 446	3.64	98.5	45 751	695
Puerto Rico		203 037	7.64	96.6	188 351	14 686
Trinidad and Tobago		38 880	3.97	92.1	0	38 880
Turks and Caicos Islands		172	2.87	67.4	116	56
Virgin Islands (United Kingdom)		74	0.82	0.0	0	74
Virgin Islands (United States)		8 824	20.05	100.0	8 824	0
Windward Islands:						
Dominica		831	1.26	0.0	0	831
Grenada		1 865	1.98	100.0	1 865	0
St. Lucia		1 032	1.09	65.6	0	1 032
St. Vincent		475	0.55	0.0	0	475
Total		4 203	1.23	60.5	1 865	2 338
SOUTH AMERICA						
Argentina		1 497 841	6.65	89.7	113 377	1 384 464
Bolivia		25 235	0.68	99.6	21 100	4 135
Brazil		1 320 003	1.61	83.0	1 251 363	68 640
Chile		263 183	3.04	84.9	261 183	2 000
Colombia*		443 000	2.41	97.0	9 000	434 000
Ecuador		43 499	0.84	99.1	0	43 499
Falkland Islands and Dependencies*		443	20.14	0.0	0	443
French Guiana		1 592	4.42	0.0	0	1 592
Guyana		10 665	1.63	93.4	0	10 665
Paraguay		13 962	0.68	91.7	0	13 962
Peru		136 882	1.16	87.3	136 882	0
Surinam*		7 500	1.95	98.5	0	7 500
Uruguay		185 249	6.78	84.2	0	185 249
Venezuela		282 558	3.18	97.0	282 558	0

* Estimated.
† Data are not available.
(1) Necessarily the distinction in this classification is with respect to operation rather than ownership. In particular it is to be noted that systems that are government owned in whole or in part may be privately operated, as in Italy and Japan. The word "government" refers to nations, states, or municipalities.
(2) Data for the State of Alaska are included. Data for the State of Hawaii are included under Oceania, rather than here under North America. About two-thirds of the estimated number of governmentally operated telephones are in the State of Alaska.
(3) Data exclude telephone systems of the armed forces.
(4) Data are as of 30 June 1965.
(5) Data for Albania are as of 1 January 1959 and data for China (Mainland) are as of 1 January 1948. Those parts of the telephone system which are shown in the table as privately operated continued under such operation until 1949, when they came under government operation.
(6) Data are as of 31 March 1966.
(7) Data are as of 30 September 1965.

TABLE 3—*Continued*

TELEPHONES BY COUNTRIES AS OF 1 JANUARY 1966

Area		Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation (1)	
					Private	Government
EUROPE						
Albania	(5)	4 813	0.31	50.0	0	4 813
Andorra*		700	6.36	0.0	0	700
Austria		1 008 693	13.87	95.5	0	1 008 693
Belgium		1 564 656	16.47	95.6	0	1 564 656
Bulgaria		279 200	3.39	48.6	0	279 200
Channel Islands:						
Guernsey and Dependencies		16 421	34.86	53.0	0	16 421
Jersey		23 313	36.43	63.7	0	23 313
Total		39 734	35.80	59.3	0	39 734
Czechoslovakia		1 491 621	10.51	88.6	0	1 491 621
Denmark		1 363 988	28.37	70.0	1 207 050	156 938
Finland		835 682	18.06	88.8	591 291	244 391
France		6 116 700	12.44	86.3	0	6 116 700
Germany, East		1 658 817	9.73	99.9	0	1 658 817
Germany, West		8 802 166	14.84	100.0	0	8 802 166
Gibraltar	(3)	4 538	18.91	100.0	0	4 538
Greece		508 262	5.94	95.4	0	508 262
Hungary		566 026	5.57	74.6	0	566 026
Iceland		55 800	28.79	79.7	0	55 800
Ireland		214 820	7.50	73.2	0	214 820
Italy		5 980 702	11.55	97.8	5 980 702	0
Liechtenstein		6 647	35.00	100.0	0	6 647
Luxembourg		79 744	23.95	100.0	0	79 744
Malta	(6)	23 732	7.51	89.7	0	23 732
Monaco		12 293	53.45	100.0	0	12 293
Netherlands		2 382 225	19.25	100.0	0	2 382 225
Norway		907 919	24.29	78.5	31 553	876 366
Poland		1 294 046	4.10	85.6	0	1 294 046
Portugal		550 490	5.99	78.6	378 203	172 287
Rumania*		470 000	2.46	80.0	0	470 000
San Marino		1 503	8.64	100.0	1 503	0
Spain		2 788 432	8.79	79.9	2 762 558	25 874
Sweden		3 572 630	45.96	97.6	0	3 572 630
Switzerland		2 259 077	37.78	100.0	0	2 259 077
Turkey		351 135	1.12	86.8	0	351 135
U.S.S.R.*		7 900 000	3.40	70.0	0	7 900 000
United Kingdom	(6)	10 704 000	19.45	93.5	0	10 704 000
Yugoslavia		414 656	2.11	90.4	0	414 656
AFRICA						
Algeria*		140 000	1.24	70.0	0	140 000
Angola		15 502	0.30	72.4	0	15 502
Ascension Island	(3)	77	7.00	93.5	77	0
Botswana		1 718	0.30	0.0	0	1 718
Burundi		2 259	0.07	93.5	0	2 259
Cameroon*		4 200	0.08	74.0	0	4 200
Cape Verde Islands		569	0.24	95.8	0	569
Central African Republic		2 838	0.21	93.2	0	2 838
Chad		3 257	0.10	100.0	0	3 257
Comoro Islands		339	0.15	0.0	0	339
Congo (Brazzaville)		8 172	0.96	96.8	0	8 172
Congo, Democratic Republic*		20 000	0.13	84.0	0	20 000
Dahomey*		3 500	0.15	86.0	0	3 500
Ethiopia		24 791	0.11	86.4	0	24 791
Gabon*		3 300	0.71	95.0	0	3 300
Gambia		1 189	0.36	94.7	0	1 189
Ghana		34 967	0.45	72.8	0	34 967
Guinea*		6 300	0.18	84.0	0	6 300
Ifni		244	0.46	0.0	0	244
Ivory Coast		17 461	0.45	91.5	0	17 461
Kenya		53 592	0.56	83.4	0	53 592
Lesotho		1 390	0.19	68.0	0	1 390
Liberia*		3 200	0.30	100.0	1 000	2 200
Libya		14 754	0.90	100.0	0	14 754
Madagascar		19 442	0.30	64.6	0	19 442
Malawi		7 432	0.18	88.9	0	7 432
Mali*		4 800	0.10	70.0	0	4 800
Mauritania		900	0.10	66.7	0	900
Mauritius and Dependencies		13 634	1.82	71.5	0	13 634
Morocco		118 390	0.88	83.6	10 831	107 559

TABLE 3—*Continued*

TELEPHONES BY COUNTRIES AS OF 1 JANUARY 1966

Area		Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation (1) Private	Government
Mozambique		19 599	0.28	85.2	0	19 599
Niger		2 399	0.07	87.8	0	2 399
Nigeria		68 748	0.12	76.8	0	68 748
Portuguese Guinea		990	0.19	86.9	0	990
Réunion		9 695	2.40	0.0	0	9 695
Rhodesia		101 228	2.34	90.1	0	101 228
Rwanda*		850	0.03	0.0	0	850
Sahara, Spanish		540	1.13	0.0	0	540
St. Helena		142	2.84	0.0	0	142
São Tomé and Principe		494	0.77	65.8	0	494
Sénégal		25 100	0.71	83.1	0	25 100
Seychelles		347	0.72	100.0	347	0
Sierra Leone		5 800	0.25	80.0	0	5 800
Somalia		3 754	0.15	88.3	426	3 328
Somaliland, French		1 722	1.96	100.0	0	1 722
South Africa	(6)	1 198 421	6.64	74.5	0	1 198 421
South West Africa		24 781	4.28	52.2	0	24 781
Spanish Equatorial Guinea		1 344	0.50	88.5	1 344	0
Spanish North Africa		9 058	5.66	100.0	9 058	0
Sudan		37 019	0.27	83.6	0	37 019
Swaziland		3 218	1.09	58.7	0	3 218
Tanzania		22 554	0.21	75.1	0	22 554
Togo*		3 000	0.18	75.0	0	3 000
Tunisia*		35 000	0.74	57.0	0	35 000
Uganda		19 306	0.25	83.9	0	19 306
United Arab Republic*		330 000	1.11	86.0	0	330 000
Upper Volta*		2 300	0.05	30.0	0	2 300
Zambia		34 658	0.92	98.3	0	34 658
ASIA						
Aden and South Arabia, Protectorate		7 670	0.68	98.3	0	7 670
Afghanistan*		9 000	0.06	72.0	0	9 000
Bahrein		6 911	3.64	100.0	6 911	0
Bhután		0	—	—	—	—
Brunei*		2 000	1.96	92.0	0	2 000
Burma*		24 000	0.10	75.0	0	24 000
Cambodia		4 775	0.08	84.9	0	4 775
Ceylon*		43 000	0.38	98.0	0	43 000
China, Mainland	(5)	244 028	0.05	72.9	94 945	149 083
China Taiwan		166 709	1.32	67.4	0	166 709
Cyprus		28 105	4.70	99.4	0	28 105
Hong Kong		261 475	6.84	100.0	261 475	0
India	(6)	881 407	0.18	66.8	3 326	878 081
Indonesia*		215 000	0.20	20.0	0	215 000
Iran		207 530	0.88	81.7	0	207 530
Iraq*	(6)	65 000	0.89	80.0	0	65 000
Israel		255 780	9.84	100.0	0	255 780
Japan	(6)	13 998 831	14.18	69.8	13 250 913	747 918
Jordan*		26 000	1.29	70.0	0	26 000
Korea, North†		—	—	—	—	—
Korea, Republic of		274 380	0.96	70.0	0	274 380
Kuwait		26 041	5.56	100.0	0	26 041
Laos		1 025	0.05	76.0	0	1 025
Lebanon*		105 000	4.43	90.0	0	105 000
Macao		2 810	1.60	100.0	0	2 810
Malaysia:						
Malaya		116 053	1.42	87.9	0	116 053
Sabah		7 278	1.34	100.0	0	7 278
Sarawak		8 337	0.98	90.8	0	8 337
Total		131 668	1.38	88.7	0	131 668
Maldive Islands		0	—	—	—	—
Mongolia		13 527	1.24	79.3	0	13 527
Muscat and Oman		395	0.07	100.0	395	0
Nepál		3 000	0.03	90.0	0	3 000
Pakistan		137 311	0.13	74.7	0	137 311
Philippine Republic		164 850	0.50	82.7	148 478	16 372
Portuguese Timor		579	0.10	0.0	0	579
Qatar		5 418	7.22	100.0	5 418	0
Ryukyu Islands	(3)	31 332	3.32	83.8	0	31 332
Saudi Arabia*	(4)	28 000	0.41	40.0	0	28 000

TABLE 3—*Continued*

TELEPHONES BY COUNTRIES AS OF 1 JANUARY 1966

Area		Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation (1)	
					Private	Government
Sikkim*		250	0.14	0.0	0	250
Singapore		86 869	4.60	100.0	0	86 869
Syria		78 022	1.38	92.0	0	78 022
Thailand	(7)	77 733	0.25	91.6	0	77 733
Trucial Oman		2 013	1.48	100.0	2 013	0
Viet-Nam, North†		—	—	—	—	—
Viet-Nam, Republic of		23 160	0.14	82.9	0	23 160
West Irian*		3 000	0.38	14.0	0	3 000
Yemen*		1 200	0.02	100.0	0	1 200
OCEANIA						
Australia	(4)	2 810 833	24.75	83.5	0	2 810 833
British Solomon Islands		649	0.48	98.6	0	649
Canton Island		60	18.75	100.0	0	60
Caroline Islands		750	1.27	0.0	0	750
Christmas Island	(4)	127	3.85	100.0	127	0
Cocos (Keeling) Islands		63	6.30	100.0	0	63
Cook Islands		454	2.16	0.0	0	454
Fiji Islands		11 298	2.40	60.9	0	11 298
Gilbert and Ellice Islands		0	—	—	—	—
Guam		17 280	20.33	98.6	0	17 280
Mariana Islands (less Guam)		400	4.00	100.0	0	400
Marshall Islands		1 230	5.86	97.6	0	1 230
Midway Island		1 230	41.00	98.2	0	1 230
Nauru		0	—	—	—	—
New Caledonia		4 745	5.16	78.6	0	4 745
New Hebrides Condominium*		600	0.87	100.0	0	600
New Zealand	(6)	1 025 084	38.38	81.6	0	1 025 084
Niue Island		129	2.58	0.0	0	129
Norfolk Island		62	6.20	0.0	0	62
Papua and New Guinea		10 570	0.49	79.7	0	10 570
Pitcairn Island		0	—	—	—	—
Polynesia, French		4 134	4.59	0.0	0	4 134
Samoa, American*		700	3.04	100.0	0	700
Samoa, Western		1 556	1.23	0.0	0	1 556
Tokelau Islands		0	—	—	—	—
Tonga (Friendly) Islands		716	0.98	0.0	0	716
United States: Hawaii		323 522	45.31	100.0	323 522	0
Wake Island*		210	14.00	100.0	0	210

TABLE 4

TELEPHONE CONVERSATIONS DURING 1965

Area		Thousands of Conversations			Average Conversations per Person
		Local	Long Distance	Total	
Angola		22 383	761	23 144	4.5
Argentina		4 132 028	56 805	4 188 833	187.4
Australia	(1)	2 043 000	106 300	2 149 300	191.1
Bahama Islands		42 795	326	43 121	303.7
Barbados, West Indies		34 000	29	34 029	138.9
Belgium		811 623	197 229	1 008 852	106.6
Bermuda		17 079	116	17 195	358.2
Brazil		6 829 900	110 100	6 940 000	85.4
Cambodia		6 486	604	7 090	1.1
Canada		12 159 000	301 614	12 460 614	635.6
Chad		2 839	38 (2)	2 877	0.9
Channel Islands		21 597	1 313	22 910	206.4
Chile		679 362	23 289	702 651	82.0
China, Taiwan		568 165	19 465	587 630	47.3
Congo (Brazzaville)		6 055	533	6 588	7.8
Costa Rica		50 707	1 365	52 072	36.3
Cyprus		30 336	2 907	33 243	56.0

(1) Data are for the year ended 30 June 1965.
(2) 3-minute units.
(3) Data are for the year ended 31 March 1965.
(4) Data are for the year ended 30 June 1966.
(5) Data are for the year ended 30 September 1965.

TABLE 4—*Continued*

TELEPHONE CONVERSATIONS DURING 1965

Area		Thousands of Conversations			Average Conversations per Person
		Local	Long Distance	Total	
Czechoslovakia		932 384	121 848	1 054 232	74.5
Denmark		1 324 009	362 985	1 686 994	354.6
Ethiopia		32 166	1 760	33 926	1.5
Fiji Islands		11 700	1 220	12 920	27.8
France		1 586 000	849 500	2 435 500	49.8
Germany, East		834 082	253 425	1 087 507	63.9
Germany, West		4 497 750	1 833 440	6 331 190	107.2
Ghana		28 231	2 498	30 729	4.0
Gibraltar		7 254	75	7 329	293.2
Greece		1 043 595	31 857	1 075 452	125.9
Guadeloupe		4 375	485	4 860	15.4
Guyana		8 935	1 104	10 039	15.5
Hungary		523 285	29 652	552 937	54.5
Iceland		103 140	4 828	107 968	565.3
Ireland		192 570	22 860	215 430	75.5
Italy		6 701 064	802 847	7 503 911	145.5
Ivory Coast		18 380	827	19 207	5.0
Jamaica, West Indies		79 800	1 236	81 036	45.7
Japan	(3)	29 080 033	1 753 586	30 833 619	313.9
Korea, Republic of		1 487 848	29 444	1 517 292	53.5
Libya		27 829	760	28 589	17.7
Liechtenstein		2 378	2 574 (2)	4 952	275.1
Madagascar		15 443	823	16 266	2.5
México		1 774 593	32 006	1 806 599	44.2
Morocco		152 567	9 258	161 825	12.1
Mozambique		28 701	2 064	30 765	4.4
Netherlands		1 311 425	725 343	2 036 768	165.7
Netherlands Antilles		33 324	43	33 367	160.4
New Caledonia		2 735	242	2 977	32.7
Nicaragua		34 369	895	35 264	21.3
Nigeria		105 460	4 366	109 826	1.9
Norway		602 913	74 228	677 141	181.9
Papua and New Guinea		7 343	245	7 588	3.5
Peru		485 814	9 988	495 802	42.6
Philippine Republic		1 276 160	1 416	1 277 576	39.5
Polynesia, French		2 400	137	2 537	28.5
Portugal		543 665	72 156	615 821	67.2
Puerto Rico		375 639	8 580	384 219	145.9
Réunion		4 465	422	4 887	12.3
Ryukyu Islands		88 349	2 335	90 684	96.1
Sénégal		15 200	860	16 060	4.6
Singapore		265 357	1 473	266 830	143.1
Somalia		2 949	80	3 029	1.2
South Africa	(3)	1 655 769	106 388	1 762 157	98.1
South West Africa		18 063	3 268	21 331	37.2
Swaziland		1 423	914	2 337	8.0
Sweden	(4)	3 633 000	575 563	4 208 563	541.4
Switzerland		812 872	882 307 (2)	1 695 179	285.1
Syria		109 814	3 093	112 907	20.3
Thailand	(5)	141 737	858	142 595	4.7
Trinidad and Tobago, West Indies		89 726	12 438	102 164	104.8
Turkey		329 885	21 565	351 450	11.3
United Kingdom (3)		6 107 000	849 000	6 956 000	127.1
United States		115 876 000	4 734 000	120 610 000	620.0
Uruguay		423 158	8 357	431 515	158.9
Viet-Nam, Republic of		30 730	416	31 146	1.9
Virgin Islands (United States)		24 761	220	24 981	581.0

Soviet Minister Sergueitchuk Visits Standard Elektrik Lorenz—A delegation of experts led by K. Sergueitchuk, First Vice-Minister of the Soviet Post, Telegraph, and Telephone Administration, visited Standard Elektrik Lorenz during its stay in the Federal Republic of Germany from 24 August to 8 September 1966. Some members of the delegation are shown in Figure 1.

Primarily interested in post office automation, they inspected installations in Cologne, Hamburg, and Wiesbaden, as well as the postal check handling system in Nuremberg. At Stuttgart, they visited the cable plant and the quasi-electronic telephone switching center in Stuttgart-Blumenstrasse.

Standard Elektrik Lorenz
Germany

Satellite Earth Terminal in Grand Canary Island—Telephone tests have been made from the newest satellite earth terminal on Grand Canary Island via the newest commercial communication satellite, Intelsat 2, to the earth station of the Communications Satellite Corporation at Andover, Maine, and to Ascension

Figure 1—Soviet delegation visits Standard Elektrik Lorenz. From left to right are: Messrs Zabotin, Head of the Engineering and Designing Department of the Soviet Telecommunications Administration; Gille, Director of Standard Elektrik Lorenz; Abtmeyer, General Manager at Standard Elektrik Lorenz; Lamm, chief engineer in the Soviet Telecommunications Administration; Ponomarjew (interpreter); and Minister Sergueitchuk.

Island also. These are, respectively, 3500 and 3000 miles (5600 and 4800 kilometers) away over the surface of the earth.

Built for Compañia Telefónica Nacional de España, the new earth station is near an existing spacecraft tracking station of the United States National Aeronautics and Space Administration to which it will be available for use in the Apollo man-on-the-moon program. The station uses two automatic-tracking antennas that are 42 feet (12.8 meters) in diameter, ultra-low-noise receivers, and high-power transmitters.

ITT Federal Laboratories
United States of America

Nationwide Dialing Nearly Complete for Vienna—In October 1966 a new crossbar telephone exchange in Vienna-Treustrasse was cut over. (See Figure 2.) Among other services, the new crossbar switching equipment provides direct distance dialing to Austria, Germany, Switzerland, and Liechtenstein by the 9100 connected subscribers.

This is the seventh new crossbar exchange in Austria, which for the past ten years has been modernizing its telephone system with crossbar switching equipment.

Standard Telephon und Telegraphen
Austria

European Mediterranean Tropo Network—The United States Air Force has accepted the last five sites that complete the European Mediterranean Tropo (EMT) section of the Mediterranean Communications Network (Medcom).

Figure 2—Dr. Machold, President of Austrian Telecommunications Administration—Lower Austria; F. W. Mayer, Managing Director of Standard Telephon und Telegraphen; and E. Klose at the inauguration of the new crossbar telephone central office in Vienna-Treustrasse.

The newly completed European Mediterranean Tropo system comprises 23 sites in Spain, Italy, Greece, and Turkey. Voice, teleprinter, facsimile, and digital data are handled over 2.7-gigahertz tropospheric-scatter and 8-gigahertz line-of-sight transmission links. It is designed to be 99.9 percent reliable despite equipment breakdown, radio disturbances, and human errors.

The Mediterranean Communications Network uses 99 sites to cover a route of 2700 miles (4300 kilometers) and has a potential of about 300 000 circuit miles (480 000 circuit kilometers). It links the Spain–United Kingdom Tropo System running from England to Morocco with the German–United States Armed Services Network (USAFE) at Livorno, Italy, and with the United States Air Force–Turkey Tropo System.

The following services were provided for the European Mediterranean Tropo system: program management; engineering; preparation of equipment specifications; procurement and installation of equipment including operational and depot spare parts; installation, checkout, and alignment of all electronic equipment; documentation of all operations; and final testing for acceptance by the Air Force.

Federal Electric Corporation
United States of America

Tellurium Deposition for Recording—The high-speed teleprinter system *Lo 2000* uses a printing principle in which a paper surface in contact with a tellurium plate is inked by tellurium electrolytically transported at points where an electric current flows through the wetted paper. Inexpensive normal teleprinter paper may be used and the instantaneous printing does not need processing or stabilization.

This technique offers the possibility of recording a large amount of binary information at one time by replacing the printing heads of the printer by a stationary comb of many printing needles lightly pressed against the paper.

One such application is in the testing of thick metal plates by ultrasonics. The plates move continuously through the test equipment in which one or more lines of ultrasonic heads are mounted. The tellurium printer uses a set of printing needles arranged in the same pattern as the ultrasonic heads. The electrical signals generated by the ultrasonic heads indicate laminations and cavities; they are fed to the printing needles after having passed through an electrical threshold network. The result is a scaled-down diagram of the tested plate with all defects localized. Special print needles at both edges of the paper produce scales to facilitate the plotting of the recording.

This kind of equipment has been approved by rolling mills. Many other applications include the recording of data relating to traffic and seismic research.

Standard Elektrik Lorenz
Germany

Automatic Manufacture of Wire Springs for Relays—A new multipurpose machine has been designed, developed, and put into operation for all of the mechanical operations involved in the manufacture of the wire springs for twin relays that are to be carried out after the "moulding-in" and before the "contact-welding" operations.

The spring nests pass through the machine on a guide-block for the following operations: wire-ends are "contact-shaped," terminals are cut to length, terminals are twisted in 1st step at 6 positions and in 2nd step at 4 positions, twisted terminals are flattened, and the appropriate shape is given to the terminals after which they are cut to the required length.

Operations are performed by hydro-pneumatic presses having capacities of 2.4, 9.6, and 22.5 tons. The production speed is 14 units/minute.

The machine is protected against any deterioration due to badly shaped pieces by both electrical and pneumatic devices.

Bell Telephone Manufacturing Company
Belgium

Standard Telecommunication Laboratories Increases Plant—During 1964, when an article describing Standard Telecommunication Laboratories* was written, a third laboratory wing had been added to the original two, and now a fourth wing has been completed, which is to be seen in Figure 3. In this aerial view, the four laboratory wings stretch towards the left from the office block and restaurant; at the right top corner is the garage, a 2-megavolt Van de Graaff electron accelerator, and the physico-chemical laboratory.

Standard Telecommunication Laboratories
United Kingdom

*J. K. Webb, "Standard Telecommunication Laboratories," *Electrical Communication*, volume 40, number 1, pages 109–123; 1965.

New Factories in Belgium—During October 1966 three new plants were the object of official ceremonies attended by important personalities, among whom were Willy de Clercq, Vice Prime Minister of Belgium; Henri Maisse, Minister and Secretary of State of the Belgian telecommunications administration; and Ridgway B. Knight, United States Ambassador to Belgium.

The new 20 000-square-meter (215 000-square-foot) Frigibell refrigerator factory in Geel houses 350 employees and has a production capacity of 50 000 deep-freeze chests per year. This plant shown in Figure 4 will soon be extended by some 3500 square meters (38 000 square feet) to house the activities of the radio and television department.

Construction was started on a second plant in Geel that will cover 50 000 square meters

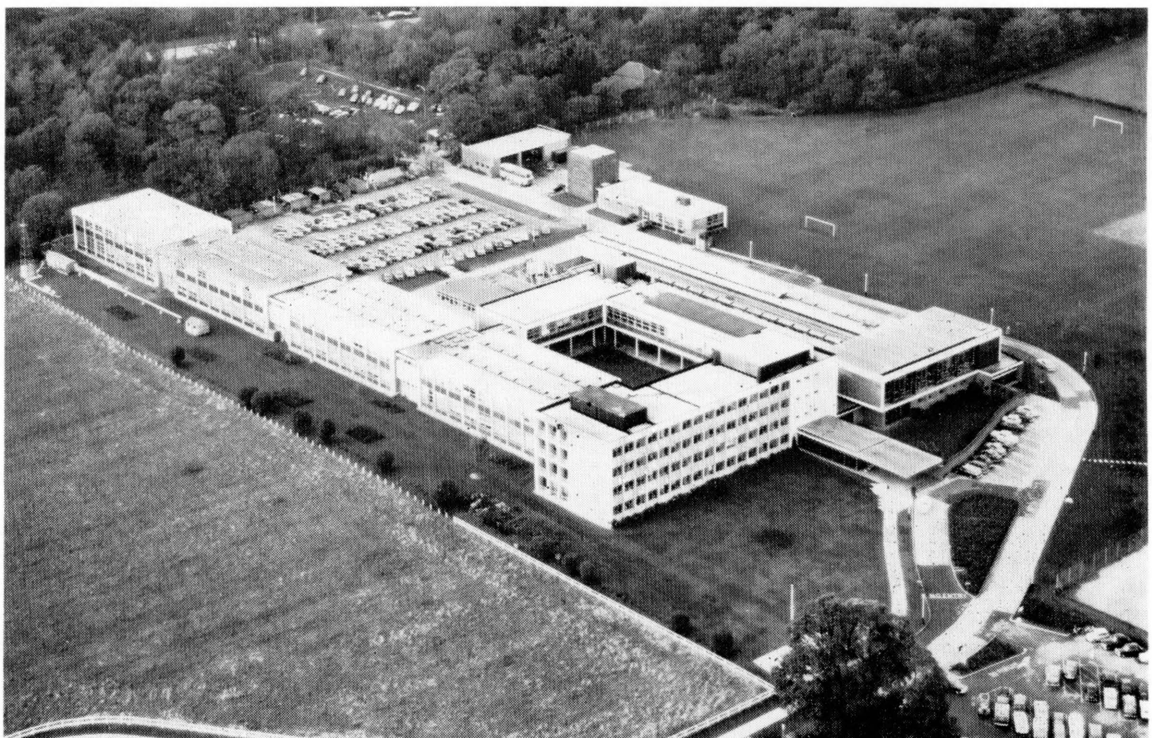

Figure 3—Aerial view of Standard Telecommunication Laboratories in Harlow, Essex, England.

(540 000 square feet) and employ 3000 workers by the end of 1969. Rotary and Pentaconta switching equipment manufacturing operations will be linked with those of the main factory, established in Antwerp in 1882.

In Wasmes, construction was commenced on an industrial products plant that will produce telephone sets and signaling equipment.

Bell Telephone Manufacturing Company
Belgium

Components for Hobbyists—A new division, Electroniques, has been formed to supply components and equipment through the United Kingdom retail trade to radio and electronics enthusiasts. The range of equipment includes test sets, modules, tools, and components—11 000 items in all—produced by over 80 British and overseas manufacturers. A 608-page reference book called "Hobbies Manual of Suppliers and Ideas" is on general sale to assist the hobbyist. It includes details of components and circuits and shows how to obtain the best performance.

Standard Telephones and Cables
United Kingdom

Grosscitomat Crossbar Exchanges to Finland and Mexico—Kansallis Osaki Pankki, the largest Finnish banking institute, in Helsinki, has placed an order for a Grosscitomat crossbar telephone exchange to replace an existing installation. The new switching equipment has a capacity of 150 exchange lines and 1200 extensions.

A hotel version of the Grosscitomat private automatic branch exchange for 60 trunk lines and 450 extensions will be installed in one of the modern hotels now being built in Mexico City to accommodate visitors to the 1968 Olympic Games.

Standard Elektrik Lorenz
Germany

Pentaconta Crossbar Equipment for Zambia—An order has been received for Pentaconta crossbar equipment to be installed at four main trunk switching centers in Lusaka, Kitwe, Livingstone, and Ndola with interfacing equipment at ten other exchanges in various parts of Zambia. The equipment will provide Zambia with a modern subscriber trunk dialing system.

Standard Telephones and Cables
United Kingdom

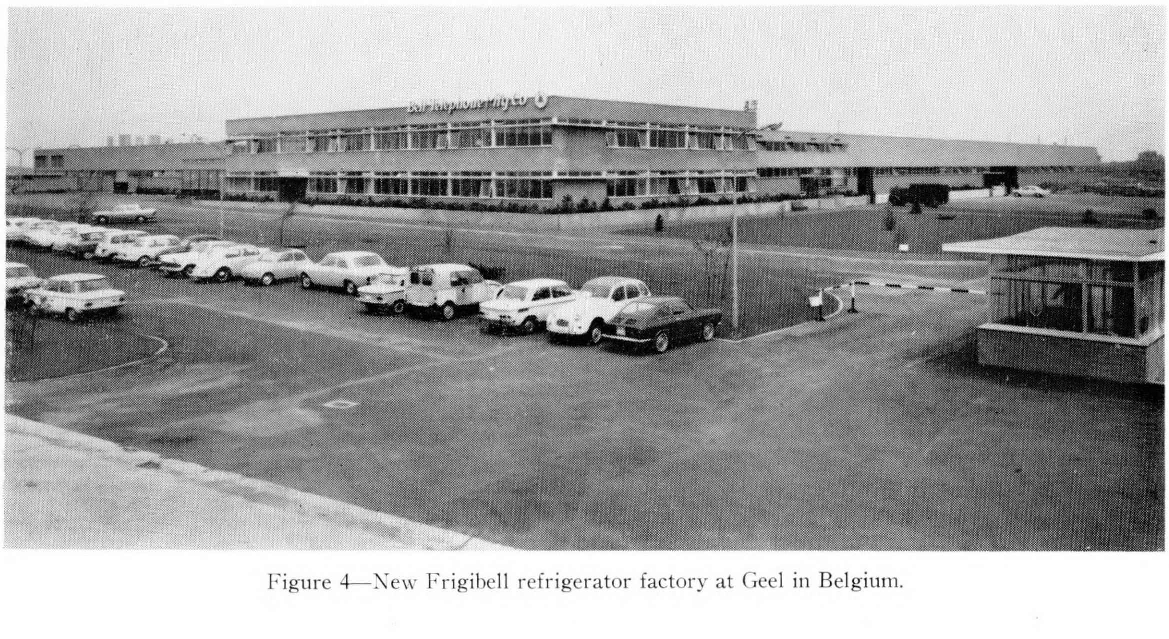

Figure 4—New Frigibell refrigerator factory at Geel in Belgium.

Artemis Electronic Exchange Completed—The Artemis exchange, shown in Figure 5, utilizes reed-contact switches and a stored-program centralized control. It has a capacity of 2000 lines and is now equipped for 800 subscribers.

It will be used as a private automatic exchange at the main factory of Le Matériel Téléphonique near Paris but, to study its interconnection with rotary and Pentaconta exchanges, it has been integrated into the Paris public network in the sense that it will operate as a normal public exchange for a certain number of lines. The corresponding telephone sets will arbitrarily be equipped with dial or push-button signalling.

This Artemis exchange is the result of close cooperation with the CNET (Centre National d'Études des Télécommunications) and SO-COTEL (Société Mixte pour le Développement de la Technique de la Commutation dans le Domaine des Télécommunications). The former developed the computer with centralized control unit, called a multiregister, which was constructed by the latter. Le Matériel Téléphonique designed and built the speech network and the junctors for connection with the various rotary and Pentaconta public exchanges (urban, suburban, and toll exchanges) and provided the programming.

Artemis was operative, carrying a progressively increasing load, for several months before its official inauguration in June 1967. It is the first automatic exchange using reed contacts and

Figure 5 —The Artemis exchange in Paris uses reed contacts and stored-program centralized control.

stored program that has been cut over in Europe. Its integration into a large public network required solving many difficult interconnection problems.

Le Matériel Téléphonique
France

Programed Instruction—An 8th-grade class of students taught by programed instruction acquired the same knowledge of algebra in a half year as a 9th-grade class learned in a year with conventional teaching. In another case 400 employees were selected to learn a new data collecting system. A control group of 40 taught by conventional means reached a 2-percent error level in 7 weeks while the larger group under programed instruction achieved a 1-percent error level after only 1 week.

Based on behavioral psychology, programed instruction takes the form of a book, a text, or a manual that presents small units of information one at a time in the most-informative and easy-to-remember order and regularly challenges the student to prove that he has learned what he read. Each student works at his own pace, the fast learner accelerates his pace to avoid boredom, while the slow learner goes at a reduced pace to avoid anxiety over possible failure.

The cycle of learning involves presentation of a small unit of information followed by a question, these two providing a stimulus. If the response to the stimulus is wrong, the subsequent material will show him how to derive the correct answer. This is called feedback. If the answer is correct, he is so informed. This is a psychological reward or, as the psychologists say, his knowledge is reinforced.

In experiments by the United States Army, trainees taking programed instruction progressed twice as fast as those using conventional lecture–textbook methods and retained the information longer.

Over the past few years, dozens of programed instruction texts and training courses have been developed for industry and government and have shown their effectiveness in many subjects and with a wide range of students.

Federal Electric Corporation
United States of America

Isolator Filters Use Active Signal Regeneration—The series *4200* isolator filters use active solid-state design to control the loss in the pass band. A typical unit has zero attenuation in the pass band from direct current to 8 kilohertz and at least 100 decibels attenuation from 14 kilohertz to 1 gigahertz in the input-to-output direction. In the reverse direction the attenuation is not less than 100 decibels from direct current to 1 gigahertz.

The input and output are powered from separate direct-current sources, which may be obtained from the associated equipment or from special power supplies. This provides direct-current isolation between the interfacing equipments of greater than 50 megohms.

Input and output signals may be polarized pulses, sine waves, or the equivalent of electronic switch contacts. The latter permit locally generated output signals of any variety.

This ferrous-shielded device has input and output connectors at opposite ends; a flange near the middle provides for bulkhead mounting.

The capability of regenerating signals with voltage level and/or polarity conversion is particularly suited to teleprinter systems. Input and output modules may be separated by up to 50 feet (15 meters) and coupled with a low-level interface.

ITT Federal Laboratories
United States of America

Submarine Cable between Portugal and Britain Uses Transistors—A 1000–mile (1850-kilometer) undersea telephone cable between Lisbon, Portugal, and Cornwall, England, will use 5-megahertz repeaters at intervals of 7.5 nautical miles (14 kilometers) to provide both-way amplification for 480 circuits with 4-kilohertz spacing or 640 with 3-kilohertz spacing. Each repeater is fully transistorized and has a gain at top frequency of 43 decibels. Supervisory techniques employing pulses allow all repeaters to be similar. Gas-discharge and zener diodes are incorporated for surge protection. The repeater housing is suitable down to 3400 fathoms (6200 meters).

The laying of the cable will be simplified by a new technique for testing equalizers. The equalizers will be permanently jointed into the cable and as each one appears during the laying operation it will be opened and a shipboard test lead attached. Adjustments can then be made, the test lead detached, and the equalizer resealed and paid out with the cable. This technique removes the need for the time-consuming task of jointing equalizers into the cable aboard ship during the laying operation.

About 700 miles (1300 kilometers) of cable will be British Post Office Mark-II lightweight cable shown in Figure 6 and 300 miles (550 kilometers) at shore ends will be heavily armored cable.

Standard Telephones and Cables
United Kingdom

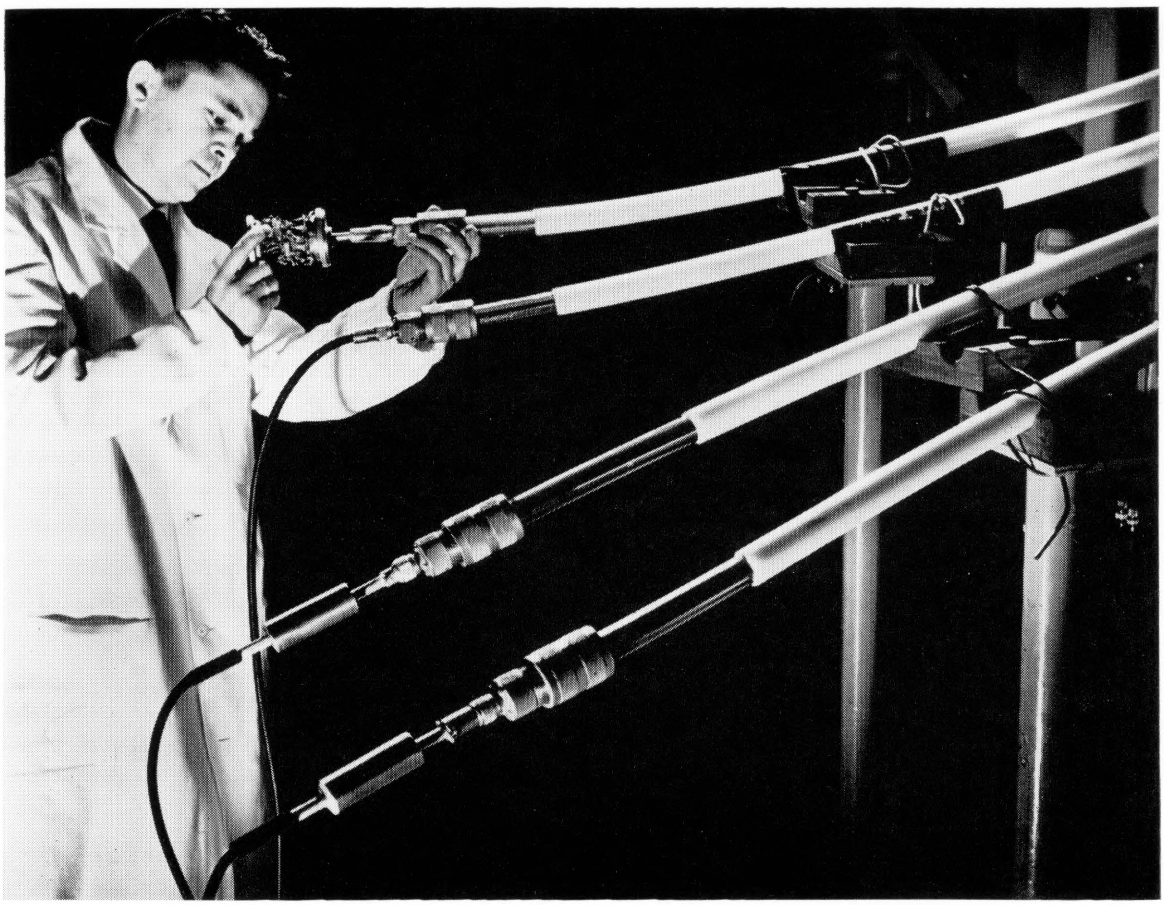

Figure 6—Transmission tests being carried out on completed lengths of deep-water submarine cable.

Automatic Toll Network for Spain—Pentaconta telephone switching exchanges are being installed to permit the Spanish Telephone Company to provide fully automatic toll operation on a national basis.

During 1966, nine new toll exchanges were cut over in Valencia, Seville, Gerona, Málaga, Bilbao, Las Palmas de Gran Canaria, Santa Cruz de Tenerife, Barcelona, and Madrid. The last two are complementary exchanges of existing toll offices although installed in separate buildings. Part of the Madrid–Almagro exchange is shown in Figure 7. Among other exchanges required to complete the national network will be two exchanges having a total of 17 000 incoming and outgoing junctions for Madrid and Barcelona.

The present signaling method uses a single-voice-frequency arythmic code; subsequent extensions of the network will use a multifrequency compelled code.

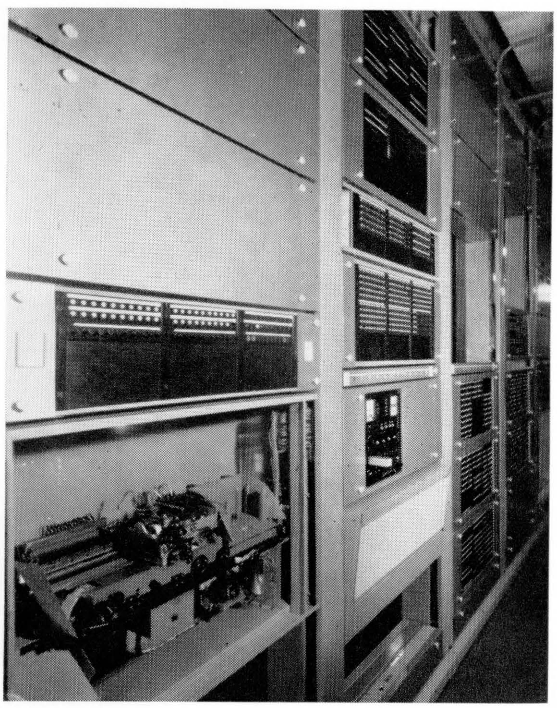

Figure 7—Madrid–Almagro toll exchange test and traffic control bays. A punched-card machine is shown at the lower left.

Standard Eléctrica
Spain

Transponder *NR-A1-2A*—The *NR-A1-2A* tranresponder is an airborne part of the Identification-Friend-or-Foe system. It receives coded pulses transmitted by ground radar equipment, decodes these pulses, then transmits a coded response signal, which provides the ground controller with data such as aircraft identification, altitude, et cetera. The transmissions from the aircraft are much stronger than the echoes that would be produced by normal radar reflections, and this greatly aids the ground radar in locating the aircraft.

The transponder uses transistors except for a single lighthouse triode in a self-oscillating circuit in the transmitter. The transmitted peak power is 500 watts at 1090 megahertz. The receiver, tuned to 1030 megahertz, has a sensitivity of −74 decibels referred to 1 milliwatt. The video circuits, which make use of plug-in printed cards, provide for decoding 5 distinct modes and for encoding 4096 response signals.

The height is less than that of the previous model; the dimensions are 325 by 268 by 182 millimeters (12.8 by 10.6 by 7.2 inches). The total weight is 8.5 kilograms (18.7 pounds).

This new radio navigation apparatus is being manufactured for the French Air Force.

Le Matériel Téléphonique
France

TransITT 12 Very-High-Frequency Main Station—TransITT 12 is a very-high-frequency frequency-modulation 50-watt radiotelephone set for operation on 8 channels as a base station for mobile and portable systems. It meets international specifications.

This simplex base station may be extended to duplex service by adding a hybrid or by using two antennas. It can be operated directly through the control unit in the cabinet or through a subcontrol unit connected over a multicore cable of up to 100 meters (325 feet) in length.

Operation over public telephone lines is made possible by adding units that fit in the cabinet, continuing the use of the controls for normal functions. Remote control can be achieved over a 600-ohm balanced line with a maximum loop resistance of 2000 ohms.

This set is built in Ministac design. It is shown in Figure 8.

Standard Electric Denmark

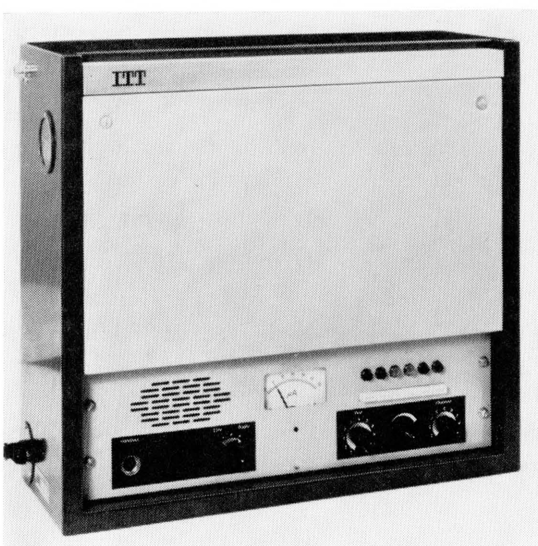

Figure 8—The TransITT 12 base station for very-high-frequency mobile frequency-modulation systems.

TransITT Very-High-Frequency Marine Radiotelephone STR 60—Fulfilling the international regulations of the Hague, this extremely small marine radiotelephone set is provided with a 20-watt transmiter and will operate on 37 very-high-frequency channels. Transistors are used throughout.

It provides for continuous supervision on a calling and emergency channel (normally channel 16) even when listening to signals on another channel. Up to four remote control positions are available with provision for 2- or 4-wire telephone operation and with connectors for handsets on the wings of the bridge of the ship. The built-in test instrument also indicates radio-frequency output.

The set is made in two versions. The one shown in Figure 9 is a 19-inch (480-millimeter) rack unit measuring 135 by 320 millimeters (5.3 by 12.6 inches); the other is mounted in a modern style wall cabinet measuring 440 by 520 by 140 millimeters (17.3 by 20.5 by 5.5 inches). It is in the Ministac line of equipment, characterized by a miniaturization technique based on compact assembly of components.

Standard Electric Denmark

Measurement Instruments Introduced—A new range of measurement equipment has recently been introduced.

(A) Multimeter *MX 101 A*. This meter allows measurements of direct and alternating voltages up to 500 volts with a sensitivity of 2000 and 666 ohms per volt, respectively, of direct and alternating currents up to 30 amperes, of resistance in two ranges from 0.1 to 500 ohms and from 0.01 to 50 megohms, and of temperature with a thermal probe from −20 to +150 degrees Celsius.

(B) Multimeter *MX 202A*. Shown in Figure 10, this instrument is designed for simplicity in use, having a single large scale for voltage and current measurements and a single control for selecting ranges and functions. The internal resistance for direct voltage measurements is 40 000 ohms per volt.

It permits high-precision measurements of direct and alternating currents and voltages and of resistance. Additional accessories extend the direct-current ranges to 500 amperes and 30 kilovolts and the alternating-current ranges to 1000 amperes and 3000 volts. Simultaneous voltage and current measurements may be made on machines operated from the power mains. Lighting intensity may also be measured.

(C) Multimeter *MX 205A*. This instrument is for research and laboratory work. Its taut-band-suspension meter allows the sensitivity to reach 100 000 ohms per volt for direct voltages. It is very well protected against overloads, external magnetic fields, and mechanical shocks. Full-scale measurement ranges for direct current are 100 millivolts to 1500 volts and 10 microamperes to 5 amperes. For alternating current the full-scale ranges are 1.6 to 1500 volts and 1.6 milliamperes to 5 amperes. Signal levels may be measured from −6 to +56 decibels. Resistance values between 1 ohm and 20 megohms are measured, and capacitance scales of 1000 picofarads and 10 microfarads are provided.

Accessories increase the direct-current ranges to 33 kilovolts and 160 amperes and the alternating-current ranges to 16 kilovolts and 1000 amperes.

(D) Electronic Millivoltmeter *VX 203 A*. Shown in Figure 11, this universal test instrument may be used as a normal multimeter

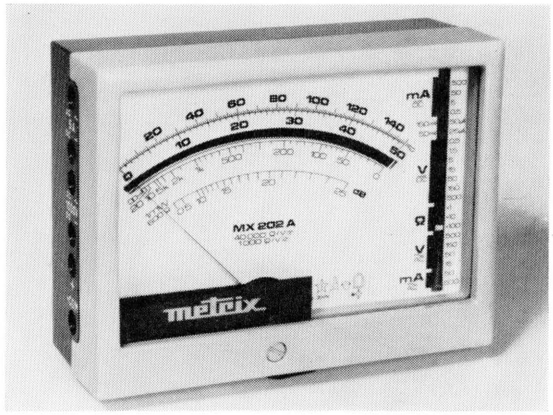

Figure 10—Multimeter *MX 202A* with connector side visible.

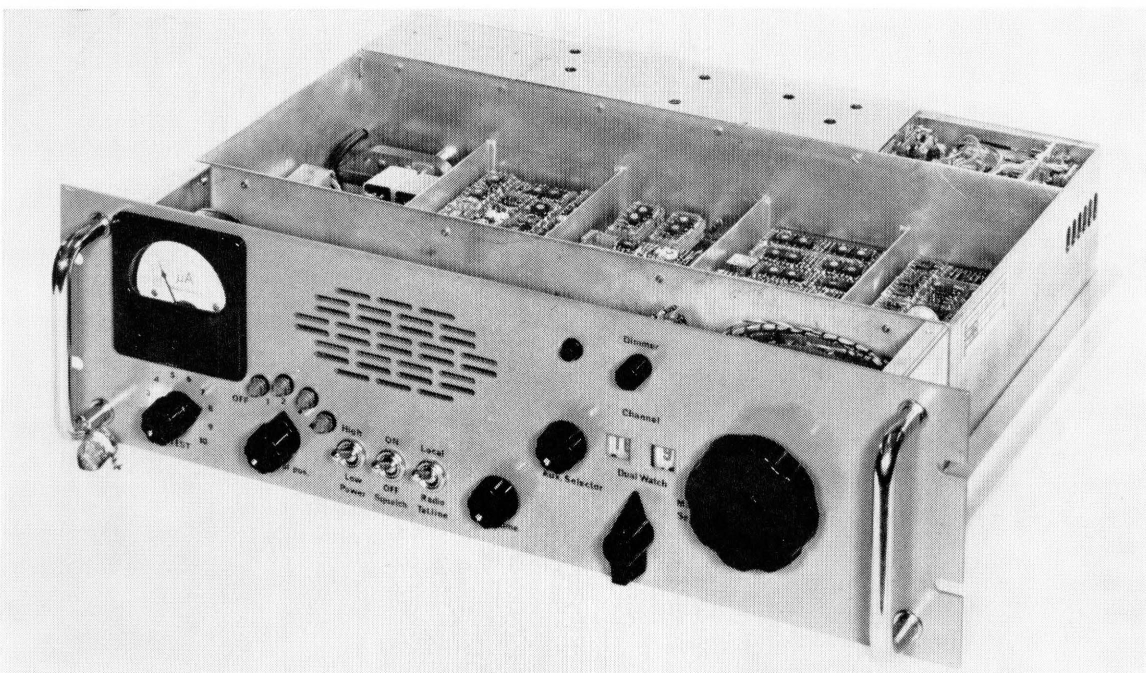

Figure 9—Rack version of TransITT very-high-frequency marine radiotelephone set showing Ministac construction.

as well. It comprises a differential transistor amplifier with battery power supply. It permits measurements of direct voltages from 10 millivolts to 1000 volts, positive or negative, with a sensitivity of 1 megohm per volt. Direct currents are measured from 1 microampere to 10 amperes. Resistances are measured from 3 ohms to 30 megohms. Additional accessories extend these ranges to 30 kilovolts and 300 amperes, direct current, and permit the measurement of alternating voltages and direct voltages on radio-frequency circuits.

(E) Television Signal Strength Meter *VX 403A*. This equipment has been especially designed for optimizing adjustments on television antenna installations. It covers four megahertz frequency ranges: 41.25, 48–110, 160–230, and 470–850. The voltage range is from 10 microvolts to 30 millivolts in six subranges.

(F) Amplitude- and Frequency-Modulation Generator *GX 303 A*. This generator shown in Figure 12 is intended for testing and maintenance of domestic radio sets. It consists of two parts. The first part is an amplitude-modulation generator (*G1 303 A*) covering the range from 100 kilohertz to 30 megahertz, with an expanded range between 420 and 500 kilohertz. The signal may be modulated at 1000 hertz and the expanded band wobulated at 50 hertz.

The second part is a frequency-modulation generator (*G2 303 A*) covering the range from 88 to 108 megahertz and the intermediate-frequency range from 9 to 12 megahertz. The first one may be modulated internally at 1000 hertz or externally at frequencies between 0 and 100 kilohertz. The second one may be wobulated at 50 hertz. There is also a crystal-controlled marker giving reference frequencies of 10.7 ± 0.1 megahertz.

(G) Telephone Multimeter *1034 B*. This instrument is approved by the French telecommunications administration and permits measurements of direct and alternating voltages from 3 to 500 volts and currents from 0.003 to 6 amperes. Resistances from 0 to 20 kilohms and from 0 to 2 megohms may be measured.

(H) Luxmeter *MX 602A*. This very compact instrument has been designed to be used by lighting technicians and conforms to the latest French standards. It has two ranges, 0–50 and 0–200 foot-candles, as well as other features such as correction of errors due to the angle of incidence of light and spectrum correcting filter.

Compagnie Générale de Métrologie
France

Leafield Radio Station Officially Opened—The radio station in Leafield, Oxfordshire, was opened by the Assistant Postmaster General of

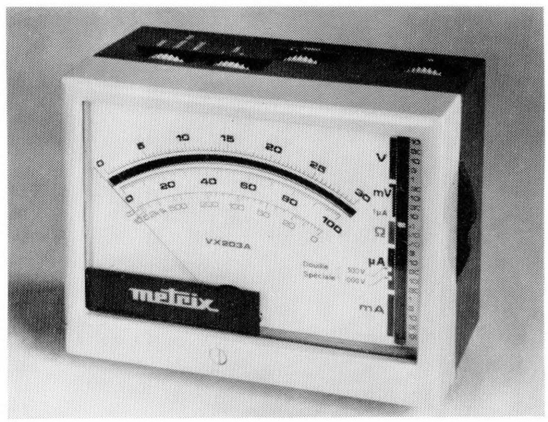

Figure 11—Millivoltmeter *VX 203 A* with selector control visible.

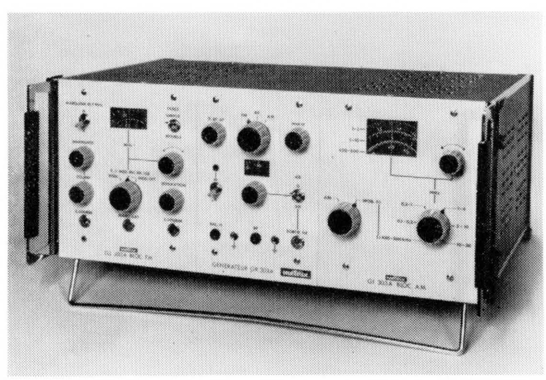

Figure 12—Generator *GX 303 A*.

the British Post Office in October 1966. The equipment consists of 12 transmitters, type *QT4,* of 30-kilowatt rating for radiotelegraph services to Aden, Athens, Beirut, Bombay, Dar-es-Salaam, Nairobi, Pretoria, and for combined telephone and telegraph services to Nicosia and Tehran; and 6 transmitters, type *QT5,* of 75-kilowatt rating for press services to East and West Africa, the Middle East, India, and Southeast Asia. A view of the transmitter room is shown in Figure 13.

Transmitters are tuned automatically. To maintain traffic under varying conditions, the transmitters automatically change frequency; a motorized switching system chooses the appropriate aerial.

Only one man is needed to control the entire station from a central console. A single switch controls all the functions necessary to set up a radio circuit. From the console the operator can start up and shut down a service, initiate frequency changes, arrange for simultaneous operation of two transmitters (dualling), and monitor performance. Automatic switchover from a faulty transmitter is provided.

For reliability, solid-state circuits have been used wherever possible and all components are conservatively rated. The system is designed so that control might later be exercised from the radio traffic terminal in London.

Standard Telephones and Cables
United Kingdom

Microwave Link for Electricity Authority—The North-Eastern Electricity Board have ordered a microwave link for light traffic between Newcastle and York in England. It will initially provide 12 circuits for telemetry, telegraphy, data transmission, and speech.

The *RM15A* equipment has been designed to meet the British Post Office specification *W6503* for 1500-megahertz private user service. It provides in a single 6-foot (1.8-meter) rack a duplicated radio terminal together with up to 24 channels of Mark-6 multiplex. It is all solid state. An engineering order wire and alarm facilities are provided.

Standard Telephones and Cables
United Kingdom

Figure 13—The interior of the new overseas radio station at Leafield.

Transmission Test Set *UN2*—Transmission test set *UN2* permits program-controlled automatic testing of active or passive 4-terminal networks within the range of 30 to 30 000 hertz. It is shown in Figure 14.

Control is by a 5-track perforated tape, which can be punched by a standard teleprinter. For series tests, the tape can be made endless by joining the ends together.

The following characteristics can be checked: effective attenuation, input return loss, output return loss, input longitudinal to transverse attenuation (symmetry), and output longitudinal to transverse attenuation (symmetry).

Each of these characteristics can be tested at various levels and frequencies. The automatic test set compares the sample with the limits of the test program.

The measurement consists in principle of comparing a reference quantity with an unknown quantity. The reference path supplies a constant-level signal to the input of a differential amplifier. In the measuring path, the sample is in series with the attenuation compensation device and the latter is controlled in such a manner that, with the mean value of the sample, the same level is obtained at the other input of the differential amplifier. An evaluation unit decides between "good" or "reject."

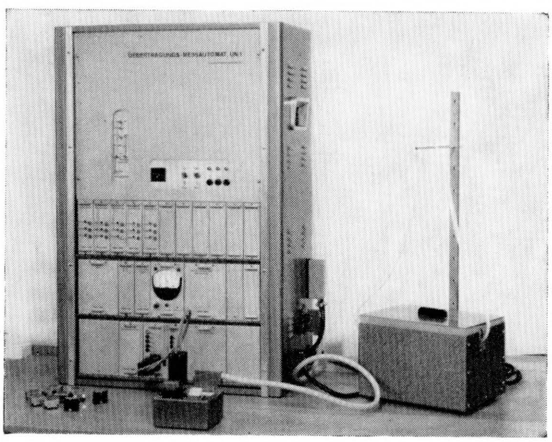

Figure 14—Automatic transmission test set *UN2*. To the right is the perforated tape reader; in front, the adapter with plug-in socket for the samples; and to the left are some samples.

If a fault occurs, the program operation is interrupted and the fault is signaled. After its registration, the operation continues when the start button is pressed. The serial number of the measurement can be printed out when a printer is used.

Any 20 frequencies may be selected for broadband reception. Measurement of attenuation is within ±0.01 neper between 300 and 20 000 hertz and with ±0.02 neper for the full range from 30 to 30 000 hertz. Send level is adjustable in 1-neper steps from 0 to −7 nepers referred to 1 milliwatt, the receive level in steps of 0.01 neper between +1.99 and −6.99 nepers referred to 1 milliwatt. The input and output impedances are 600 ohms, symmetrical. The test time per measurement is approximately 3 seconds between 30 and 300 hertz and 0.6 second between 300 and 30 000 hertz.

Standard Téléphone et Radio
Switzerland

Frequency-Modulation Discriminator Using Thin Films—The responses shown in Figure 15 can be obtained from a frequency-modulation discriminator that uses distributed resistance–capacitance null networks instead of inductance–capacitance circuits. This makes it suitable for production as a thin-film circuit.

Two resistance–capacitance null networks with different null frequencies situated on either side of the carrier frequency determine the frequency range in which a signal can be demodulated. The frequency scale of the graph is normalized, unity corresponding to the mean value of the two null frequencies. The steepness of the response depends on the distribution of resistive and capacitive components of the networks. Those shown are responses for uniform distribution ($D = 1$) and exponentially tapered distribution ($D = 10$). The output signals of the networks are separately amplified and rectified and are then subtracted. The resulting output signal can be either balanced or unbalanced.

Discriminators studied so far are suitable for the demodulation of frequency-modulated signals with frequency deviations of up to ±20 percent. Harmonic distortion of the demodulated signal resulting from nonlinearity of the response is approximately 0.35 percent for each 1 percent of frequency deviation. This value remains constant if the carrier frequency is not situated at the zero-axis crossing frequency, but anywhere on the response. Adjustment is consequently not critical.

Experimental thin-film discriminators for carrier frequencies of 10 megahertz have been produced on a single substrate of 25 by 12.5 millimeters (1 by 0.5 inch) that includes all passive circuit components, with transistors and diodes attached.

Standard Telecommunication Laboratories
United Kingdom

Relay for Printed Circuits—A miniature relay type *A2600* has been produced for the 2.5- or 2.54-millimeter reference grid. Its dimensions are 15 by 24 by 29 millimeters (0.59 by 0.95 by 1.14 inches).

The maximum switched voltage is 60 volts and the current is 200 milliamperes. It has 4 change-over contacts. The contact springs carry twin precious-metal contacts.

It is available for operation at 6, 12, 24, 36, and 48 volts. The operate time is 5 to 10 milliseconds at nominal voltage, the release time 2 to 5 milliseconds. The number of operations during the assessed lifetime is 2×10^8. The relay is protected against the environment by a plastic casing from which the connecting wires protrude.

Standard Elektrik Lorenz
Germany

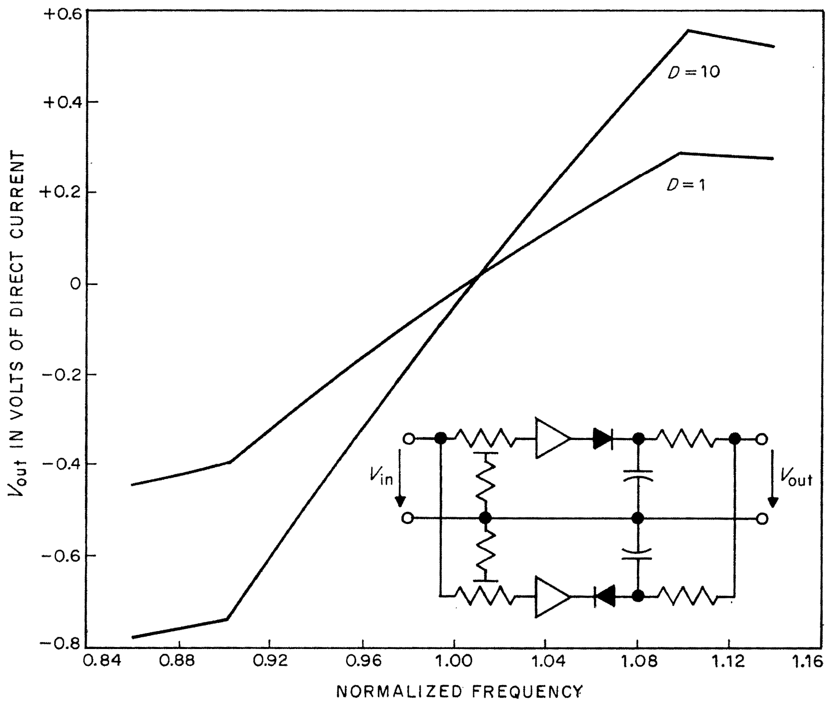

Figure 15—Frequency-modulation discriminator for wideband demodulation using two thin-film distributed resistance-capacitance null networks. *D* is the ratio of the width of the resistive film at the input and output of the network. The amplifiers have gains of 20 decibels and the input signal is 1 volt, root mean square.

Alarm Receiver *E 47*—The signaling and alarm receiver type *E 47* in Figure 16 is designed for operation in the very-high-frequency radiotelephone bands. In case of an alarm, the associated fixed stations radiate coded call signals for alerting the alarm receivers individually or in groups. A call is indicated by sound from the built-in loudspeaker, a visual indicator, and optionally an external buzzer or bell. Following the alarm signal, a message can be transmitted.

The receiver is intended for portable, mobile, and stationary use. A plug-in rod antenna is available but any other 60-ohm antenna suitable for the receiving frequency can be connected via a coaxial cable. The transistor circuits are arranged in functional groups mounted on easily replaced printed-wiring boards.

The receiver is delivered tuned to the receiving frequency stated in the order. The loudspeaker and the visual indicator are automatically actuated on arrival of a call and the latter is reset by momentarily depressing a clearing push button. The sound volume of the loudspeaker can be reduced by use of a locking push button.

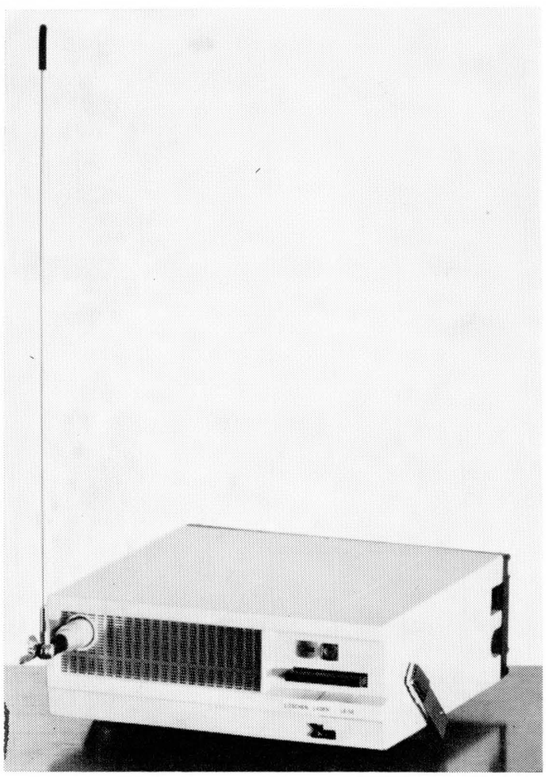

Figure 16—Signaling and alarm receiver *E 47*. A suitable rod antenna is mounted at the left.

Operation is from the alternating-current mains, a built-in rechargeable nickel–cadmium battery, or a 12-volt external battery. In case of mains failure, automatic changeover to battery operation takes place. The battery can be recharged from the mains by pressing the charging push button.

Standard Elektrik Lorenz
Germany

Piezoelectric Materials—There is a need for new piezoelectric materials capable of being used in crystal filters operating between 0.1 and 30 megahertz and in electromechanical filters operating in the intermediate-frequency band. Quartz is used extensively in many of these applications, but it has the disadvantages of a low electromechanical coupling constant and it can only be grown extremely slowly by the hydrothermal process. Apart from the requirement of superior piezoelectric properties, any new material should also be capable of being grown in single-crystal form, both rapidly and of good quality. Growth from the melt offers obvious advantages in this respect, but not many piezoelectric materials are known which can be grown in this way. However, an unusual material reported to be piezoelectric is calcium pyroniobate. $Ca_2Nb_2O_7$, and single crystals have been melt grown by the Czochralski pulling method.

Calcium pyroniobate reputedly belongs to the monoclinic crystal system, and growth in any crystallographic direction in the (100) plane has been found to be easy, at rates greater than 1 centimeter per hour. With careful control of the growing process, thin ribbon crystals typically 10 centimeters long by 1 centimeter wide by 0.1 centimeter thick have been obtained with large-area mirror facets parallel to the (100) plane. On these facets, occasional growth steps occur with a height between 0.5 and 1 micrometer but between the steps the surface appears to be atomically flat, as shown by multiple beam interferometric techniques. A photograph of a ribbon crystal is shown in Figure 17, and a double reflection of the caption in the (100) mirror facets on opposite sides of the crystal is evident in the original photograph. The stability of such large facets indicates that there is a very great difference between the surface free energy of a (100) plane and other principal planes in the lattice. This makes growth in the [100] direction difficult, and slow growth rates of about 0.3 centimeter per hour have had to be used to obtain small crystals, typically 1 centimeter in diameter by 3 centimeters long, of this orientation.

Piezoelectric measurements have been made at the Quartz Crystal Division of Standard Telephones and Cables. For X-cut crystals the electromechanical coupling constant k is approximately 14 percent (the value for X-cut quartz is 9.8 percent), Q lies in the range 1800–3600, and the temperature coefficient is about 220 parts per million per degree Celsius, while for Y-cut crystals k falls to approximately 6 percent and the temperature coefficient to about 100 parts per million per degree Celsius. While these figures are not encouraging for piezoelectric applications as filters, the high temperature coefficient might be of interest for temperature sensing applications. Crystals of other materials, for example lithium metatantalate $LiTaO_3$ and lithium metagallate $LiGaO_2$, are now being grown; their piezoelectric properties are more promising.

Standard Telecommunication Laboratories
United Kingdom

Toll Originating Exchange for Paris Area—A new originating toll exchange for the Paris area was cut into service in March 1966. It is called CESAR for *CE*ntre *S*ortant *A*utomatique *R*égional.

This exchange handles part of the Paris area toll traffic toward what is called the Paris Regional Area 2, extending for 70 kilometers (44 miles) beyond the Paris suburbs.

Since 1951, such traffic was handled by *2FR*, a special outgoing exchange using rotary apparatus located in the same building with the new exchange.

Using the Pentaconta switching system, CESAR is connected to the Paris network either by rotary code adaptors or by multifrequency code when other Pentaconta exchanges are involved. The originating toll junctors are usable with decimal toll code or with multifrequency code depending on the connected terminating point.

At present 600 circuits are in operation. By next year 1000 originating circuits will be

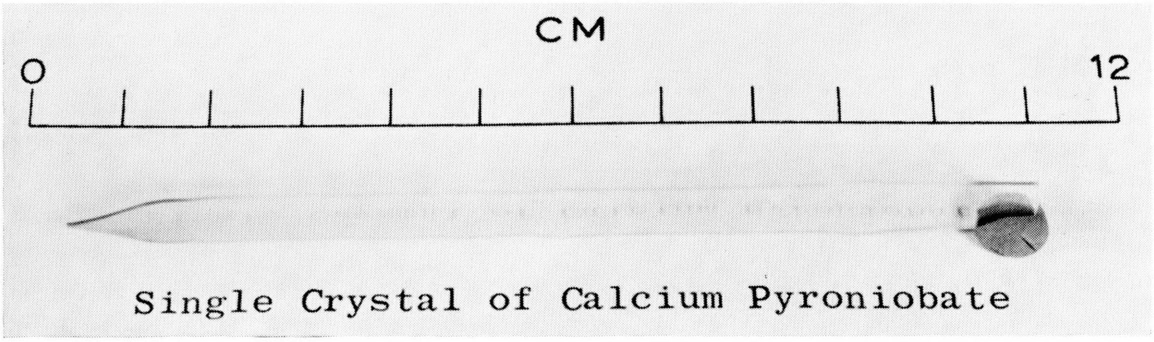

Fig. 17—A ribbon crystal of calcium pyroniobate. The reflections of the caption seen in the (100) mirror facets are precisely doubled owing to extreme parallelism of opposite sides of the ribbon.

connected. A second originating toll exchange is planned for 1969.

Le Matériel Téléphonique
France

Computer Type *822 P*—Testing has been completed on the prototype of the *822 P* computer intended to be a centralized computer for installation in aircraft. Shown in Figure 18, it is composed of 1400 direct-coupled transistor logic integrated circuits in *TO5* packages and a ferrite microcore memory having a capacity of 4096 words of 25 bits each. Programed with a set of 40 instructions, it is able to perform 100 000 additions per second or 15 000 multiplications, divisions, or square roots per second. Its volume is 10 liters (610 cubic inches), its weight 12 kilograms (27 pounds), its power consumption 70 watts, and the mean time between failures is 400 hours.

Laboratoire Central de Télécommunications
France

Computer Type *825 P*—The *825 P* laboratory model computer is now completed and fully tested. It is a general-purpose microminiature digital computer for real-time applications, particularly for aircraft. It is a single-address computer with indexing and interrupt features and is composed of 500 diode–transistor micrologic flat-pack integrated circuits and of a ferrite microcore memory having a capacity of 4096 words of 25 bits each. It can be programed with a set of 30 instructions and is able to perform 160 000 additions or a tenth as many multiplications or divisions per second. A symbolic language has been defined and both assembling and simulating programs are available. The computer model is now in operation on various experimental programs.

Laboratoire Central de Télécommunications
France

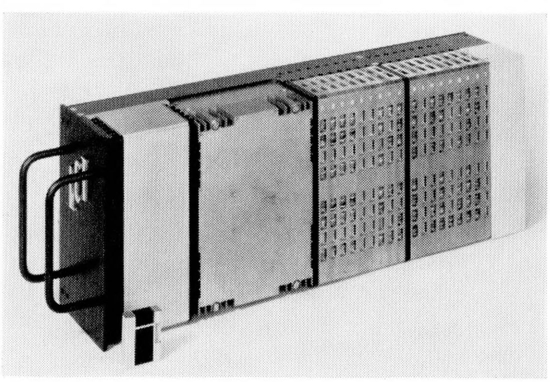

Figure 18—Side view of the *822P* computer. Lettered circuit cards are at right; the memory case and power supply, both provided with cooling fins, are at the left.

Computer Center Expands Capabilities—Our data processing centers at Paramus, New Jersey, and El Segundo, California, have been expanded with the installation of the new System/*360,* Model *50,* computers. These large-scale multipurpose computers by International Business Machines have 65 000-word core memories, disk packs, and magnetic tapes for processing and storing data. For use by outside clients, satellite data processing and data transmission facilities in the greater New York area are connected to the Paramus center over high-speed data transmission lines.

A computer program called *Staff* provides an economical way to convert existing programs written in Fortran *4,* the most commonly used scientific computer language in the United States, to Fortran *H* required by the System/*360* series of computers. *Staff* analyzes programs presently used for scientific computers, detects those instructions or statements that are incompatible or incomprehensible to System/*360,* and converts them to a form acceptable to the new computers.

ITT Data Services
United States of America

Solenoids for Linear Action—A new series of solenoids operating either push or pull plungers are more powerful and economical than conventional units. The smaller unit in Figure 19 weighs 1.5 ounces (43 grams), occupies 0.5 cubic inch (8 cubic centimeters), and will provide 11 ounces-force (300 grams-force) over a stroke of 2.17 inches (5.5 centimeters) for an input power of 30 watts for the direct-current version. The larger size has a volume of 0.8 cubic inch (13 cubic centimeters) and weighs 2.25 ounces (64 grams). Under the same operating conditions, it produces 25 ounces-force (700 grams-force) for a 35-watt input.

Both units are available for either alternating or direct current with coils rated from 6 to 48 volts and from a 5-percent to a continuous working cycle.

Standard Telephones and Cables
United Kingdom

Motor Protector—The small solid-state plug-in module in Ministac construction shown in Figure 20 has been developed to protect the windings of electric motors from overheating by controlling the alternating-current power supply to the motor. A positive-temperature-coefficient thermistor is embedded in the motor windings to control the switching action.

Standard Telephones and Cables
United Kingdom

Finland and Chile Radio Relay Systems—A radio relay system will be installed in the lake district of Finland between Iyväskylä and Kuopio to expand the telephone network. The 6-gigahertz equipment will provide up to 1800 telephone circuits.

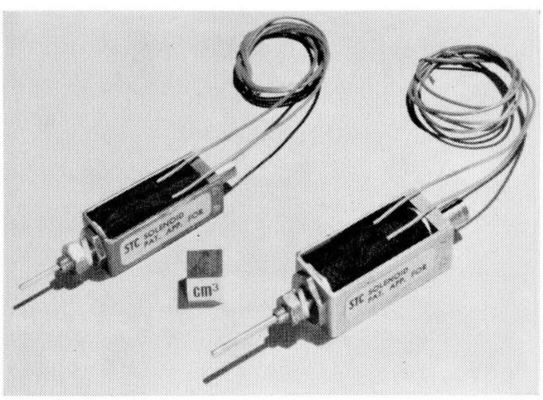

Figure 19—Small and large solenoid linear actuators fitted with push plungers. Corresponding pull-plunger units are also available.

In Chile, a radio relay route from Santiago to Concepción is about to be installed and a further order has been placed by the Chilean telephone company to equip the route from Chillán to Temuco with 4-gigahertz equipment.

Standard Elektrik Lorenz
Germany

Toll Terminating Exchange "Pastourelle"—In May 1966 a Paris terminating toll exchange located in the Pastourelle exchange building was cut into service. A view of the test positions is shown in Figure 21.

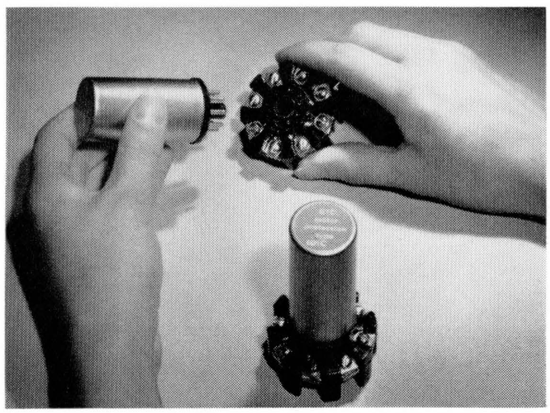

Figure 20—Motor protection device type *001C*.

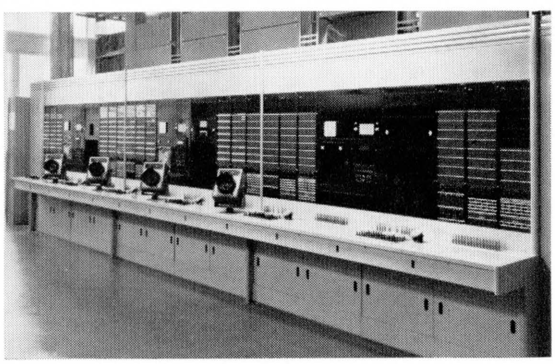

Figure 21—Test positions of the Pastourelle toll exchange.

Using the Pentaconta switching system, this exchange has a final capacity of 5500 terminating toll circuits and 7000 originating junctions toward the Paris network exchange. At present, 1500 toll circuits are equipped with 2700 being planned for early connection.

The three selection stages needed for such an important exchange are made up of a single guide switching stage operating with two normal switching stages.

Signals for long-distance and large-capacity toll connections are transmitted in SOCOTEL multifrequency code. This is also used at the originating exchange and enables transit connections toward local Pentaconta exchanges to be made; thus the exchange control equipment may be released rapidly.

Le Matériel Téléphonique
France

Interorgtechnika Exhibition in Moscow—At the Interorgtechnika in Moscow in September 1966, Standard Elektrik Lorenz participated in a special display on "The Modern Office" provided by the German Federal Republic. Part of the display is visible in Figure 22.

Among its contributions were a push-button system for interconnection between various desks in a large office, a lightweight pneumatic tube system for conveying letters and documents among three stations, an optical document sorter type *ODS 2*, an *Lo 133* teleprinter with Cyrillic characters, a model of an automatic letter sorter, and a station for a penumatic tube system using a tube of 125-millimeter (5-inch) diameter.

Standard Elektrik Lorenz
Germany

Exploding Bridgewire Electronics Units—A follow-on contract has been received from The Martin Company for electronic modules and cables for the exploding bridgewire system used in the United States Army Pershing missile program.

Exploding bridgewire is a type of fine wire exploded by a high-voltage pulse to activate a thrust device, which may separate parts of a rocket, start an engine, extend a radio antenna, or perform a variety of such tasks. An important feature is that relatively insensitive thrust charges can be used to avoid accidental explosion from stray radio fields or other stimuli.

ITT Industrial Products
United States of America

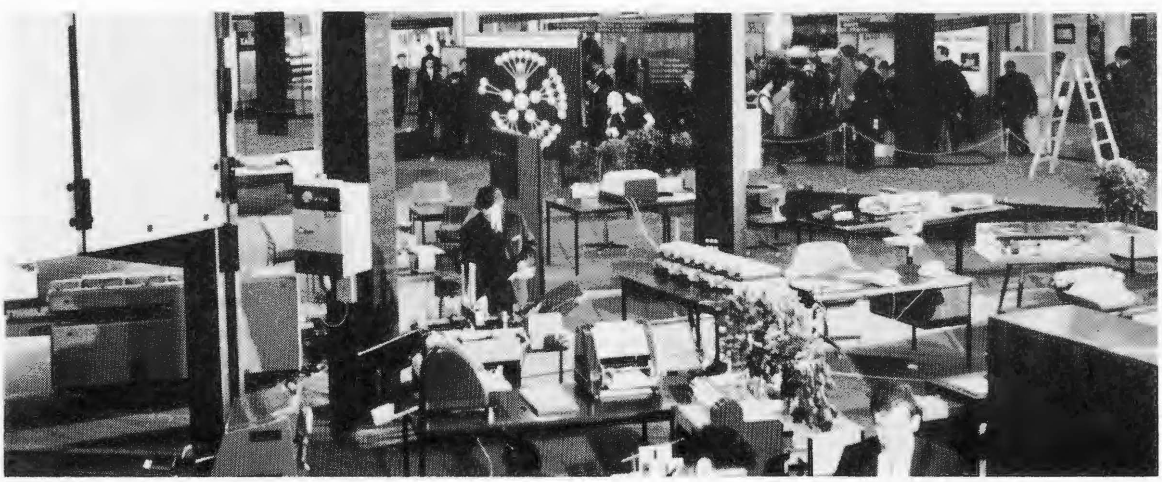

Figure 22—Part of "The Modern Office" display at the Interorgtechnika in Moscow.

United States Patents Issued to International Telephone and Telegraph System; November 1965–April 1966

Between 1 November 1965 and 30 April 1966, the United States Patent Office issued 174 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

F. G. Adams and B. D. Mills, Standard Telephones and Cables (London), Semiconductor Devices, 3 244 555.

H. H. Adelaar, Bell Telephone Manufacturing Company (Antwerp), Resonant Transfer Time Division Multiplex System Using Transistor Gating Circuits, 3 226 483.

H. H. Adelaar, F. Clemens, and J. L. Masure, Bell Telephone Manufacturing Company (Antwerp), Control System for Communication Network, 3 221 103.

F. Ambrosino, Standard Telephones and Cables (London), Subscribers' Metering Systems, 3 222 457.

C. Anderson and R. Rinehart, ITT Cannon Electric, Method for Making an Electrical Contact Socket, 3 243 868.

M. Arditi, ITT Federal Laboratories, High Stability Gas Cell Frequency Standard, 3 234 483.

R. E. Arseneau, ITT Kellogg, Speech Path Controller, 3 221 106.

R. E. Arseneau, J. Bereznak, and P. E. Osborn, ITT Kellogg, Electronic Switching Telephone System, 3 221 105.

E. A. Ash, Standard Telecommunication Laboratories (London), Slow Wave Structure Having a Plurality of Curved Conductors Disposed About the Beam and Mounted Transversely Between Opposite Walls, 3 244 932.

R. A. Bachman, ITT Cannon Electric, Contact Retention Device With Safety Stop, 3 229 244.

J. M. Balkow and W. G. U. Aye, Standard Elektrik Lorenz (Stuttgart), Power-Supply Apparatus with a Battery Being Provided for Supplying the Load in the Event of Failure of Main Rectified Supply, 3 240 949.

L. Bauer and W. Gruger, Standard Elektrik Lorenz (Stuttgart), Cradle-Switch Spring Assembly, 3 218 238.

J. Bauwens, Bell Telephone Manufacturing Company (Antwerp), Pulse Source Arrangement, 3 235 841.

E. Behun, ITT Federal Laboratories, Optical Fiber Face-Plate Assembly for Image Tubes, 3 244 921.

H. Benmussa, Compagnie Générale de Constructions Téléphoniques (Paris), Telephone Systems, 3 226 487.

H. Benmussa, P. R. L. Marty, and S. Kobus, Compagnie Générale de Constructions Téléphoniques (Paris), Selection System, 3 226 486.

H. Benmussa, P. R. L. Marty, and S. Kobus, Compagnie Générale de Constructions Téléphoniques (Paris), Telephone System With Electronic Selection, 3 242 265.

G. Beszedics, Standard Telephon und Telegraphen (Vienna), Control Arrangement for Amplifier Stages, 3 248 661.

G. Beszedics and R. Konecny, Standard Telephon und Telegraphen (Vienna), Loudspeaking Intercommunication System, 3 215 780.

E. Beyerle, Mix & Genest Werke (Stuttgart), Voice-Frequency Signal Receiver With Speech-Immunity Circuit, 3 242 267.

R. A. R. Boyer and A. E. J. Chatelon, Laboratoire Central de Télécommunications (Paris), Arrangement for the Suppression of Noise in Transmission Systems, 3 231 674.

D. E. Brannon, ITT Laboratories, Gyroscope, 3 233 467.

R. F. Bridge, Standard Telephones and Cables (London), Machining Device, 3 242 776.

R. V. Browning and D. Woodgate, Kolster-Brandes (Footscray), Cathode Ray Tubes, 3 248 480.

G. Brust, Standard Elektrik Lorenz (Stuttgart), Character-Recognition Apparatus, 3 234 513.

G. Brust and W. Dietrich, Standard Elektrik Lorenz, Mix & Genest Division (Stuttgart), Centering Method for Automatic Character Recognition, 3 234 511.

G. Brust, W. Dietrich, P. Mierzowski, and W. Schrempp, Standard Elektrik Lorenz (Stuttgart), Character-Recognition Apparatus Utilizing Columnar Variations from a Reference Line, 3 245 037.

G. Buhmann, Standard Elektrik Lorenz (Stuttgart), Low-Capacitance Type of High-Frequency Cable, 3 248 473.

G. F. Carlson, ITT Bell & Gossett Hydronics, Device for Connecting Tubes or Pipes, 3 218 093.

A. E. J. Chatelon, Laboratoire Central de Télécommunications (Paris), Pulse Regenerative Devices, 3 241 075.

R. F. Cleaver, F. G. Cockerill, and T. J. Cox, Standard Telephones and Cables (London), Angle Indicator, 3 234 531.

J. E. Cox and G. J. Boehm, Kellogg Switchboard & Supply, Dropback Selector, 3 236 952.

W. D. Cragg, Standard Telephones and Cables (London), Electro-Acoustic Transducers, 3 247 927.

G. F. Craven and A. E. Karbowiak, Standard Telecommunication Laboratories (London), Apparatus for the Determination of Attenuation in Waveguides Including Means for Comparing the Amplitudes of Pulse Reflections, 3 244 978.

B. Dal Bianco and M. Scata, Fabbrica Apparecchiature per Comunicazioni Elettriche Standard (Milan), Sealed Contact Device with Ferrite Elements, 3 233 062.

B. Dal Bianco and M. Scata, Fabbrica Apparecchiature per Comunicazioni Elettriche Standard (Milan), Sealed Switch for Strong Currents, 3 236 965.

J. Dammeier, Standard Elektrik Lorenz (Stuttgart), Punched-Card Insertion Apparatus, 3 244 417.

J. Dascotte, Le Matériel Téléphonique (Paris), Error Detecting System, 3 248 695.

C. L. Day, ITT Industrial Laboratories Division, Faceplate Seal, 3 243 072.

J. DeLeers, Bell Telephone Manufacturing Company (Antwerp), Vertical Deflection and Blanking Circuit, 3 243 647.

H. M. Dorrer, Standard Elektrik Lorenz (Stuttgart), Machine for Automatic Application of Circuit Elements, Preferably of Printed Circuits, 3 225 995.

G. K. Duddridge and A. J. Millard, Standard Telephones and Cables (London), Welding of Electric Cables, 3 226 522.

W. C. W. Duncan, ITT Cannon Electric, Electrical Connector With Spring Pin Contact, 3 242 456.

D. F. T. Dunster and I. H. Morgan, Standard Telephones and Cables (London), Mountings for Semiconductor Devices, 3 243 670.

C. W. Earp, Standard Telephones and Cables (London), Dual Sideband Radio Beacon, 3 226 718.

C. W. Earp, Standard Telephones and Cables (London), Radio Beacon, 3 248 733.

C. W. Earp and E. Kramar, Standard Telephones and Cables (London), Radio Navigation System, 3 234 554.

P. T. Farnsworth, Farnsworth Electronics, Ion Transport Pump, 3 240 421.

A. Fettweis, Bell Telephone Manufacturing Company (Antwerp), Double Balanced Transistor Modulators, 3 248 673.

N. H. Fletcher, Clevite Corporation, Junction Transistor, 3 234 441.

S. L. Fudaley, L. Mourlan, Jr., and J. E. Busch, ITT Kellogg, Electronic Ringing Generator, 3 248 634.

W. L. Garfield, Standard Telephones and Cables (London), F.M. Receiver Noise Suppression Circuit, 3 241 069.

W. L. Garfield, Standard Telephones and Cables (London), Frequency Modulated Transmitter Monitor, 3 245 005.

W. L. Garfield and A. H. Babb, Standard Telephones and Cables (London), Spurious Noise Suppression Circuit Integrating Low Frequencies, By-Passing High Frequencies, 3 231 823.

W. L. Garfield and I. F. H. Goult, Standard Telephones and Cables (London), Monitoring Circuit for an FM Radar Receiver, 3 226 715.

W. L. Garfield and B. H. A. Rixon, Standard Telephones and Cables (London), Excess Speed Indicator, 3 248 728.

J. C. Gibson and T. Bowers, ITT Kellogg, Automatic Computer Adjustment System, 3 243 691.

W. F. Glover and J. G. Bendall, Standard Telephones and Cables (London), Adjustable Inductor, 3 243 745.

H. Gobrecht, Standard Elektrik Lorenz (Stuttgart), Method of Producing Photosensitive Layers of Lead Selenide, 3 226 253.

R. G. Griffin and W. J. Hyland, ITT Components Division, Hermetic Seal for Electrical Device, 3 248 613.

H. Grottrup, Standard Elektrik Lorenz (Stuttgart), Character Recognition by Contour Following, 3 245 036.

H. Grottrup, Standard Elektrik Lorenz (Stuttgart), Line-At-A-Time Printer, 3 233 540.

F. G. A. Haegele, Standard Telephones and Cables (London), Electron Discharge Tube, 3 240 981.

F. F. Hall, Jr., ITT Federal Laboratories, Dual Spectral Region Scanning Monochromator, 3 244 879.

E. R. Haskins, E. G. Platt, and J. F. Dunlap, ITT Kellogg, Electronic Switching Telephone System, 3 221 104.

G. W. H. Helwig, Standard Elektrik Lorenz (Stuttgart), Method of Producing Metallic and Dielectric Deposits by Electro-Chemical Means, 3 243 363.

E. Herter, Mix & Genest Werke (Stuttgart), Pushbutton Selection, 3 243 516.

D. Hessler, ITT Bell & Gossett Hydronics, Marlow Division, Centrifugal Pump for Handling Suspensions Containing Large Particulate Matter, 3 229 641.

A. M. Hestad, ITT Kellogg, Constant Voltage Device, 3 223 781.

S. R. Hoh, ITT Laboratories, Energy Converter, 3 243 687.

S. R. Hoh, ITT Laboratories, Thermionic Energy Converter, 3 248 577.

O. Holstein and H. Deimling, Standard Elektrik Lorenz (Stuttgart), Key Sender for Teleprinters and Data-Processing Input Devices, or the Like, 3 234 331.

A. E. E. Irmisch, Standard Elektrik Lorenz (Stuttgart), Arrangement for Through-Connection of Current Pulses to a Ferrite-Core Memory, 3 245 061.

A. E. E. Irmisch, Standard Elektrik Lorenz (Stuttgart), Blocking Oscillator with Premagnetized Transformer Core Employing Positive and Negative Feedback, 3 240 952.

L. O. Jacobs, Jennings Radio Manufacturing Corporation, Hermetically Sealed Switch with Tubular Dielectric Portions United to a Relatively Larger Metallic Intermediate Vapor Condensing Portion, 3 231 704.

H. F. Jarger, R. Ellis, and R. T. Adams, ITT Federal Laboratories, Coaxial Line Reflectometer Having a Resistance Connected Between Sections of the Outer Conductor, 3 243 704.

J. E. Jennings, Jennings Radio Manufacturing Corporation, Ignitor for Vacuum Discharge, 3 218 499.

J. E. Jennings, Jennings Radio Manufacturing Corporation, Lightweight D.C. Power Supply, 3 234 450.

J. E. Jennings, Jennings Radio Manufacturing Corporation, Vacuum Switch Envelope, 3 222 484.

R. V. Judy and R. E. Arseneau, ITT Kellogg, Two-Wire Switching System for Four-Wire Circuits, 3 230 315.

D. Kao, ITT Cannon Electric, Connector for Coaxial Cable, 3 229 241.

H. Kobayashi, Nippon Electric (Tokyo), Discharge Indicator Tube, 3 242 378.

S. Kobus, Compagnie Générale de Constructions Téléphoniques (Paris), Crossbar Switches, 3 226 518.

H. Kroll and H. Steinhardt, J. Mayr (Nuremberg), Slider Switch Construction With Interfitting Shaft Members, 3 248 491.

H. E. Lauckner, Standard Elektrik Lorenz (Stuttgart), Electrical Capacitor, 3 226 607.

G. X. Lens and J. P. H. Vandevenne, Bell Telephone Manufacturing Company (Antwerp), Multiple Repertory Encoding Keypanel, 3 226 712.

C. R. LeWan, General Controls Corporation, Reset Mechanism for Power Operated Reversible Loads, 3 218 403.

H. K. Ligotky, ITT Federal Laboratories, Compandor System Having an Analog Signal Controlled Compressor and an Auxiliary Signal Controlled Expander, 3 241 066.

W. N. Lindsay, Jennings Radio Manufacturing Corporation, Cable-Supported Remotely Actuable Relay, 3 247 347.

W. N. Lindsay, Jennings Radio Manufacturing Corporation, Drive Mechanism for Vacuum Switches, 3 248 497.

W. N. Lindsay, Jennings Radio Manufacturing Corporation, Electromagnetic Actuator, 3 218 409.

H. Mach, H. J. Peter, and F. Lippitz, Standard Elektrik Lorenz (Stuttgart), Pneumatic Dispatch-Carrier-Separating Device, 3 236 475.

B. B. Mahler, ITT Federal Laboratories, Aircraft Position Location System, 3 248 732.

H. Marko, Standard Elektrik Lorenz (Stuttgart), Generator of Parity Check Bits, 3 234 364.

J. Marley, ITT Federal Laboratories, High Speed Magnetic Cores, 3 248 676.

R. A. Mateer, ACF Industries, Connector Having an Impedance Matching Transformer, 3 223 954.

B. Mattlet, Bell Telephone Manufacturing Company (Antwerp), Signalling System, 3 245 066.

O. J. Melhus, Standard Elektrik Lorenz (Stuttgart), Tunnel-Diode Read-Out Amplifier for Evaluating Data from Magnetic Data-Storage Devices, 3 231 762.

G. Merz, Mix & Genest Werke (Stuttgart), Counting Circuit, 3 217 143.

G. Merz, Standard Elektrik Lorenz, Mix & Genest Division (Stuttgart), Time-Division Multiplex Control Method for Electronic Switching Systems in Telecommunication, Particularly Telephone Installation, 3 221 102.

M. Michelitsch, Standard Elektrik Lorenz (Stuttgart), Semiconductor Device and Method of Producing It, 3 240 571.

D. B. Miller, Royal Electric, Current Cube Tap, 3 241 096.

D. B. Miller, Purchased Invention, Electrical Conductor Bushing Arrangement, 3 243 759.

A. Mingaud, Compagnie Générale de Constructions Téléphoniques (Paris), Pulse Amplifier Including Complementary Transistors, 3 241 081.

R. E. Moore, and J. Keyes, ITT Bell & Gossett Hydronics, Heat Exchange Devices, 3 238 998.

M. Müller, Standard Elektrik Lorenz (Stuttgart), System for Eliminating A.M. to P.M. Conversion in an FM System Utilizing a Plurality of Equalizers, 3 237 121.

N. Orenstein and B. A. Chmiel, ITT Federal Laboratories, Wide-Frequency-Range Sweep Generator, 3 241 086.

R. K. Orthuber, ITT Laboratories, Electron Pulsing Device, 3 234 427.

R. K. Orthuber, Farnsworth Television & Radio Corporation, Variable Intensity Electroluminescent Radiation Amplifier, 3 244 891.

H. J. Peter and D. Zimmermann, Standard Elektrik Lorenz (Stuttgart), Pneumatic Tube Carrier With Magnetic Destination Coding, 3 226 054.

R. L. Plouffe and S. Schreiner, ITT Laboratories, Code Recognition System, 3 245 033.

P. R. Poli, Compagnie Générale de Constructions Téléphoniques (Paris), System for Displaying and Registering Signals, 3 234 533.

M. Press and J. Murgio, ITT Laboratories, Earth Navigational System, 3 244 862.

H. A. Rafler, Standard Elektrik Lorenz (Stuttgart), Safety Device for Magnetic Amplifiers, 3 244 994.

W. A. Ray, General Controls Corporation, Fluid Control Means, 3 247 868.

W. A. Ray, General Controls Corporation, Fuel Control System, 3 240 257.

W. A. Ray, ITT General Controls, Heat Motor Operated Valves, 3 239 189.

W. A. Ray, ITT General Controls, Heat Motor Operated Valves, 3 240 229.

F. H. Rees, Standard Telephones and Cables (London), Logical Circuitry for Digital Systems, 3 248 564.

G. W. Reznor, ITT Reznor, Sheet Metal Heat Exchange Stack or Fire Tube for Gas Fired Hot Aired Furnaces, 3 241 609.

M. L. Robinson, Barton Instrument Corporation, Automatic Titration Apparatus and Method, 3 248 309.

M. L. Robinson, Barton Instrument Corporation, Oxidant Sensor, 3 236 759.

C. T. Roessler, Jennings Radio Manufacturing Corporation, Miniature Hermetically Sealed Relay, 3 238 324.

H. C. Ross, Jennings Radio Manufacturing Corporation, Arc-Controlling Auxiliary Contact Assembly for Electric Switches, 3 244 843.

C. P. Sandbank, Standard Telephones and Cables (London), Encapsulated Die Bonded Hybrid Integrated Circuit, 3 244 939.

M. Scata, Fabbrica Apparecchiature per Comunicazioni Elettriche Standard (Milan), Magnetically Operated Sealed Switch Unit, 3 238 325.

U. Schottle and R. Piloty, Standard Elektrik Lorenz (Stuttgart), Space Information and Reservation System, 3 241 117.

S. M. Schreiner, ITT Federal Laboratories, Time Division Multiplex System, 3 244 813.

W. Schroder, Standard Elektrik Lorenz (Stuttgart), Radio or Television Receivers With Finder Tuning, 3 244 984.

D. F. Seemann, J. J. Dupuis, and G. K. C. Chen, ITT Kellogg, Electronic Private Branch Exchange, 3 221 108.

D. F. Seemann, E. G. Platt, W. K. C. Yuan, and N. V. Mansuetto, ITT Kellogg, PBX-Group Hunting for Electronic Switching Systems, 3 221 107.

W. Shockley, Clevite Corporation, Semiconductive Device and Method of Making the Same, 3 236 698.

R. D. Sibley, General Controls Corporation, Reset Mechanism for Power Operated Loads, 3 219 902.

N. L. Sim and A. J. Millard, Standard Telephones and Cables (London), Electric Arc Welding Circuit, 3 243 566.

K. Sobotta and R. Luce, Standard Elektrik Lorenz (Stuttgart), Arrangement for Preventing Alternative Signalling Conditions, Especially in Road Traffic Light Signalling Systems, 3 241 113.

G. B. Speen, ITT Federal Laboratories, Optical Apparatus for Testing the Accuracy of Quadric Surfaces, 3 247 760.

J. A. Stamm, ITT Federal Laboratories, Apparatus for Image Formation and Projection, 3 240 116.

K. Steinbuch, F. Zendeh, and G. Merz, Standard Elektrik Lorenz (Stuttgart), Self-Correcting Circuit Arrangement for Determining the Signal with a Preferential Value at the Outputs of a Decoding Matrix, 3 245 034.

F. Steiner, Standard Elektrik Lorenz (Stuttgart), Omni-Directional Instrument Landing System, Particularly for Vertical Take-Off and V/STOL, 3 234 553.

K. Suhr, Standard Elektrik Lorenz (Stuttgart), Pneumatic Tube Stations, 3 226 055.

H. Tanter and G. M. E. van den Broek, Laboratoire Central de Télécommunications (Paris), Electronic Switching System, 3 230 460.

H. Tanter and G. M. E. van den Broek, Laboratoire Central de Télécommunications (Paris), Moving Targets Electromagnetic Detection Systems, 3 230 526.

H. Tanter and G. M. E. van den Broek, Laboratoire Central de Télécommunications (Paris), Moving Targets Electromagnetic Detection Systems, 3 230 529.

L. D. O. Tearne, Airmatic Systems, Pneumatic Tube Systems, 3 231 218.

E. B. Tidd, ITT Bell & Gossett Hydronics, Boiler Blow Down Tank, 3 221 712.

M. F. Toohig, ITT Federal Laboratories, Image Storage Tube, 3 243 643.

M. F. Toohig and C. L. Day, ITT Federal Laboratories, Collector for Barrier Grid Storage Tube, 3 234 422.

K. F. Treen, Standard Telephones and Cables (London), Liquid-Cooled Waveguide Load, 3 241 089.

F. J. L. Turner, Creed & Company (Brighton), Tape Winding Apparatus, 3 233 840.

F. J. L. Turner, R. G. Moore, J. Marshall, and P. R. Morrison, Creed & Company (Brighton), Plural Motor Tape Drive Including Information Searching and Tension Control, 3 244 955.

G. Vogel, Mix & Genest Werke (Stuttgart), Automatic Pulse Detector Arrangement, 3 244 811.

G. Walter and M. Müller, Standard Elektrik Lorenz (Stuttgart), Mechanical Frequency Control in a Klystron Tube Comprising a Directly Attached Rectangular Cavity Resonator, 3 226 662.

H. J. Ward and E. M. Bundy, Standard Telephones and Cables (London), Electric Pulse Signalling System Having Switching Means Connected to a Constant Voltage Source, 3 234 514.

E. C. Welch, Barton Instrument Corporation, Analog to Digital Converter, 3 228 025.

K. E. Wilson, ITT General Controls, Flexible Diaphragm Operated Valve Structure, 3 240 128.

W. R. Wirtz, ITT Kellogg, Radio Frequency Shielding Cabinets, 3 247 574.

L. G. Wolfgang, ITT Federal Laboratories, Electron Multiplier Having Undulated Passage with Semiconductive Secondary Emissive Coating, 3 244 922.

B. J. Wollar, General Controls Corporation, Pre-Set or Pre-Determined Type Counter, 3 231 190.

H. Wollmann, Mix & Genest Werke (Stuttgart), Arrangement for Adjusting the Permanent Flux of a Magnetizable Element, 3 221 311.

L. R. Woods, ITT Industrial Products Division, Oscillating Vibration Table with Air Center, 3 224 255.

E. P. G. Wright, Standard Telecommunication Laboratories (London), Data Handling System with Modification of Data Control Patterns, 3 226 676.

E. P. G. Wright, Standard Telecommunication Laboratories (London), Selective Transmission of Priority Coded Message Signals, 3 226 482.

E. P. G. Wright and A. D. Marr, Standard Telecommunication Laboratories (London), Data Processing Equipment, 3 226 681.

E. P. G. Wright, V. J. Terry, and W. F. S. Chittleburgh, Standard Telecommunication Laboratories (London), Duplex Data Transmission System Utilizing a Telephone Channel, 3 226 480.

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B. Dal Bianco and M. Scata, Fabbrica Apparecchiature per Comunicazioni Elettriche Standard (Milan), Electrical Switching Device and Method for Making, Reissue 25 988.

S. B. Silverschotz, ITT Federal Laboratories, Automatic Sorting System, Reissue 25 998.

Designs

E. L. Byer and J. L. Stark, ITT Industrial Laboratories Division, Combined Television Receiver and Printer, Design 203 342.

G. B. Kamp, Terryphone Corporation, Push Button Switch Unit for Telephone Systems, Design 203 596.

G. B. Kamp, Terryphone Corporation, Speaker for Telephone Systems, Design 203 186.

G. B. Kamp, Terryphone Corporation, Telephone, Design 203 595.

J. Kloss, Standard Telephon und Telegraphen (Vienna), Intercommunication Unit, Design 202 707.

D. F. Sementa, ITT Distributor Products Division, Portable Phonograph, Design 204 317.

D. F. Sementa, ITT Distributor Products Division, Portable Radio Receiver with Detachable Speaker Wings, Design 203 704.

R. V. Tetz, Jennings Radio Manufacturing Corporation, Hermetically Sealed Electromagnetic Relay, Design 204 137.

Slow Wave Structure Having a Plurality of Curved Conductors Disposed About the Beam and Mounted Transversely Between Opposite Walls

3 244 932

E. A. Ash

A slow-wave structure for a traveling-wave tube is described. It consists of two gratings of conductor material connected between two conductive side walls of the tube and curved apart within the walls of the envelope to provide a passage for the electron beam of the tube. The gratings form effectively an open mesh which serves to produce the desired interaction of the electron beam and the signal to be operated on.

Loudspeaking Intercommunication System

3 215 780

G. Beszedics and R. Konecny

This intercommunication system has a loudspeaker and a microphone at each of two stations. Oscillator-controlled switching relays alternately connect a common amplifier between the microphone of one system and the loudspeaker of the other. A voice-operated control for the relays interrupts the alternate switching as long as voice signals are being transmitted by one of the microphones.

Radio Navigation System

3 234 554

C. W. Earp and E. Kramar

A radio beacon includes a uniformly stacked antenna array. A transmitter is connected to cyclically energize the antennas so that the phase beat signal between direct and ground-reflected energy on a mobile craft may be used to determine the angle of elevation of the craft for a landing approach. Tilting of the array will produce a frequency modulation of the received energy which may be used for azimuth determination.

Ion Transport Pump

3 240 421

P. T. Farnsworth

An ion transport pump is designed to have two ionization compartments with a potential gradient decreasing generally from the input port to the output port. An additional electrode near the outlet port tends to neutralize charges on the ions so that they may be scavenged by a mechanical pump. The two ionization compartments each have electrodes and control devices tending to oscillate electrons at ionization velocities and to maintain a concentration of the electrons and ions.

Ignitor for Vacuum Discharge

3 218 499

J. E. Jennings

A vacuum spark gap is designed for the discharge of large amounts of energy such as are stored in a capacitor bank. It is provided with an auxiliary electrode normally in contact with one of the main electrodes. A low-power solenoid, on energization, breaks this contact and initiates a discharge between the principal electrodes. A shield is also provided to prevent vaporized metal from the electrodes from being deposited on the envelope and permanently short-circuiting the discharge gap.

Compandor System Having an Analog Signal Controlled Compressor and an Auxiliary Signal Controlled Expander

3 241 066

H. K. Ligotky

A compandor system transmits a coded pair of tone frequencies along with the information signal over a compressor which is controlled by the information signal. At the receiver the coded tone frequencies are separated from the information signal and used to adjust the gain control of the expander to restore the original amplitude range.

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Principal ITT System Products

Communication Equipment and Systems

automatic telephone and telegraph central office switching systems...private telephone and telegraph exchanges—PABX and PAX, electromechanical and electronic...carrier systems: telephone, telegraph, power-line, radio multiplex...long-distance dialing and signaling equipment...automatic message accounting and ticketing equipment...switchboards: manual (local, toll), dial-assistance...test boards and desk...telephones: desk, wall, pay-station, special-environment, field sets...automatic answering and recording equipment...microwave radio systems: line-of-sight, over-the-horizon ...teleprinters and facsimile equipment... broadcast transmitters: AM, FM, TV...studio equipment...point-to-point radio communication...mobile communication: air, ground, marine, portable...closed-circuit television: industrial, aircraft, nuclear radiation...slow-scan television...intercommunication, paging, and public-address systems...submarine cable systems...coaxial cable systems

Data Handling and Transmission

data storage, transmission, display...data-link systems...railway and power control and signaling systems...information-processing and document-handling systems...analog-digital converters...alarm and signaling systems... telemetering

Navigation and Radar

electronic navigation...radar: ground and airborne...simulators: aircraft, radar...antisubmarine warfare systems...distance-measuring and bearing systems: Tacan, DMET, Vortac, Loran...Instrument Landing Systems (ILS) ...air-traffic-control systems...direction finders: aircraft, marine...altimeters...flight systems

Space Equipment and Systems

simulators, missile...missile fuzing, launching, guidance, tracking, recording, and control systems...missile-range control and instrumentation...electronic countermeasures...power systems: ground-support, aircraft, spacecraft, missile...ground and environmental test equipment...programmers, automatic...infrared detection and guidance equipment...global and space communication, control, and data systems ...system management: worldwide, local... ground transportable satellite tracking stations

Commercial/Industrial Equipment and Systems

inverters: static, high-power...power-supply systems...mail-handling systems...pneumatic tube systems...instruments: test, measuring ...oscilloscopes: large-screen, bar-graph...vibration test equipment...pumps: centrifugal, circulating (for domestic and industrial heating)...industrial heating and cooling equipment...automatic controls, valves, instruments, and accessories...nuclear instrumentation

Components and Materials

power rectifiers: selenium, silicon...transistors...diodes: signal, zener, parametric, tunnel ...semiconductor materials: germanium, silicon, gallium arsenide...picture tubes...tubes: receiving, transmitting, rectifier, thyratron, image, storage, microwave, klystron, magnetron, traveling-wave...capacitors: paper, metalized paper, electrolytic, mica, plastic film, tantalum...ferrites...magnetic cores...relays: telephone, industrial, vacuum...switches: telephone (including crossbar), industrial...magnetic counters...magnetic amplifiers and systems...resistors...varistors, thermistors, Silistor devices...quartz crystals...filters: mechanical, quartz, optical...circuits: printed, thin-film, integrated...hermetic seals...photocells, photomultipliers, infrared detectors...antennas...motors: subfractional, fractional, integral...connectors: standard, miniature, microminiature...speakers and turntables

Cable and Wire Products

multiconductor telephone cable...telephone wire: bridle, distribution, drop...switchboard and terminating cable...telephone cords... submarine cable and repeaters...coaxial cable: air and solid dielectric...waveguides...aircraft cable...power cable...domestic cord sets ...fuses and wiring devices...wire, general-purpose

Consumer Products

television and radio receivers...high-fidelity phonographs and equipment...tape recorders ...microphones and loudspeakers...refrigerators and freezers...air conditioners...hearing aids...home intercommunication equipment... electrical housewares

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