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CONTENTS

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EDITOR, H. P. Westman **Subscription: $2.00 per year; 50¢ per copy**

This Issue in Brief

Probable Evolution of Telephony—Despite rather large short-term variations, the long-term development in telephony shows strong trends that can be described mathematically for planning purposes.

If the number of telephone lines per 100 population is called the line density and its development over the years is plotted individually for many countries, it is found that each country follows the same general law but may lead or lag other countries in time as to its present stage of development. The composite curves of many countries may be described as an exponential function or as a hyperbolic tangent. It shows an annual increase of almost 5 percent. Saturation is not yet evident.

The number of subscriber sets per line varies slowly and should reach a peak when business use, with large numbers of sets per line connected through private branch exchanges, reaches saturation. As private homes then account for further increases, the sets per line will be reduced. This may again be reversed as homes are equipped with more than one set.

The annual number of conversations per capita differs greatly among countries, even with the same line densities. It appears to increase with line density and a rough estimate can be made of it.

1000B Pentaconta Crossbar Switching System—The original Pentaconta design grouped subscriber lines in 500 units served by 2 markers. The improved *1000B* type uses 1000-subscriber groups served by 2 markers that can handle 6000 calls per hour.

Two crossbar switching stages are employed. Of the 52 outlets in each primary-stage selector, 40 are used for direct junctions to the secondary stage and 12 are reserved for alternative routing of calls within the primary units. This means of providing mutual aid or reciprocal overflow is called entraide and avoids internal blocking.

For maintenance, any subscriber line can be called from the test desk by its directory number. All switching operations are timed and if the allotted interval is exceeded a fault record of the identity and position of all engaged switching elements is automatically punched on a card. Every subscriber line is checked for insulation and abnormal voltages immediately after the dialled pulses are recorded in the register. Registers, markers, and junctions are equipped for monitoring traffic loads. The usual alarms are provided for blown fuses and abnormal currents.

The *1000B* improvements in switching, equipment, and wrapped wiring over the original *500* system are significant with regard to reliability, speed, flexibility, and interconnection with other systems including national, continental, and intercontinental networks. There are now 850 000 lines of Pentaconta in service or in course of completion.

Pentaconta Line Concentrators—A concentrator is a telephone switching means to serve a relatively large group of subscribers located near each other over a small number of rather long common trunks connected to the central office. Although concentrators are not new, the Pentaconta system with its simple circuits and robust equipment not requiring constant maintenance, has generated much interest in this method of extending the capacity of existing cable. It is particularly adaptable to residential subscribers whose average utilization is of the order of 10 minutes per day.

Three designs of Pentaconta concentrators are described. Two serve 52 subscribers over 12 and 8 common 2-wire trunks to the exchange and the other serves 24 subscribers over 6 similar trunks. The remote unit is near the subscribers and simply extends the engaged subscribers' set to the exchange over the trunk pair without effecting its electrical properties. All classes of service may thus be provided. The number of common trunks are calculated so as not to loose as many calls as are lost in the terminal selection stage at the exchange. Only 800 milliseconds are lost in obtaining dial tone and ringing over a direct connection to the central office.

As subscribers' lines represent about 60 percent of the cost of a local telephone network, concentrators offer a significant economic possibility. For a distance of 1.55 miles (2.5 kilometers) between the exchange and a group of 56 subscribers, the cost of 2 overhead 28-pair distribution cables for normal direct connections to the exchange and of one similar 14-pair cable connected to a 52-line 8-trunk concentrator, with 4 subscribers directly connected, will be equivalent.

New networks are usually designed for future expansion and have spare pairs. Concentrators would then be uneconomical for they would simply increase the number of spares. However, they may be useful in new plant serving areas distant from the exchange and having low population density. Their outstanding value is in providing for expansion of overloaded systems without laying new cable. A newer design will permit combining the exchange concentrator equipment with existing terminal selection apparatus to ease its accommodation in already crowded rooms.

Telegraph Transit Exchange Using Crossbar Pentaconta Design—The telegraph transit exchange for the Orly airport near Paris employs semiautomatic continuous-type operation using crossbar selectors and relays designed for the Pentaconta telephone switching system. Daily, it handles an average of 19 000 messages having either single or multiple addresses.

Messages of standard format are reproduced at the incoming position on a typing reperforator, the tape from which is directly threaded to a transmitter distributor. The operator notes the routing indication and selects the required outgoing junction via a crossbar multiselector. When the connection is made and the receiver motor at the destination office is running, the message is sent from the transmitter. If the outgoing channel is to a radio station, the message is first stored in a reperforator at the radio teleprinter position to permit any delay required in completing the radio circuit.

If the incoming crossbar selector is busy, the call goes to an overflow selector. If the outgoing channel is busy, the message is accepted at an overflow position which can store one extra message. If this is occupied, the message goes to the multiple-address position. Correction and transmission of messages received with faulty addresses is done at a supervisory position.

Assistant Type Telephone Set—A new series of subscribers sets called the Assistant type have been developed. In compact form with miniature components mounted on printed-circuit boards suitable for dip soldering, they are available in four different circuits to meet the needs of various administrations and in both desk and wall models.

Several types of transmitters and receivers may be assembled in the handset to produce desired operating characteristics. The handset is short to give a high signal-to-noise ratio based on presented statistics on human ear-to-mouth measurements. Amplitude-versus-frequency characteristics are given for several transmitters, receivers, and combinations.

Intercommunication Telephone Sets—There are several types of intercommunication systems, some are connected to the public telephone network while others are private. As the terminal equipment must provide for switching not normally required of a subscribers' set, the intercommunication sets are correspondingly larger. This emphasizes the need for small components and for combining functions to reduce size.

One system permits up to 5 extensions to be connected to one line to the public network. A green lamp operates on the extension connected to the exchange and red lamps on all other extensions warn that the party-line is in use. The exchange line may be held while another extension is called and the call then transferred to the second extension. Up to 10 extensions may also be served over 2 local exchange lines.

The secretarial system bridges the executive's and secretary's phones so all calls are handled by the secretary and transferred to the executive when this is desirable. The secretary may also complete outgoing calls and transfer them to the executive when the called party has been reached.

While private automatic exchanges normally provide intercommunication among all extensions, special sets permit additional services such as loudspeaker handsfree operation, direct selection, staff location, transfer, camp-on busy, priority call, and group hunting. Transistor amplifiers provide for loudspeaker operation or a handset can be used for privacy or under noisy conditions.

Another system provides for a master station and up to 10 extensions, any one of which can be called by or can call the master station. In an alternative arrangement, any of the 11 stations can call any other station and may also set up conference calls.

Matrix Multiplication in Search for Alternate Routes—A high degree of adaptability is a prime requirement of a military communication system. One of the most important characteristics of such a system is the multialternate routing scheme by means of which outage of a link or of a communication center due to war damage, or virtual outage due to a local traffic congestion, will not seriously impair the functioning of the system. The pattern of the multialternate routing must be adjusted as quickly as possible whenever the damage or the congestion becomes more widespread.

The routing pattern must be stable; the possibility of the phenomenon known as the "ring-around-the-rosie," which is a snowballing loop connection that ties up the system, has to be eliminated.

A procedure for determination of an optimum alternate routing pattern by a computer has been developed. The procedure incorporates a step by which routes that can lead to ring-around-the-rosie are eliminated as allowed routes.

The computer program can be used in the central control facility of a communication net. This facility would receive status information on the whole network, compute the optimum routing for the whole network, and send the solution to all the nodes, where the new route translators are simultaneously implemented for the whole network.

The procedure has been programed for the IBM 704 computer.

Theoretical and Practical Aspects of Telephone Traffic—The mathematical description of telephone traffic employs three distinct classes of distribution functions; the holding times of connections, the arrival times of calls, and the number of calls simultaneously in progress. An equation is derived relating these three classes.

The agreement between actual and theoretical traffic is considered. The distribution functions describing the arrival of calls agree quite well, but the simple negative exponential law for holding time does not and cannot correspond with actual conditions.

Methods of observing and evaluating actual traffic data are examined to make sure that they yield quantities which, when used in the calculations, give reliable results.

The concepts of busy hour and of quality of service are discussed as are the arithmetical rules to be applied when traffic flows merge or divide.

The strangling effect of inadequate switching is considered. Some methods are presented for estimating the traffic offered to a group of switches from observations of the traffic carried by the group.

Slow-Wave Structures for Millimetre-Wavelength Backward-Wave Oscillators—Progress in millimetre-wavelength beam tubes is closely linked with the design of the slow-wave structure that propagates the electromagnetic wave. These structures must have phase and group velocities that will minimize the effects of losses and must also avoid random reflections without incurring highly critical mechanical tolerances. Both attenuation and the interaction impedance are inversely proportional to the group velocity, which is therefore a critical design factor. It may be chosen so as to minimize the starting current or to maximize the efficiency.

The use of multiple internally combined slow-wave structures corresponds to operating several tubes in parallel. Parallel operation could, however, impose insuperable difficulties. Theoretically, where M is the number of slow-wave structures in a multiple array, the gain in power output should be about $2 \cdot 5M$. A 4-ladder array should produce an order of magnitude higher power than a single-ladder design.

Ladder-shaped structures are readily adapted to multiple assemblies and, importantly, dissipate heat readily through short elements that are connected to relatively massive heat sinks. The simple symmetrical ladder does not propagate a wave as its rungs, acting as resonators, are equally and oppositely coupled by the electric and magnetic fields. Several methods are shown of perturbing one field and so providing a pass band. A design having a wide pass band and means for matching the slow-wave multiple ladder structure to a waveguide is discussed.

Lewin Receives Papers Awards

Leonard Lewin of Standard Telecommunication Laboratories at Harlow, Essex, England, has received two awards for his paper "On the Resolution of a Class of Waveguide Discontinuity Problems by the Use of Singular Integral Equations" that appeared in the IRE Transactions of the Professional Group on Microwave Theory and Techniques for July 1961.

The Professional Group awarded him its annual Microwave Prize of $100 and the parent organization, the Institute of Radio Engineers, gave him its annual W. R. G. Baker prize of $1000 for the best paper published in all of the transactions of its Professional Groups.

Mr. Lewin joined Standard Telecommunication Laboratories in 1946 and is now assistant manager of the Telecommunication Transmission Systems Division in charge of developing microwave systems. His book on the *Advanced Theory of Waveguides* was published in 1951.

Recent Achievements

Data-Transmission Error-Rate Analyzer—An error-rate analyzer employing transistors has been produced for development, factory testing, alignment, and maintenance of data-transmission systems. It is shown in Figure 1. Measurements may be made on actual traffic. Each analyzer contains all the equipment needed for the measurements, which are made on a synchronous basis.

Element error rates and various kinds of time distortion can be measured. The probability of time distortion exceeding a selected degree may be evaluated. Mutilation disturbances may be studied.

For point-to-point measurements, 24 crystal-controlled modulation rates are available between 45 and 3000 bauds and, for closed-loop measurements, the modulation rate is continuously adjustable from 25 to 3000 bauds.

A variety of modem characteristics can be tested with a white-noise generator. The error rate may be obtained for different signal-to-noise ratios. Phase and attenuation distortion of a modem and line may be expressed as impairment in decibels. The relative merits of different midchannel frequencies may be determined. With the use of an error-distribution analyzer, detailed studies can be made of error occurrence.

Standard Radio & Telefon
Sweden

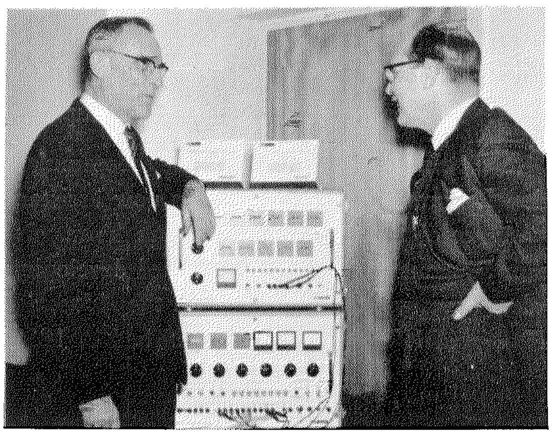

Figure 1—Dr. H. Sterky, General Director of the Swedish Board of Telecommunications, left, and Managing Director F. Hammar of Standard Radio & Telefon discuss the error-distribution and error-rate analyzers shown in the picture.

Laser Displayed to French Society of Physics—Four laser equipments were displayed and demonstrated at the Paris exhibition of the French Society of Physics in October 1962.

Of the two gas lasers shown, one was a simplified design primarily for instruction use and the other was a high-stability unit for research. In the latter, the gas tube and mirrors are readily adapted to the study of a wide range of wavelengths. Two low-power pulsed ruby lasers were also exhibited. See Figure 2.

More recently, at the Third Symposium of Quantum Electronics, there was presented a high-stability gas laser emitting continuously a strong red-orange light beam at a wavelength of 0.63 micron.

Laboratoire Central de Télécommunications
France

Figure 2—Mr. G. Palewsky, Minister in charge of Scientific and Technical Research, listens to a description of how a ruby laser beam may machine small holes in hard razor-blade steel given by Mr. Cagnard, head of the physics department of Laboratoire Central de Télécommunications.

Record-Communication Automatic Switching System—Fast switching, great flexibility, and inherent security are achieved in a record communication system by using a digital computer having a stored program to control the receiving, analyzing, processing, storing, re-routing, and transmitting of messages and data. It is capable of handling various transmission speeds, codes, and message formats to and from hundreds of addresses.

Installed in the United States embassy in Paris, the initial ITT 7300 ADX automatic exchange is the center for the European communications of the State Department. An on-line real-time fully automatic system, information may be received simultaneously from high-speed data transmitters and standard 60-word-per-minute teleprinters. Lower-priority traffic will be stored automatically to make way for urgent messages.

ITT Information Sytems Division
United States

New Zealand-Fiji Cable Inaugurated—The light-weight deep-sea telephone cable linking Auckland, New Zealand, with Suva, Fiji Islands, over a stretch of 1150 nautical miles (2130 kilometers) was placed in service on 3 December 1962. It is the second link in Compac, the trans-Pacific submarine telephone cable system.

The new cable provides for 80 simultaneous 2-way telephone conversations. It is equipped with 37 submerged repeaters and 6 submerged equalisers.

Standard Telephones and Cables
United Kingdom

Gallium-Arsenide Laser—New techniques have produced gallium-arsenide of both very-high purity and crystal perfection, and point-contact and diffused-junction diodes made of it have emitted noncoherent light. This suggested the development of a laser, which was successfully operated in January 1963.

Laser action occurs above a threshold current density of about 2000 amperes per square centimeter, which is considerably lower than previously reported values. The infra-red emission is polarized and spatially coherent. Above the threshold, the bandwidth is less than 5 angstrom units, while below the threshold it is about 150 angstrom units.

In Figure 4, the emission pattern observed on an image converter tube shows interference fringing caused by reflections from the base plate and, therefore, parallel to the junction plane. At right angles to this plane is the bright band of laser emission with line narrowing. It is polarized along the line of the junction.

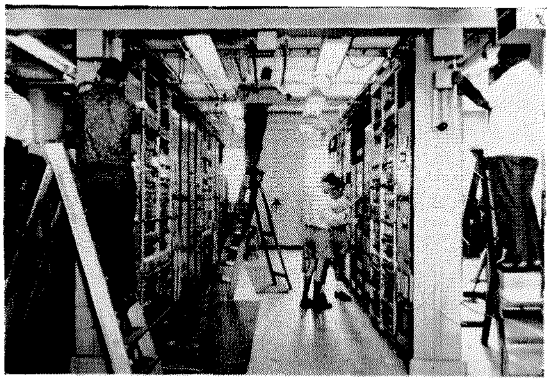

Figure 3—Installation work at the Suva terminal of the New Zealand-Fiji submarine telephone cable installation.

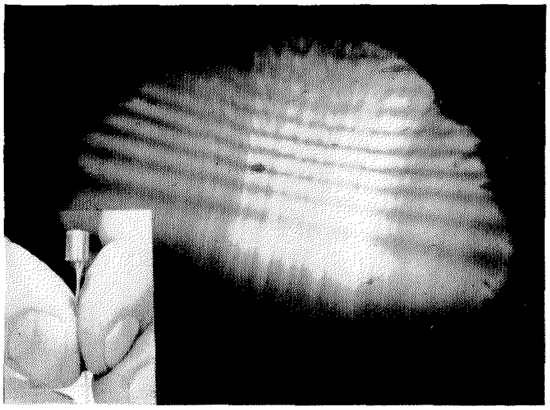

Figure 4—Gallium-arsenide laser capsule and emission pattern.

An interference pattern, probably resulting from light from different points of the junction, indicates spatial coherence.

Standard Telecommunication Laboratories
United Kingdom

Radio Guidance for Blind Landing—Under completely fogbound conditions that grounded all other air traffic, a Ministry of Aviation aircraft recently made the first fully automatic blind landing at London airport. The perfect landing was controlled by information supplied to the automatic pilot from a radio altimeter and from the STAN.7 localizer and STAN.8 glide-slope equipments that are now standard at Britain's main airports.

Standard Telephones and Cables
United Kingdom

Transmitting Antenna for Television Bands III and V—A 172-meter (563-foot) circular reinforced-concrete tower on the Donnersberg in Palatina supports an antenna array for television band V. It consists of a 20-meter (65.6-foot) steel hexagonal mast, on each face of which antenna arrays are arranged in 9 tiers, as may be seen in Figure 5. The center section receives more power than the others and this produces a smooth vertical radiation pattern for angles from 0 to −10 degrees. The vertical gain is approximately 16 decibels over a half-wave dipole.

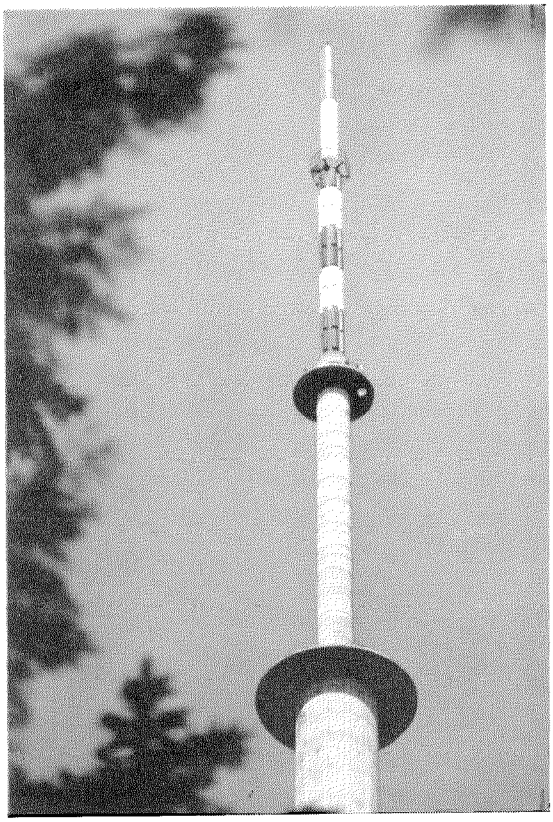

Figure 5—Antennas for television transmission on bands III and V.

Atop the band-V antenna, which is used for the second program and will be used later for a third program, is a 13-meter (42.6-foot) cylindrical slot antenna for band III. Four stacked cylinders each having four vertical slots provide a vertical gain of about 11 decibels.

The plain cylindrical surfaces of these antennas minimize the accumulation of ice and offer low resistance to wind, which can be very strong at their elevation of about 900 meters (3000 feet) above sea level.

Standard Elektrik Lorenz
Germany

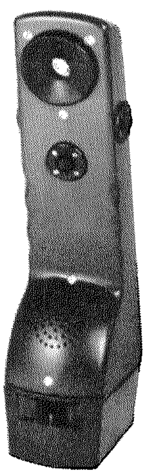

Figure 6—Lightweight field telephone set.

Lightweight Field Telephone—Designed primarily for military field service and suitable also for civilian field activities, the watertight telephone set shown in Figure 6 weighs only 750 grams (26.5 ounces).

It is a complete telephone system that may be connected to the public telephone network or to a radio system. In addition to the telephone set, there is a switching unit, a call converter for connection to a local or to a common-battery telephone system, and a remote control unit for use with a radio transmitter and receiver. It was developed in cooperation with Standard Elektrik Lorenz.

Bell Telephone Manufacturing Company
Belgium

Radio Link for Rural Telephony—For use in sparsely populated regions, a radio link to connect a subscriber over distances up to 30 kilometers (18.6 miles) to a telephone central office has been developed. The 500-milliwatt transmitter uses frequency modulation in the 148–174-megahertz band. Signalling is done by keying the carrier.

The use of transistors permits operation from dry cells with reasonable replacement demands. The power required in the stand-by condition has been minimized. A subscriber terminal is shown in Figure 7.

Standard Eléctrica
Spain

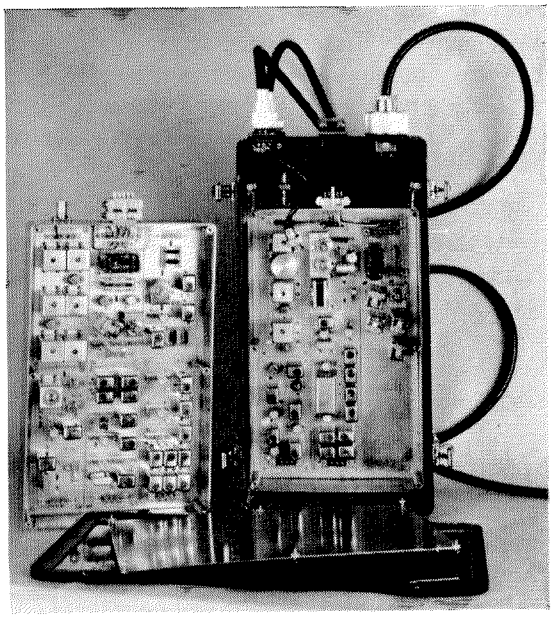

Figure 7—The receiver (left) and transmitter for the radio terminal to connect a subscriber to the nearest telephone exchange.

Pentaconta Exchanges in Chile and Philippines—Three Pentaconta telephone exchanges were cut over in October 1962 at Antofagasta, La Cisterna, and San Bernardo in Chile. They have 3800, 3000, and 1500 lines, respectively. Mr. Jaime Silva, Home Undersecretary of State of the Chile government, officiated in placing the exchanges in service.

A 1500-line Pentaconta exchange was officially opened in Zamboanga on Mindanao island by the wife of President Macapagal of the Republic of the Philippines.

These new exchanges bring to 17 for Chile and to 4 for the Philippines the installations of Pentaconta in these countries since 1955.

Compagnie Générale de Constructions Téléphoniques
France

Multiple-Angle Diversity Radio Transmission—An experimental radio system uses a 28-foot (8.5-meter) paraboloidal reflector to radiate 7 separate beams, each from its own transmitter. Two corresponding receiving antennas, each with 7 collector horns, parametric amplifiers, and recorders compile statistics on the 14 received signals for analysis by data-processing equipment. This experiment, under contract with the United States Air Force Rome Air Development Center, permits a single paraboloidal antenna to transmit or receive over several diverse paths.

ITT Federal Laboratories
United States of America

Telephone Traffic Measuring Set—Measurement of the occupation of junction groups, registers, selection stages, and other facilities in telephone toll offices and rural main exchanges may be made automatically and recorded by a teleprinter with a new test set.

The program circuit controlling the sequence of operations and the connecting of the measuring circuits to the equipment under observation use relays whereas the measuring, summing, translation, and printing are done electronically. Finders are used as storage elements and also as the time base for the teleprinter.

In Figure 8, the access selectors within the exchange are marked by a scanning circuit that is at the top of the bay. The electronic scanner is mounted below and explores the terminals under test at the appropriate times and determines the number of occupancies. The internal timing circuit is controlled by the exchange master clock.

An electronic translator and converter transform the stored information into teleprinter code for recording. Operation is from the 48-volt exchange battery, augmented by built-in power supplies.

Standard Telephone & Radio
Switzerland

Error Correction of Data Transmission at 170 Characters per Second—Tests over the public switched telephone network of Sweden confirm the high accuracy of an error-correction system used in transmitting data between tape, cards, or two computers. As no error has passed uncorrected in the tests, it is probable that only a component failure will disable the equipment.

Error detection is performed on a character-by-character basis and employs an analog-type disturbance detector in combination with a simple code control. Errors are detected at the receiver and correction is achieved by retransmission. The modems use frequency-shift modulation and are suitable for speeds of 600 to 1200 bauds. The return channel over which repetition is requested operates at only 75 bauds.

An installation with tape input and output operating at 133 characters per second has been delivered to the Swedish Board of Telecommunications. A receive terminal is shown in Figure 9.

Standard Radio & Telefon
Sweden

Three-Dimensional Electrocardiograph—By applying three pairs of electrodes to the human body to sample the electric activity of the heart in three orthogonal planes, a single pattern can be produced on a cathode-ray tube in which variation in brightness is the third "dimension."

The single presentation shows the instantaneous relations among the three directional activities, which would not be clearly evident if the three views were displayed separately. Now under evaluation in a research hospital, it is anticipated that this will become another diagnostic tool in the war against heart disease.

ITT Federal Laboratories
United States of America

Data Transmission Demonstration—Throughout the last quarter of 1962, demonstrations were made of a 1000-baud data transmission system that connected by telephone line a data processing center and a large number of users.

Four agents equipped with special keysets were connected, via a station capable of accommodating 100 agents, to a message control cubicle in which a simulator substituted for a central processor. Each agent sent queries to the simulator and received information in return within 1 or 2 seconds.

Another arrangement connected 12 agents with the simulator over 50-baud telegraph circuits

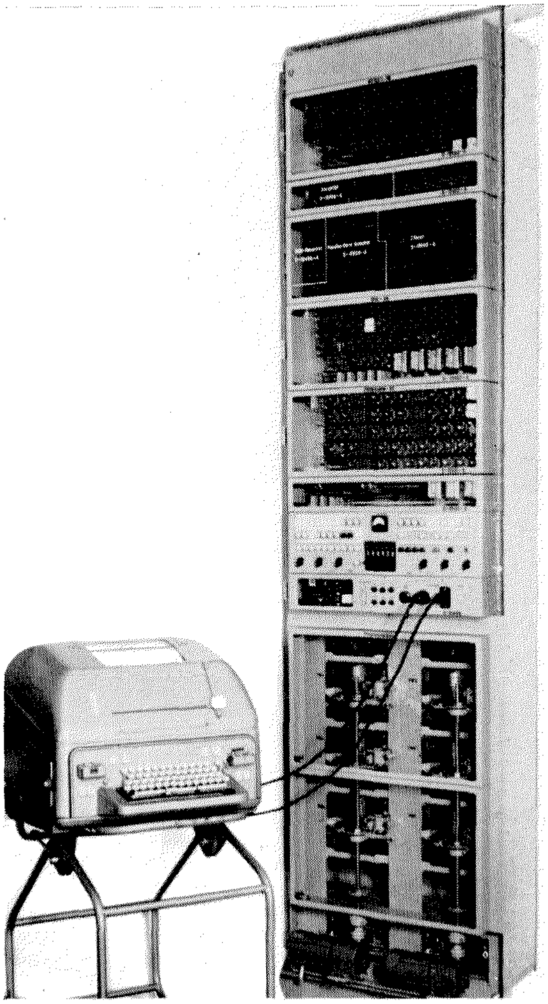

Figure 8—Telephone traffic measuring equipment.

through a parallel-to-serial converter and a subscriber concentrator.

To ensure accurate transmission of all messages, automatic repetitions were made each time a parity fault was detected.

Le Matériel Téléphonique
France

7E Telex Exchanges in Italy—During 1962, automatic telegraph exchanges were installed in Cagliari, Catania, Catanzaro, Florence, Genoa, Naples, Palermo, and Rome, for the Italian Ministry of Post and Telecommunication. The Rome exchange, in addition to handling national calls, also controls international and intercontinental traffic. Bell Telephone Manufacturing Company of Belgium collaborated in this work.

Fabbrica Apparecchiature per
Comunicazioni Elettriche Standard
Italy

Infrared Tracking—A high-resolution infrared tracking system has been placed in operation at the Cape Canaveral missile range. It is particularly useful during the launching period of a missile when ground clutter masks the significant radar signals.

Mounted on the antenna pedestal of an AN/FPS-16 instrumentation radar, as shown in Figure 10, the angle-error signals from the infrared tracker keep the pedestal on target until the ground clutter disappears and reliable radar tracking can be obtained. Switching between infrared and radar may be either manual or automatic.

The bright Florida skies place great importance on a high degree of background suppression, while close proximity to large missiles at

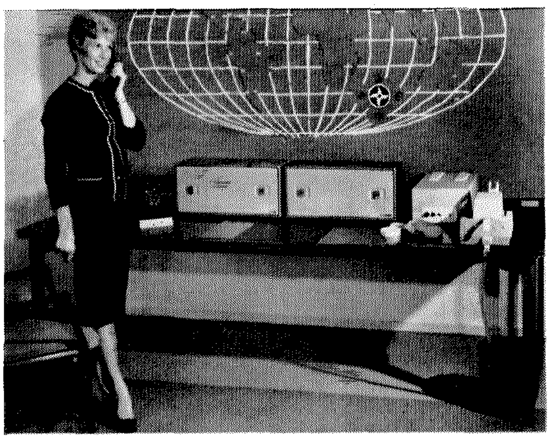

Figure 9—Receive terminal of data communication system with error correction equipment.

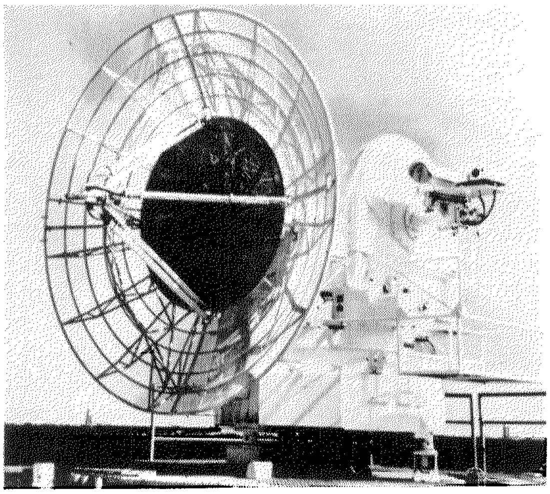

Figure 10—The infrared tracker is in the box mounted at the upper right of the AN/FPS-16 radar.

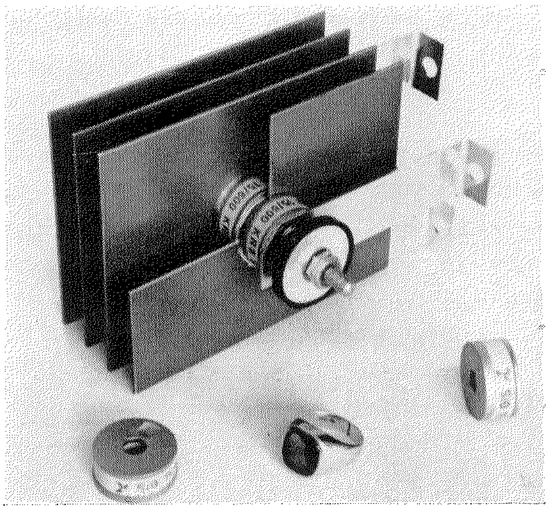

Figure 11—Silicon ring-type rectifier cells and arrangement for mounting in a stack of fins similar to selenium-rectifier practice.

launch and the necessity of tracking small missiles at great range necessitate a dynamic range of sensitivity of 100 000 to 1. A single detector cell provides both radiometric and tracking information. It is protected from damage from direct sunlight by an automatically operated shutter.

ITT Federal Laboratories
United States of America

Silicon Rectifier Stacks—Compact, easily mounted, high-capacity silicon rectifiers are now available in the stack-type of assembly well established over the years for selenium rectifiers.

A diffusion-type silicon rectifier is mounted in a ceramic ring sandwiched between large contact plates that readily transfer heat to suitably dimensioned fins. Any required number of these Silring rectifiers may be assembled with cooling fins and connecting strips on an insulated bolt, which also provides for mounting the stack. The design is evident from Figure 11.

Ratings between 2.5 and 280 amperes are available and may be doubled for forced-air cooling. At an ambient temperature of 50 degrees centigrade, a 2.5-ampere unit without fins will handle 5 amperes with 50-by-50-millimeter (2-by-2-inch) fins, 10 amperes with 75-by-100-millimeter (3-by-4-inch) fins, and 15 amperes with 125-by-125-millimeter (5-by-5-inch) fins.

Standard Elektrik Lorenz
Germany

Ground Beacon for Air Navigation Distance Measuring—A ground beacon for civilian use as part of the Vordac air-navigation system has been developed basically on the designs by ITT Federal Laboratories and Standard Telephones and Cables (London) of military tacan beacons. It meets the specifications of the International Civil Aviation Organization.

The *FSD.1* beacon shown in Figure 12 includes duplicate transponders and monitors, antenna system, remote control unit for both beacon and monitor operable over 36 kilometers (22.4 miles), and other accessory equipment.

If the monitor indicates a fault in transmission, the standby monitor will be placed in operation and only if it confirms the fault will the standby beacon be put in service.

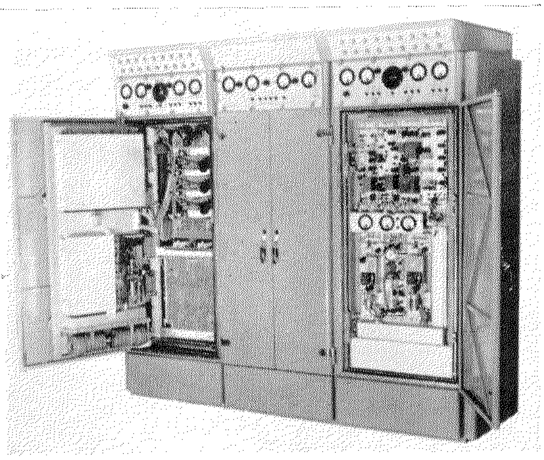

Figure 12—Ground beacon for distance-measuring element of Vordac air-navigation system.

The antenna system produces an omnidirectional horizontal pattern and in the vertical plane a gain of at least 9 decibels referred to a half-wave dipole.

Emphasis has been placed on reliability and accuracy. Direct access from the front is provided to all vacuum tubes and tuning circuits. Long-life klystrons also have high linearity for stability. All components are of established reliability as is essential for equipment for unattended operation.

Fabbrica Apparecchiature per Comunicazioni Elettriche Standard
Italy

Multicolor Processor and Projector for Computer Readout—This processor and projector is capable of working with any computer that provides for multicolor or black-and-white readout. The three primary colors, their complementary colors, and white on black may be produced by the color-addition principle.

The demonstration model projects the processed image on a 12-inch (305-millimeter) screen but this can be increased by suitable optics. The exposure and processing time, which precedes display, is only 8 seconds. The accuracy to which an image can be positioned depends only on the precision of the symbol generator and is very high. Among the uses of such a device are military command, air-traffic control, and the presentation of complex data.

ITT Federal Laboratories
United States of America

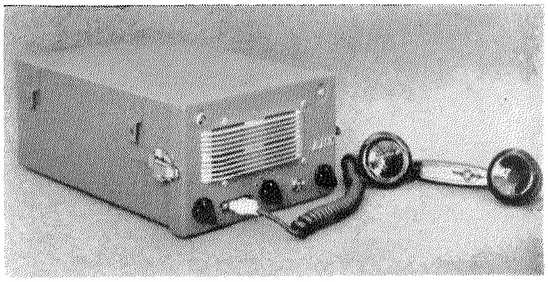

Figure 13—Very-high-frequency transceivers used by the French security services.

Mobile Transceiver—Since 1959, about 3000 transceivers of the type shown in Figure 13 have been manufactured by Le Matériel Téléphonique to equip most of the vehicles of the French police, fire, and ambulance services and of important administration officials.

Making extensive use of transistors, the equipment operates in the 70-to-90-megahertz band. The transmitter delivers about 20 watts to the antenna.

Le Matériel Téléphonique
France

Small Radio Transceivers—In the survival unit of astronaut Walter M. Shirra, Jr. in his MA-8 flight was a 15-ounce (425-gram) radio transceiver that fortunately he did not need. Had the astronaut landed outside the planned area, as happened in an earlier test, he could have been in voice communication over a distance of about 20 miles (37 kilometers) with aircraft flying at 5000 to 10 000 feet (1524 to 3048 meters). The crystal-controlled transceiver is operated from two mercury cells. Over a hundred homing receivers are installed in the search aircraft.

For intercommunication within a team such as in a space craft, for missile refueling, fire fighting, and warehouse operating, where high noise levels or other hazardous conditions exist, a 9-ounce (255-gram) compact radio transmitter and receiver provide duplex hands-free operation through the use of voice switching of the transmitter. The equipments may be operated with each other and a base station may also be employed for supervisory control.

ITT Kellogg Communications Systems
United States of America

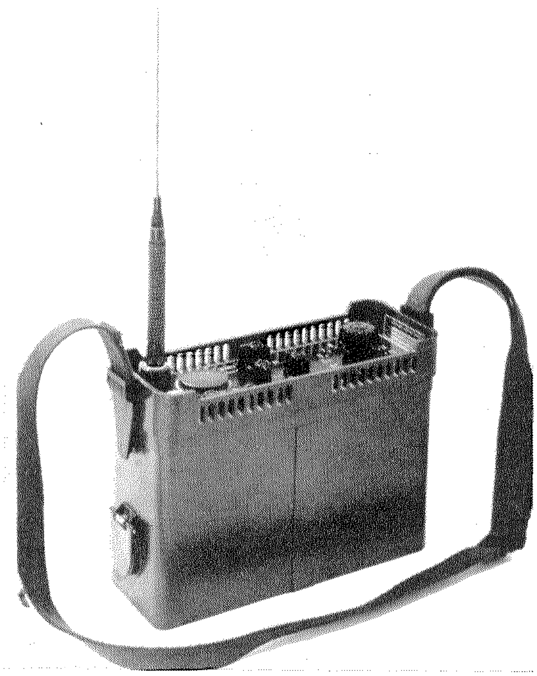

Figure 14—Portable air-raid-warning receiver operating in the very-high-frequency band.

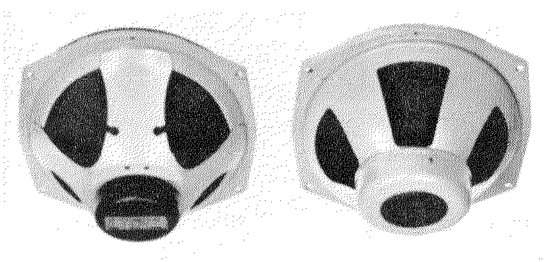

Figure 15—Magnetically shielded loudspeakers that avoid picture distortion in portable television receivers where the loudspeaker is mounted near the picture tube.

Air-Raid-Warning Receiver—The air-raid-warning receiver shown in Figure 14 covers the band from 35.85 to 36.55 megahertz on which early warnings and reports will be broadcast for use by emergency services and places such as theaters in which there are large assemblies of people.

The double-heterodyne transistor receiver employs a 12-circuit filter in the second intermediate-frequency section to provide high selectivity. A switch permits selection among 15

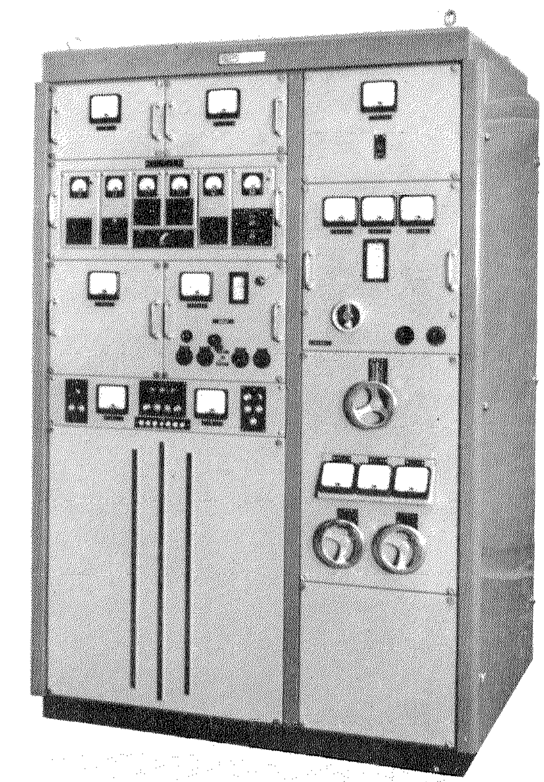

Figure 16—High-frequency 4-kilowatt marine radio transmitter.

channels and crystal control of the oscillator ensures adequate frequency stability.

A replaceable battery operates the set for 50 hours and it may be connected to the alternating-current mains for continuous operation and battery charging. Alternatively, it will work from any 6-to-24-volt vehicle battery.

The sturdy spray-waterproof case is 187 by 245 by 95 millimeters (7.4 by 8.6 by 3.7 inches) and has a belt for over-the-shoulder or arm carrying.

Standard Elektrik Lorenz
Germany

Magnetically Shielded Loudspeaker—Portable television receivers often place the loudspeaker very close to the picture tube and nonlinearity of scanning may result from the magnetic field of the loudspeaker.

A new series of oval-diaphragm loudspeakers, shown in Figure 15, having specially shielded 7000- and 8000-gauss magnets have been produced for this service. The basket dimensions of the 3 sizes are 130 by 180 millimeters (5.1 by 7.1 inches), 150 by 210 millimeters (5.9 by 8.3 inches), and 130 by 260 millimeters (5.1 by 10.2 inches).

Standard Elektrik Lorenz
Germany

Multifrequency Code Signalling Between Pentaconta Exchanges—The first installation for multifrequency code signalling between Pentaconta liaison telephone exchanges in France became operative between the Albi and Mazamet exchanges in the Toulouse area. Further installations are being made in this and in the Lyons areas.

Each signalling code group consists of the simultaneous transmission of 2- out-of-5 frequencies between 700 and 1700 hertz. The called number is sent digit by digit at the request of the distant exchange, which also signals its receipt and termination of that transmission. The distant exchange also uses this code to signal the condition, free or busy, of the called line.

Compagnie Générale Constructions Téléphoniques
France

Single-Sideband 4-Kilowatt Radio Transmitter—The new ocean liners: *Marconi, Galilei, Michelangelo,* and *Raffaello* will be fitted with recently developed 4-kilowatt radio transmitters for operation between 2.5 and 22 megahertz.

The F.912 radio transmitter is shown in Figure 16 and is designed primarily for high-quality radiotelephony. In addition to double-sideband operation, either single-sideband or independent-sideband transmission may be used and each sideband may provide for 2 commercial-quality telephone channels and 3 teleprinter channels. Amplitude and frequency-shift telegraph keying is also available.

The units include exciters, modulation equipment, and power supplies. They feature rapid frequency change and simple tuning. The telephone terminal equipment and radio receivers will also be supplied.

Fabbrica Apparecchiature per
Comunicazioni Elettriche Standard
Italy

Probable Evolution of Telephony *

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1. Introduction

In planning the future development of a telephone network, it is necessary to estimate how the present number of telephone lines, sets, or conversations will expand during the next 5 or 10 years. Although many personal estimates are founded on experience, systematic and generalized studies are rather scarce. Conclusions reached in this way, even though sketchy or incomplete, should provide useful guidance.

A consideration of statistical data on telephone development in a number of countries may permit the derivation of some laws or rules for predicting future numbers of telephone lines, sets, or conversations. As telephone developments are easily influenced by numerous unpredictable factors, all conclusions reached in this study must be regarded only as probable for the time being and far from being certain.

* This paper is a revision of one presented at the Third International Teletraffic Congress in Paris on 15 September 1961.

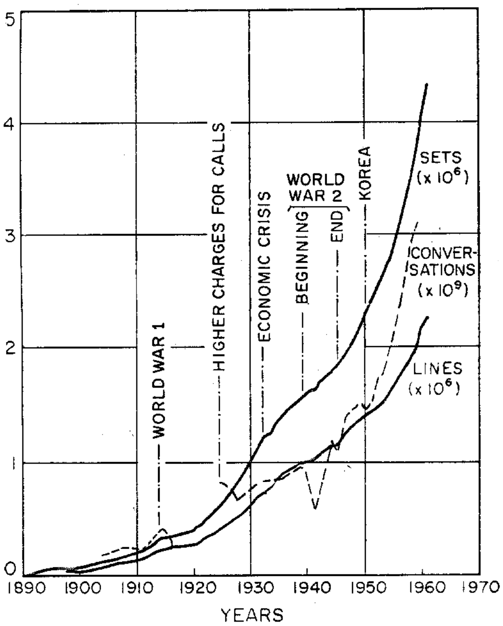


Figure 1—Telephone development in France.

2. Disturbances in Evolution

The use and number of telephones in any country increases regularly with time but with occasional irregularities due to economic crises, wars, or other events. Figure 1 shows such an evolution for France since 1890.

The influence of such disturbing elements on the normal trend of the growth curve will be briefly investigated with the help of some characteristic examples.

2.1 Economic Crisis of the 1930's

Not every country was upset to the same extent by the economic crisis of the 1930's. From the telephone viewpoint, it was most heavily felt in such countries as the United States of America, Canada, and Germany, while others suffered only mildly, if at all.

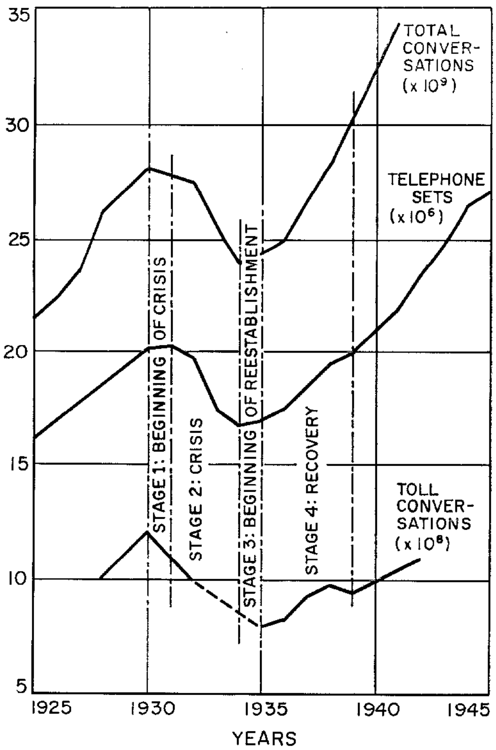


Figure 2—United States telephone sets and conversations during the economic depression of the 1930's.

Starting late in October 1929, this crisis developed in several phases, not all of which occurred in every country or at the same time in various countries.

An early effect was a slowdown in growth of or even a reduction in the total number of telephone conversations, which was most marked for toll calls. The number of subscriber sets remained constant or increased less rapidly. These changes stemmed from lessened commercial activity with its reduced need for long-distance business calls, while local business and social conversations were not affected to the same degree. As everybody hoped that the depression would be short lived, telephones were retained although there was little inclination to install new ones.

Figure 2 illustrates this history for the United States. Similar diagrams can be drawn for other countries among which Germany and Canada show corresponding sharp regressions, while others are less markedly affected.

The second stage showed a still sharper decline in communications, which now also included local traffic, as well as a decrease in the number of telephone sets as businesses were then forced to reduce expenses or even to discontinue operations entirely.

When the lowest point (1933 in the United States) was passed and business recovered slowly, the number of conversations increased again while the number of sets tended to stabilize as there was still some apprehension for the future.

At last after the general restoration of commerce, all the curves resumed a regular increase and, after some 5 to 8 years, the situation existing before the crisis was again reached. As the Second World War broke out shortly afterwards, it is difficult to prove that the re-establishment of telephone communication had a tendency to accelerate and thus to compensate for the losses during the crisis, but every indication points in that direction.

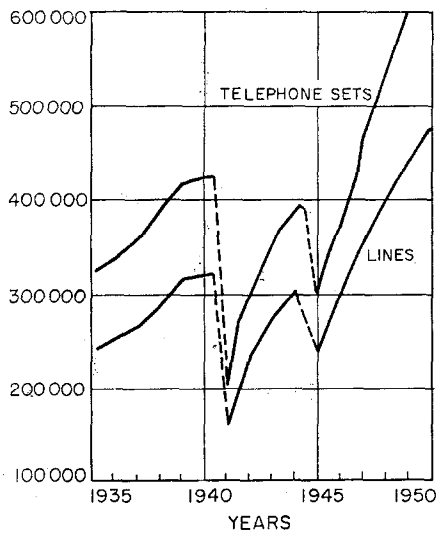


Figure 3—Effects of Second World War on telephony in Belgium.

2.2 Second World War

A considerable amount of information is missing for the period of the Second World War so that an over-all interpretation seems impossible. Nevertheless, there are no apparent signs that telephone development in countries that did not suffer from direct war activities and devastations was influenced by the hostilities.

Even in the countries of Western Europe in which the actual fighting occurred, the number of sets kept increasing although often at a slower pace because of shortages of raw materials. Sharp drops can be noted, however, where the actual fighting occurred with the concomitant destruction of equipment. After the battle front moved, there was a quick recovery that, however, was also incomplete as all equipment could not be repaired immediately. An example of this can be seen in Figure 3, which gives the number of lines and sets in Belgium from 1935 to 1950.

The number of conversations, especially for long distances, seems still more closely related to the events as can be seen in Figure 4, which shows their history in Belgium during the war and the immediate postwar period. Similar sharp drops in the conversations at the beginning and the end of the war can be seen for France in Figure 1, while the number of lines and sets grew steadily.

After the war, all countries experienced a very rapid improvement as repairs and extensions of equipment in a few years compensated for the losses. Normal expansion was then resumed.

2.3 Other Disturbances

Next to these general crises, the particular national tribulations of the different countries are also reflected in their telephone communications.

Some events extend their influence over a considerable area. Thus, the Korean war in 1950 caused a marked drop in conversations as can be seen in Figure 1.

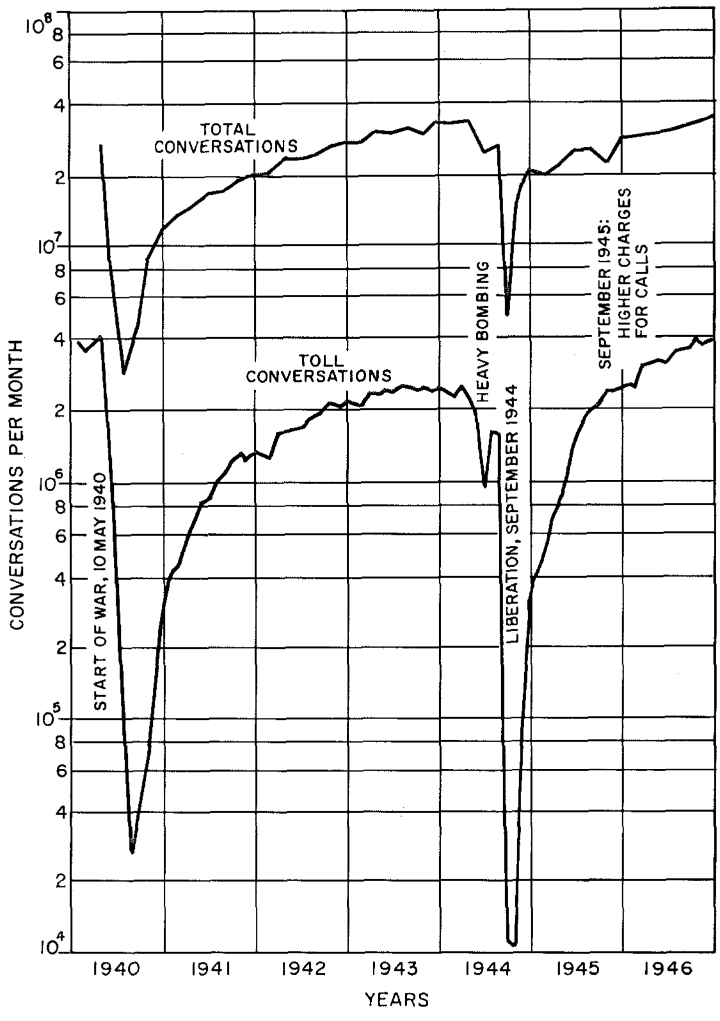


Figure 4—Conversations in Belgium in the war period.

Increased charges for calls reduces traffic, at least for a certain time. Figure 4 shows the result in Belgium of somewhat higher charges imposed in September 1945, and Figure 1 the effects in France in 1924 of imposing charges for conversations that had previously been partially free.

In general, social, economic, and political events have a tendency to influence toll traffic first; local traffic is affected somewhat later if the crisis continues. The number of operative telephone lines and sets decreases only after a long and violent economic crisis or through direct destruction.

In every case, each drop is compensated for after a few years and we can disregard those temporary crises in a general study.

3. Number of Telephone Lines

The term *telephone line* can be misleading when encountered in statistics. Often the term subscriber's line is used instead but this does not necessarily imply that every city line of a private branch exchange is taken into account. Another question is whether in party-line operation each party is counted as an individual line. As information on the number of lines is readily found in the yearly statistical survey of the International Telecommunications Union, its definition of line is adopted.

The number of telephone lines in a country can be related to its population. The line density is the number of lines L divided by the number of inhabitants N, or in percent

$$d = 100\ (L/N). \qquad (1)$$

This line density can be very different from one country to another as it depends on economic, technical, and social levels. It increases steadily when temporary crises, which are compensated for in the following years, are ignored.

As quite accurate forecasts can be made of population increases, if a general law for the growth in line density could be found, it would be possible to predict the probable number of lines in a country at a future date.

3.1 General Law of Line Density

It is remarkable how the line-density curves of some countries coincide with each other. The density in Switzerland from 1940 to 1961, for instance, is substantially the same as that in Sweden from 1931 to 1952. Thus, the Swiss line density seems to lag that of Sweden by some 9 years. Figure 5 shows this superposition.

Application of the same procedure to many countries produces a composite development curve from which it is evident that within a small deviation, each country follows the same general law in the evolution of its line density. Its present or future state of development can be expressed as a function of time.

$$d = f\ (T + c) \qquad (2)$$

where T is time in years and c is a constant indicating the time lead or lag with respect to other countries.

The trend of this general law of evolution can be seen when the density curves of several countries are superposed in such a way as to cover a minimal area. The result is shown in Figure 6, where a number of density curves from 1930 to 1961 are superposed. The zero of the time scale coincides with the smallest density used in the superposition operation. The figure shows the line density for each indicated country as of 1 January 1961.

The effectiveness of this procedure indicates clearly that growth of line density follows some general rule. Certain features should be noted.

(A) The relative deviation from the average is more pronounced in the early years. The fact that many individual density curves occupy this region tends to produce a higher probability of deviation. The war period for many countries is also situated in this part of the diagram, resulting in some erratic behavior due to partial destruction of the telephone plant.

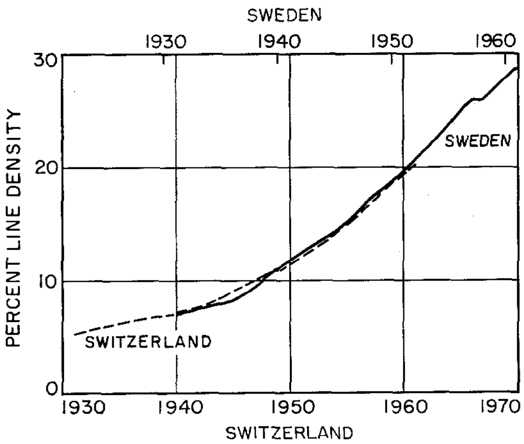


Figure 5—The line-density development in Switzerland is similar to, but 9 years later than, in Sweden.

As the trend changes substantially in the reconstruction period after the war, these short-time departures from the general trend do not invalidate the over-all superposition procedure. Also, the line density being a percentage of population, it will change most rapidly with increases in lines in countries having only a small number of telephones. In such cases, greater deviations from the average must be considered to be normal.

(B) There are countries that do not conform to this pattern. Denmark and Argentina seem to be developing at half speed, and France is also slowed down but to a lesser degree. When investments in the telecommunications system do not entirely cover the necessary expansion, there will be a serious handicap in development. This seems to be the case for France, where budget reasons delay normal development; there are, consequently, thousands of unsatisfied applications for telephones (some 115 000 at the beginning of 1959). If for social or economic reasons, a large part of a population is not interested in having telephones, the over-all picture of that country will show a slower development even if the remaining part of the population follows the general trend. This might explain the evolution in Argentina and similar countries. The reason for the slower evolution in Denmark is not evident, but the fact that only 56 percent of the network is automatic has perhaps some influence.

Figure 6—Composite line-density curves for various countries as a function of time in years t and a constant c of relative lag or lead with respect to all others. The development of each country is indicated as of 1 January 1961.

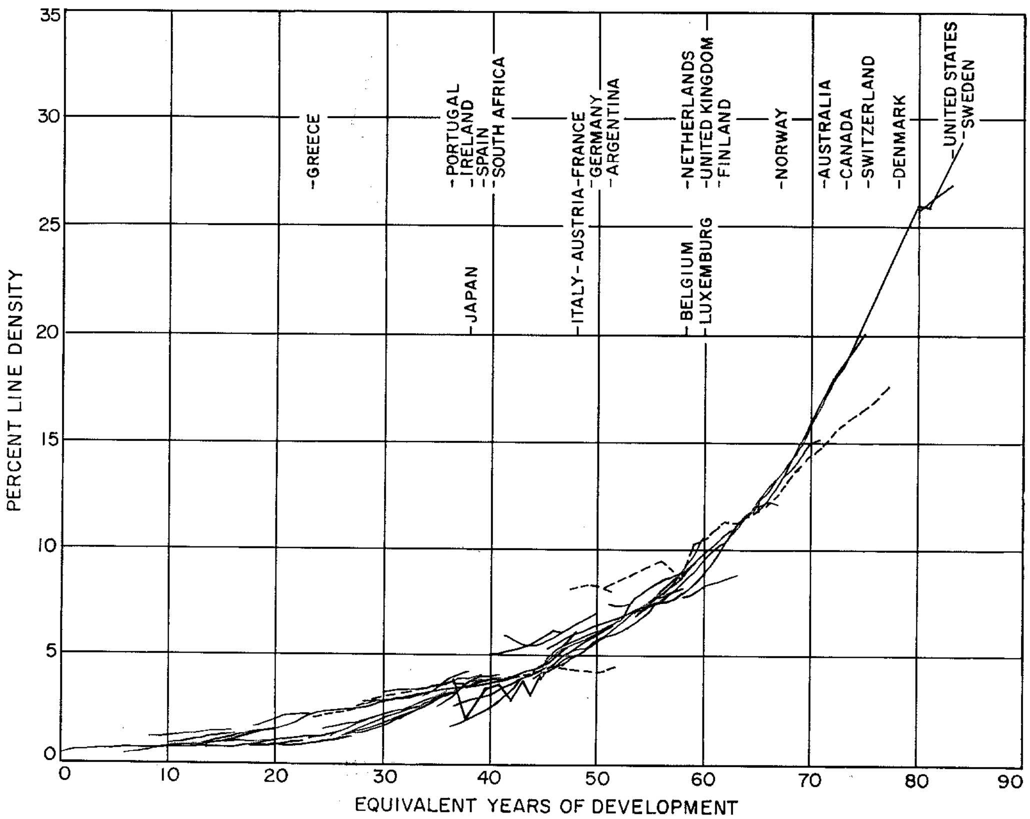


Figure 7 shows the average of the composite curves of Figure 6. It represents an experimentally derived general law of the line-density evolution. Two limit curves only 1 line per 100 inhabitants distant from the average, enclose quite satisfactorily all the component curves.

Expression (2) can be formulated as

$$d = f\ (t + c). \qquad (3)$$

Here $(t + c)$ is time as shown in Figures 6 and 7 and defined for 1961 by

$$t = T - 1961.$$

Figures 6 and 7 are based on $T = 1961$ and include $t = 0$, and the values of c in years for the different countries, can be read directly on the abscissa scales of Figures 6 and 7.

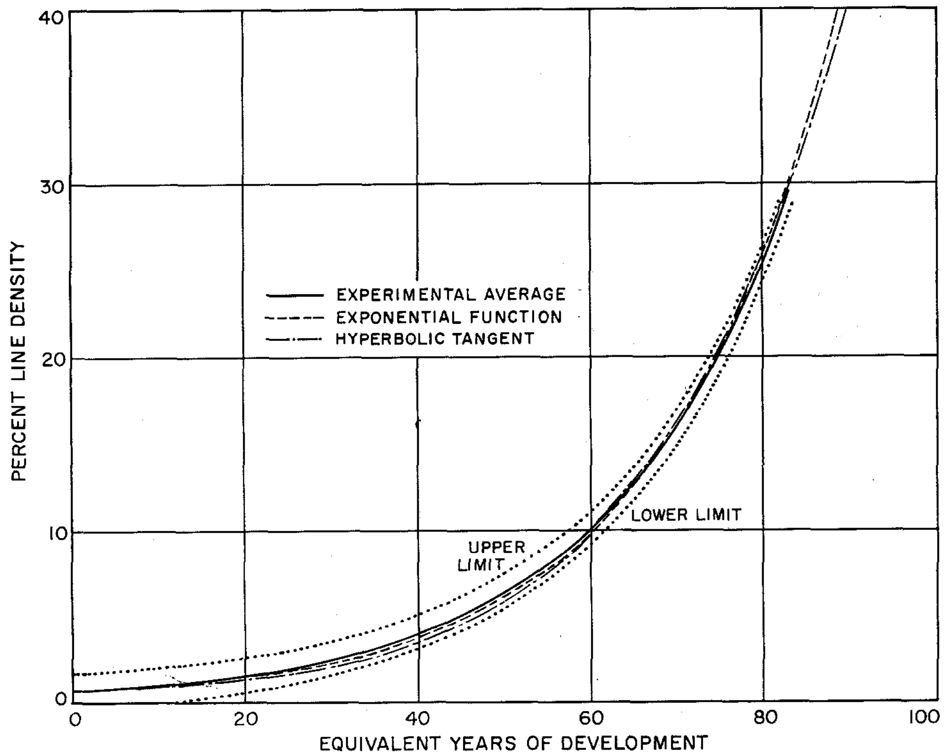
The higher the value of c, the higher is the line density; the difference between c for two countries gives the time lag between the present states of evolution for these countries. This time difference is, however, not a static figure but a dynamic characteristic of the actual development for 1961 when the general law was experimentally established.

3.2 Mathematical Forms of the Law

The average curve of the experimental law of evolution can now be used for forecasting the line density of a country in the near future.

However, when establishing a projection, account must be taken of the immediate past. This should be done as close as possible to the

Figure 7—The solid line is the average of the composite curves of Figure 6. The upper and lower limits, which would enclose all the smoothed individual curves, are only ±1 line per 100 inhabitants from it.



date of making the forecast; when this precaution is neglected, serious errors can be introduced. Even if the line-density curve of the country involved is up to date, it should again be superposed on the average curve to obtain the best possible coincidence to confirm the c value. This emphasizes again the fact that the time difference is not to be considered as a static and invariable figure.

Forecasts of future line densities will, however, be much easier to project with a mathematical form of the evolution law.

3.2.1 *Exponential Function*

The regularity of the average evolution curve suggests a constant increase of line density with time and the similarity of the average curve to an exponential function.

$$d = a^{[(t+c)+b]}. \tag{5}$$

In fact, a number of telephone administrations use such an exponential for their planning and assume a constant rate of change of line density. Figure 8 shows yearly density growth as a function of time for half a dozen countries. As can be seen, each country has a pronounced characteristic growth rate. Although the curves oscillate violently, there is no visible trend toward a steady increase or decrease in any of them. On the contrary, all the oscillations take place around the same common average of almost 5 percent per year. These irregularities stem from various temporary influences such as local crises, budget allocations, postwar reconstruction, and so on.

A good approximation, as plotted in Figure 7, of the experimental average is given by the following exponential expression.

$$d = 1.05^{[(t+c)-13.4]} \tag{6}$$

or, with $t = T - 1961$

$$d = 1.05^{(T-1974.4+c)}. \tag{7}$$

This exponential function can be used for calculating future line densities of a country if $(t + c)$ is smaller than about 80, this means during some 20 years from now on for a country with a present c value of about 60. Expressions (6) and (7) suppose a yearly growth of 5 percent, a value that could be foreseen by the study of Figure 8.

Although this exponential function now gives acceptable forecasts, the fact that such a function tends to infinity indicates a future failure of the law. Caution is therefore necessary in making a line-density forecast beyond the presently known part of this experimentally determined law.

3.2.2 *Hyperbolic Tangent*

As in the long run the exponential law will give highly improbable, if not quite impossible, values, another approach should be tried.

Consider a network serving an isolated area of C elementary communities (families, commercial, and industrial concerns) that can have telephone connections [1]. At a given moment, L of these communities have their telephones; $p = L/C$ is then the saturation quotient.

The probability W that a contact requiring telephone communication is established between a subscriber, group L, and a nonsubscriber, group C-L, is given by

$$W = 2\frac{L}{C}\cdot\frac{C-L}{C} = 2\,p(1-p). \tag{8}$$

The frequency f of the contacts between a given elementary community and another community can, as a first approximation, be considered as constant. On the other hand, if n is the average number of contacts between a nonsubscriber and the subscribers, sufficient to induce the former to request a telephone line, the saturation quotient increases during a time dt with

$$dp = W(f/n)dt = 2(f/n)p(1-p)dt \tag{9}$$

or, with $f/n = \omega$

$$dp = 2\,\omega p(1-p)dt. \tag{10}$$

This is the differential equation of p, the proportion of elementary communities having a telephone line in the considered network. Resolving this equation, we get the evolution in time.

$$\int \frac{dp}{p(1-p)} = 2\omega t \qquad (11)$$

$$p = \tfrac{1}{2}\left[1 + \operatorname{tgh}(\omega t - k)\right]. \qquad (12)$$

This equation, giving the variation of p in time, is a hyperbolic tangent translated in the coordinate system. This curve, known also as a logistic curve [2], is much used to represent the trend of various growth phenomena in the demographic and biological sciences.

As $p = L/C$, and with the help of (1), it is now possible to formulate a second mathematical expression of the general law for line density.

$$d = \frac{100C}{N}\,\tfrac{1}{2}\left[1 + \operatorname{tgh}(\omega t - k)\right]. \qquad (13)$$

A good approximation of the experimental average shown in Figure 7 is given by the following logistic curve

$$d = 115.81\left(1 + \operatorname{tgh}\frac{T - 2080.6 + c}{38.3}\right). \qquad (14)$$

This hyperbolic tangent coincides nearly completely with the known part of the experimental average curve as does the exponential function given by (7). It similarly shares the necessity of being used with great caution when extrapolating beyond the known part of the experimental curve.

Indeed, complete saturation, $p = 1$, will be reached when each elementary community has its own line. This gives for (14) a density of nearly 232, or that number of lines per 100 inhabitants. It seems unlikely that the line density will ever reach such a high level even after an infinitely long time and assuming such

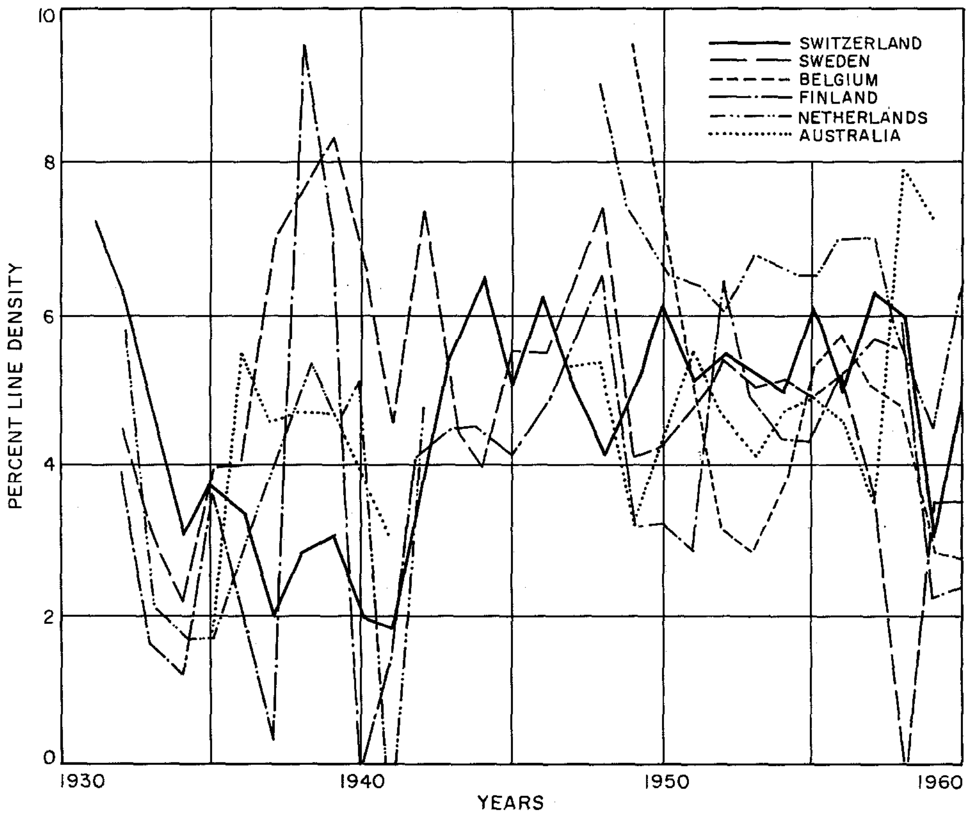


Figure 8—Yearly density growth of these countries oscillates around 5 percent.

developments as a second line in many homes, telephones in many cars, in trains and planes, more pay stations, emergency sets along the road, et cetera.

The actual development of the line density will probably follow more or less the logistic curve till a certain density is reached and will then gradually tend to a saturation density lower than the maximum given by the logistic curve. Both this departure from the common curve and the corresponding saturation may be different for each country, depending on local factors. In this way, the general law of density evolution would be described with the help of two or more mathematical functions, one of them being the logistic curve. The other factors in the evolution will be expressed otherwise but the data necessary for computation seem to be incomplete or missing now.

A factor that can be interesting in this respect is the coefficient $\omega = f/n$ in (9). The frequency f of the contacts between subscribers and nonsubscribers, and the threshold value n of the contacts sufficient to stimulate a request for a telephone connection were both considered as being constant. This is perhaps a simplification of the real situation. The frequency of contacts will probably increase and the threshold value will decrease as the public subscribes more and more readily to the telephone. Both factors are influenced by the social level but it is not certain that they are functions of time only, if at all.

3.3 Maximum Line Density

The line density in a country will reach its maximum when each elementary community has its own telephone connection, at least for the assumption that no communities will be granted more than one line while others have no telephones. When the ultimate number of communities among a population can be evaluated, an acceptable estimate of the saturating line density becomes possible.

The elementary communities can be divided in two main groups: residential and professional.

3.3.1 *Residential Communities (Households)*

To the residential group belong families, persons living alone, and also all sorts of communities of people living together or sharing the same quarters as in hotels. The number of families per 100 persons is not constant in time. In Belgium, there were 24.66 families per 100 inhabitants in 1910; 26.79 in 1920; 29.34 in 1930; and 33.33 in 1947. Today there may be 35 families per 100 inhabitants.

This family density varies also from one country to another and was for instance: 31.37 in France (1954), 27.83 in Switzerland (1950), 24.86 in Italy (1951), and 28.4 in the United States (1958).

Not all families will ever have their own telephones: some related families, for example, parents and married children, may live in the same house and share a line. Also, a sufficient economic status must be reached before a family will install a telephone in preference to buying anything else. But there will also be households with a second and perhaps even a third line.

3.3.2 *Professional Communities*

Commercial and industrial enterprises and offices form the professional group. Not all of them will have a telephone; many small shops will use the family line for business purposes. In contrast, the bigger firms will have several connections between the public exchanges and their private branch exchanges. It is therefore nearly impossible to estimate the line density for this group. Other factors are that time seems to make the telephone more of a necessity in all countries, and that a fully industrialized country will have more lines in this group than an agricultural country.

Also in this group are pay stations, sets in public offices, and emergency sets along the roads. Finally, there must be included sets in cars, trains, planes, and ships, connected by radio with the general network. For the moment their number is still small but it will certainly grow.

It will be extremely difficult to estimate a saturation value for the line density. There are, however, no indications of an imminent saturation and a line density of at least 40 seems attainable in countries having high industrial and social development as is the case in Western Europe.

4. Subscriber Sets per Telephone Line

The first people to install telephones were certainly businessmen, who considered the new invention as a complement of the already widespread telegraph network. As telephony was a novelty, there was only one set in a building for the exclusive use of a few selected employees. Seldom was a second set found. Residence telephones were rare for there was almost nobody to talk with. So in those early days the relation of sets to lines (S/L) exceeded unity only by a small fraction.

As the practical value of telephones became apparent, more and more lines were installed for business purposes, but still with only one or at best a small number of sets per line. In the meantime, the residence telephone made its entry into the higher social levels.

Later on more and more homes were equipped, but, because business and industry installed larger and larger private branch exchanges, the relation of sets to lines increased steadily. Most countries are today in this stage of telephone expansion.

After a certain time, each firm reaches saturation. Service to houses and apartments becomes commonplace but tends to retain its one set per line status. This causes a decrease in the S/L relation; at this moment the United States, New Zealand, Switzerland, and maybe a few other countries seem to have reached this stage.

In the future, many homes will have more than one set per line and an increased S/L may be expected.

As a result of these conditions, the S/L relation develops as indicated in Figure 9.

Figure 10 shows the sets-per-line evolution with time for a few countries for which sufficient information was available to give a large part of the development curve, or which are to some extent especially characteristic. Sweden, for instance, a country where the telephone has always been a widespread social object, shows a remarkable stability of the S/L relation. The curves for Switzerland, New Zealand, and the United States indicate that these countries have passed the maximum; unfortunately some data for this last country are missing and the new increase is difficult to interpret. A maximum need not always be conclusive as is emphasized

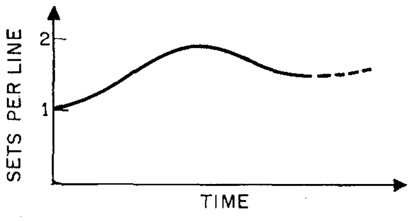


Figure 9—General development of sets per line.

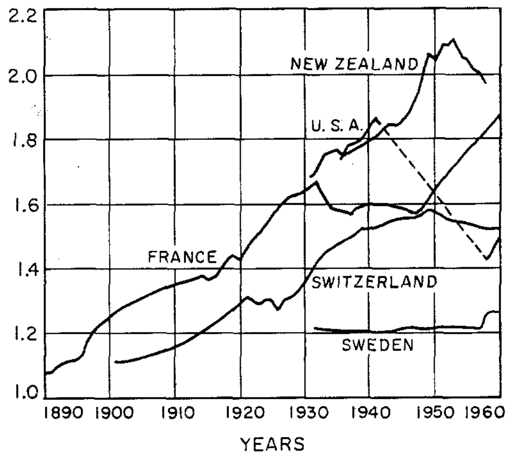


Figure 10—Development in sets per line for several countries

for France, where a new increase can be seen after a first maximum and subsequent decrease.

How the relation between sets and lines will be at a given moment depends on the industrial and commercial conditions of the country and also whether the population considers the residence telephone to be a social necessity. The first factor tends to increase the S/L relation, while the second has an opposite effect.

The density of subscriber sets s can now be defined as a function of the line density.

$$s = (S/L)\ d. \tag{15}$$

As stated before, the line density can be forecast with some accuracy but it is difficult to predict the evolution of S/L. Because the variation of S/L over a relatively short period of, say, about 10 years, is normally not larger than some 10 percent, it is possible to obtain a fairly good approximation of the future density of sets in a given country by multiplying the projected line density with its present S/L relation. If out of the normal trend of this relation, a future value can be estimated, still better results will be obtained.

5. Telephone Conversations

With the help of the above-stated law of evolution, future line densities can be forecast within acceptable limits. As explained, the density of sets is more difficult to foresee because the relation of sets to lines depends on many local factors that can easily change in time. Despite this, set density can be projected albeit with a larger deviation possibility.

The number of conversations depends strongly on and responds immediately to the social, economic, and political situations of the moment. Examples of this close dependency have already been cited.

The number of conversations is also directly related to the character of the people in the different countries. No single rule would be applicable everywhere. For instance, in Ireland there are 51 conversations per capita per year while in Japan, which has the same line density, each inhabitant makes an average of 164 calls per year. These differences exist even between neighboring countries; Belgians now make some 79 calls per year while the Dutch have 114 conversations for the same line density.

However, if large enough deviation limits are accepted, there seems to be a roughly linear relation between the total number of conversations per capita and per year g and the line density in a given country.

$$g = a\,d + b. \tag{16}$$

For the post-war values, this expression gives an approximation that is generally within 15 percent.

With a rare exception, most countries have an increasing number of conversations per capita per year as the line density grows, but it is quite possible that this trend will be reversed as the line density increases further.

6. Conclusion

No attempt is made to present the basic reasons that control the evolution of telephony. A rigorous mathematical treatment of this evolution may even be impossible as it depends on a large number of economic, social, and psychological influences. The purpose of the paper is to emphasize that the individual development curves of most countries are not as incoherent as they appear to be at first glance, but that they have as a general characteristic a nearly identical growth rate.

This common characteristic is formulated in a general law of line-density evolution and, mathematically expressed, even though incomplete and approximate, can make planning for the future expansion of telephony less obscure and unsurveyable.

7. Acknowledgment

The author expresses his thanks to Mr. J. Mallet of Laboratoire Central de Télécommuni-

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1000B Pentaconta Crossbar Switching System

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1. History of Pentaconta

The Pentaconta crossbar dial telephone switching system was developed in 1953. Its basic element is a crossbar switch having 14 horizontal bars, one of which is used as a change-over bar, to provide for switching 52 outlets. This switch and the relays mainly used for other switching functions were described in this magazine.[1]

The first design was called the Pentaconta *500* because the subscribers' lines and their associated equipment were divided into 500-subscriber units each served by 2 markers. The first exchange of this type was cut over at the end of 1954 at Cento, near Ferrara, Italy. Others were installed during the next four years in France, Chile, Brazil, and Argentina, the largest being at Bergamo, Italy, with 17 000 subscribers' lines.

From experience with this equipment, it was decided to increase the capacity of the line unit to 1000 subscribers, while retaining the same principles of operation.

Actually, 2 markers can handle 6000 calls per hour with a marker holding time per call ranging between 450 and 500 milliseconds. Other detailed improvements were effected in circuit operation, the equipment layout was revised, and it was decided to use wrapped wiring connections for both internal wiring and outside cabling of the equipment units. This second design is referred to as the *1000A* type. It was first installed in Albi, France, in 1959. A large number of these exchanges are operating all over the world.

Experience with the *1000A* system, the requirements for the establishment of international connections, and the decision of the French Administration to adopt Pentaconta for the Paris network, led to the development of the *1000B* type, which is suitable for public exchanges of 1000 to 50 000 lines.

Some of the most-outstanding features of the *1000B* system are as follows.

(A) Full accessibility to large groups in the group selection units (1040 terminals) with negligible internal blocking so that outgoing junctions may be calculated on the basis of ideal groups.

(B) Second attempt in case of alternative routing or faulty operation.

(C) The group markers can bring about overflow operations by providing for paths of first and second choice.

(D) The group markers will effect alternative routing, provided the original program for such selections is not modified by the translator.

(E) The translators will carry out two alternative routings in case of a change of program. It must be pointed out that the holding time of a translator is about 300 milliseconds. A set of 2 translators can handle 14 000 calls an hour. Each selection coupler has access to 2 translators. The number of translators will be based on the traffic of the exchange.

(F) It is possible to incorporate in the translators a nucleus of subscriber translation, enabling the connection of the outgoing lines of very large private branch exchanges directly to the outlets of the group selection units. This will reduce the traffic to the line selection units.

(G) Any type of signalling code may be provided for through auxiliary control circuits that are available to the registers.

(H) Provision for automatic message recording.

2. Switching Functions

Figure 1 shows a block diagram of a Pentaconta exchange of the *1000B* type. The outgoing and incoming junctions use only relay groups, whereas the line and group selection units use

[1] F. Gohorel, "Pentaconta Dial Telephone Switching System," *Electrical Communication*, volume 31, pages 75–106; June 1954.

2-stage crossbar switches under control of markers for conditional-selection operation.

Figure 2 shows the arrangement of a line or group selection unit. The two crossbar switching stages are called the primary stage and secondary or terminal stage; each stage consists of several sections made up of one or more multiswitches.

By way of example, the standard group selection unit for a large exchange may include 7 primary sections, each consisting of 2 multiswitches having 22 verticals to provide $2 \times 7 \times 22 = 308$ inlets, and 20 secondary sections, each of 1 multiswitch with 14 verticals. Each secondary section gives access to 52 outlets so that an incoming junction connected to an inlet of the primary stage has access to $52 \times 20 = 1040$ outlets. The 2-stage link arrangement is therefore the equivalent of a selector with 1040 terminals.

The 52 outlets of the primary sections are divided into two classes: 40 outlets (20×2) are assigned to the direct junctions between primary and secondary sections, and 12 outlets are reserved for alternative routing of calls within a selection unit, which will be referred to as an "entraide." *

* The French term "entraide" has the meaning of "mutual aid" and "reciprocal overflow," which differs widely from the usual overflow process.

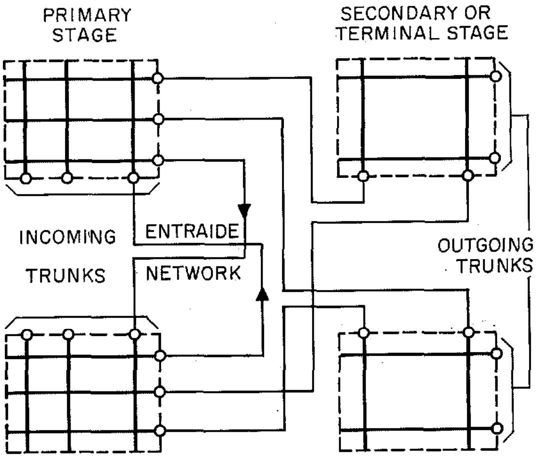


Figure 2—Arrangement of links in line and group units.

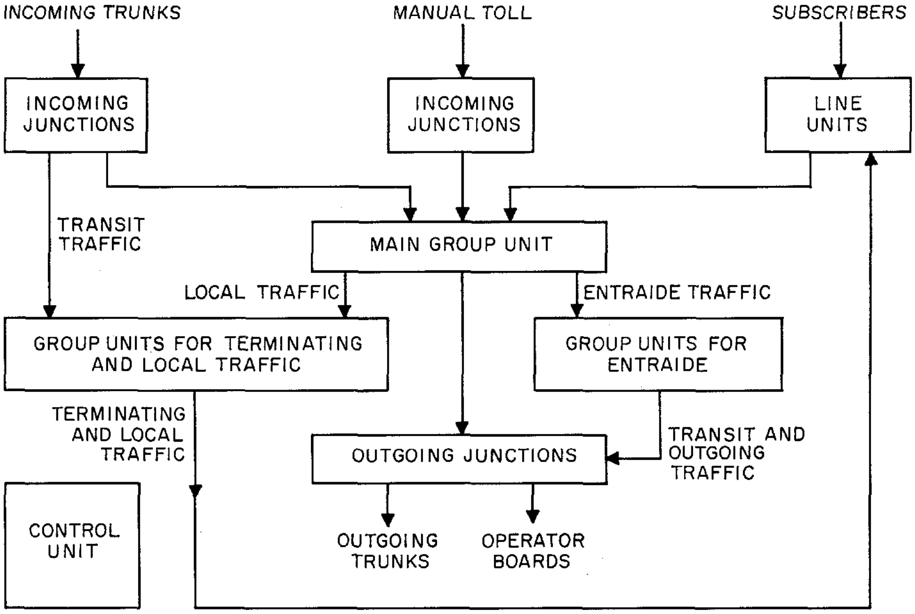


Figure 1—Functions of a Pentaconta exchange.

In conditional selection, the marking of a group of outgoing junctions causes a certain number of secondary sections that have free paths of access to the primary section in which the call originates to be selected as being available for handling the call. A lack of free paths between the originating primary section and those secondary sections having access to free outlets to the desired outgoing route (even if free paths of access to other secondary sections are available) causes an internal blocking of the link system. See Figure 3.

Assuming that b is the average load of a junction between the primary and secondary stages, c the average load per line of the outgoing group under consideration (the route), f the number of links between each primary section and each secondary section, q the number of lines constituting the route, and m the number of secondary sections, the probability of congestion E is given by

$$E = [b^f + c^q (1 - b^f)]^m$$
$$= [c^q + b^f (1 - c^q)]^m$$

if the independence of the 2 stages is admitted. This equation applies to a link system without concentration or expansion, that is, a link system in which the primary sections contain an equal number of links and inlets, which is the most-frequent case in the Pentaconta group selection unit.

Calculations show that a 2-stage link system is not fully "permeable"; a 3-stage link system must be used to reduce internal blocking to an acceptable value. The function of the entraide arrangement is to provide a third stage only for those times when no free access path is available directly between the primary and secondary sections. The total congestion will obviously depend on the permeability of the entraide network. See Figure 4.

It must be pointed out that a 2-stage arrangement of multiswitches will provide accessibility without an unreasonable amount of internal blocking only if q the number of lines of the routes is considerably higher than 1 and these lines are distributed equally over the secondary sections. This is the case for a group of outgoing junctions or for a number of subscriber's lines constituting a private-branch-exchange group. On the other hand, a single subscriber's line has only one position in one terminal section; the entraide network then provides a 2-stage conditional selection and the necessary accessibility.

Figure 5 shows the arrangement of a group selection unit of 7 primary sections having 40 inlets each, 4 entraide selectors per primary section, and 20 secondary sections with 14 verticals each, providing a total of 280 inlets and 1040 outlets. The largest line selector designed so far to cater for the maximum traffic per subscriber's line comprises 8 primary sections (containing so-called call finders for

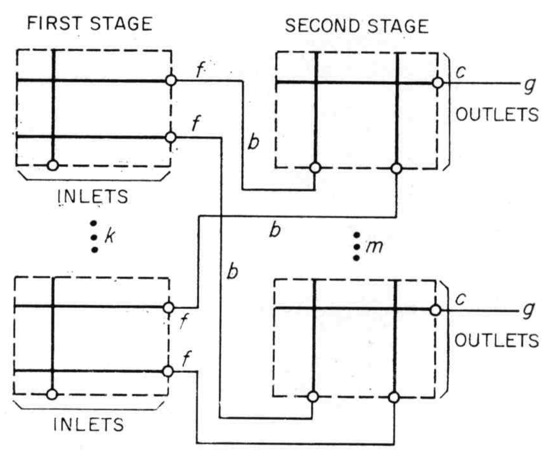


Figure 3—Link system having 2 stages.

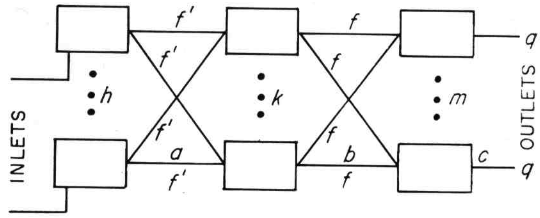


Figure 4—Link system having 3 stages.

handling originating calls and so-called "fifties" selectors for handling terminating calls) and 20 terminal sections equipped with a maximum of 16 verticals, each terminal section handling the originating and terminating traffic for 52 subscribers' lines.

Figure 6 shows the symbol of a line or group selection unit with entraide.

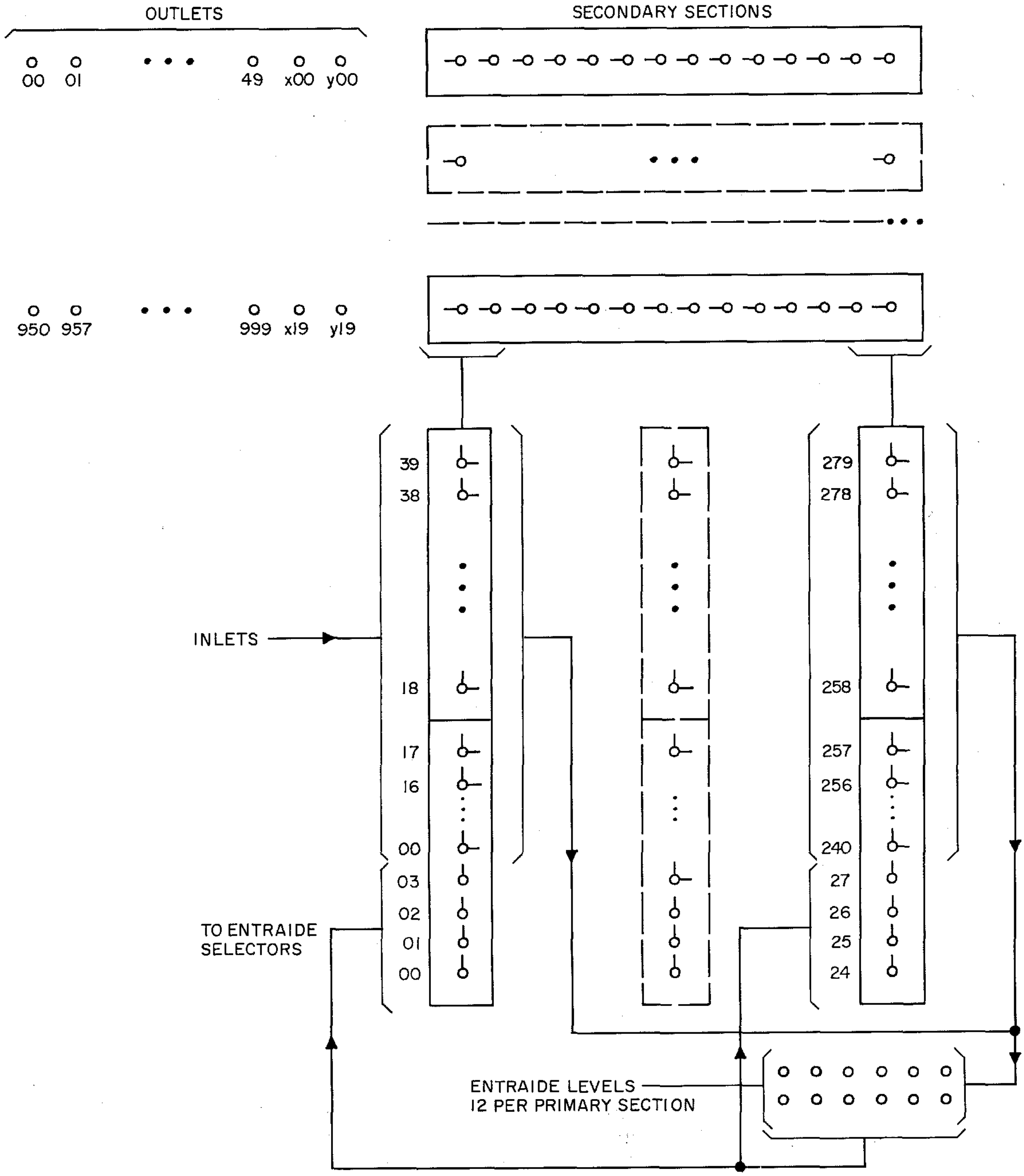


Figure 5—Typical arrangement of a group selection unit.

3. Local Calls

Figure 7 is a block diagram indicating the devices and selecting units engaged in the completion of a local call.

3.1 Line-Finder Operation

When subscriber *A* lifts his handset, the common relays controlling the line-finder operation ascertain which primary sections have access to free registers via free call finders. A register is chosen by the register finder as is also a single primary section having access to the terminal section to which the subscriber is connected.

One of the 2 markers is seized by the primary section designated to handle the call to mark the subscriber and primary section outlets. Simultaneously, the register is connected to a line-finder coupler, 2 of which may be provided for 12 registers. The marker records the class of the calling subscriber. For this purpose, all subscriber lines as well as incoming and outgoing junctions are characterized by a class-of-line indication, which serves to signal their class of service, type of signalling (loop break, revertive impulses, multifrequency code), supervision method, et cetera, to the marker controlling the connection. Once this is done, the marker is connected to a free path to the information bypass as well as to the coupler by means of a simple process of identification. When the register has received the calling line's class via the bypass, it proceeds to operate the vertical bar magnets. The subscriber is thereby connected to the register, after which the marker, line-finder coupler, and information bypass are released. Information is transmitted via the bypass by a self-checking 2-out-of-5 code.

If several subscribers in the same line unit call simultaneously, each of the 2 markers will serve one of these lines provided they belong to different fifties groups.

It must be noted that when establishing a connection from a calling line to a free register, a conditional selection is made via a 3-stage link system (group of registers, call finders, and terminal selectors) without use of the available entraide. Only in the very few occasions when all primary sections having access paths to free registers cannot reach directly the terminal section in which the calling subscriber is located, does the entraide mechanism come into action. The conditional selection is then made by a 4-stage link system, which practically affords full accessibility to all the groups of devices involved.

It is worth mentioning that the line-finder operation provides a delay function so that calls encountering occasional congestion will be served after a short wait instead of being rejected.

3.2 Group Selection

The calling subscriber dials after receiving dial tone from the register. When the register has received enough digits to undertake the first group selection (exchange selection), it engages a selection coupler, which simultaneously connects itself to both a translator and a group marker, the latter via a primary section of the group unit. The group marker as well as the coupler are then connected to the information bypass. The translated route is transmitted from the register to the marker via the coupler and the information bypass. Once informed of the route, the marker releases the bypass and also forces the coupler and translator to do so. The group marker marks the outlets belonging to the desired route (100 markings are possible) and chooses among them a particular one that can be reached by the primary inlet used for the call, preferably through a direct link or alternatively through the entraide stage. The marker receives the class-of-line indication from the chosen outgoing line and controls the connection of the coupler to the information bypass. The register next receives from the marker the class of the outgoing junction and possibly further indications concerning the selection (case of overflow for instance). It then controls the operation of the vertical bars. On connection of the outgoing junction through the main group unit, the marker is released as well as the multichannel bypass and the selection coupler.

A second group selection will be made in the terminating group unit following the same process when the register has received the required number of digits. It should be noted that one of the two group units may not be provided if this is not justified by the size of the exchange.

3.3 Line Selection

The subscribers' lines are divided into numerical groups for 1000 numbers, each served by a line selection unit. As the selection in a 1000-line group takes place in one operation, this can start only after the last digit has been received.

The selection process is the same as for a group selection; however, the selection coupler does not use the translator; the last 3 digits of the subscriber's number are transmitted untranslated to the line marker. In the Pentaconta system, a form of translation of these 3 digits takes place inside every line unit by a marker distributing frame enabling the assignment of any outlet within the line selection unit to any number of the thousands group. The individual lines of a private-automatic-branch-exchange group that share a common directory number may be distributed over different terminal sections. No additional equipment needs be provided for private-branch-exchange lines; ordinary single subscribers are treated as private-branch-exchange subscribers having only one line. Complete similarity exists between the marking of a route in group selection and the marking of a group of private-branch-exchange lines, and also for an ordinary subscriber. The information on the condition of the called line (subscriber free, with or without charge on answer, subscriber busy, absentee subscriber, et cetera) is transmitted during the line selection to the register, which may if necessary carry out a rerouting operation to direct the connection to special groups of junctions connected to the outlets of the group selection units, particularly in the case of absentees and unobtainable numbers.

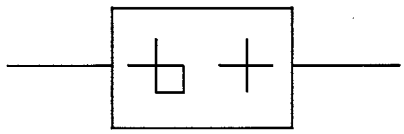


Figure 6—Symbol of a selection unit with entraide. The symbol at the right is for a crossbar switch and that at the left indicates the entraide arrangement.

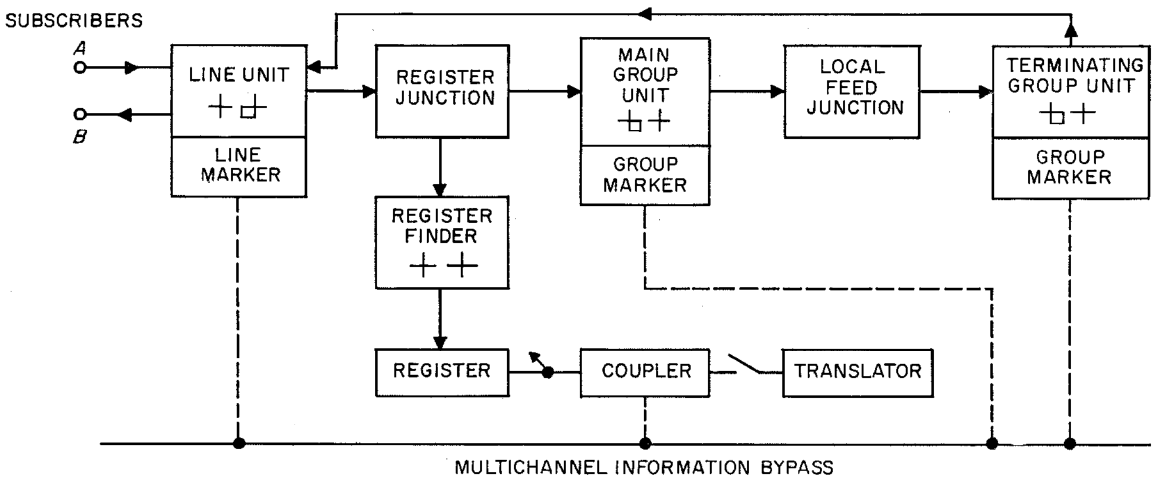


Figure 7—Switching network for local calls.

3.4 Establishing Speech Connection

After it has connected the called line *B*, the register informs the local feed junction of the type of operation it will have to provide (charge, supervision adaptation) by means of a direct-current compelled code, after which it releases. Subscribers *A* and *B* are now interconnected through the local feed junction, which controls the further operations required, such as ringing, metering, and release of the switching train at the end of the conversation.

4. Call to Another Exchange

Figure 8 is a block diagram showing the route and the switching and controlling units used for an outgoing call.

4.1 Line-Finder Operation

The line-finder operations, including seizure of a register, are described in Section 3.1.

4.2 Selection of Outgoing Junction

When the register has received sufficient information to determine the route, it calls the translator. When all elements required for choosing an outgoing junction have been collected, the group selection is effected as in Section 3.2. The class of the outgoing junction and the information supplied by the translator to the register, inform the register of the operations it will have to perform.

4.3 Distant Selections

Once connected to the outgoing junction, the register also seeks through a finder an auxiliary control circuit that provides a decimal sender, multifrequency sender, or receiver of revertive impulses to meet the operational requirements of the selection at the terminating exchange. The auxiliary control circuit controls the distant selections, receiving the called numbers from the register in which they were stored. When the numerical information must be translated for selecting purposes, the auxiliary control circuit obtains the translated information via the multichannel bypass from the translator and its associated selection coupler.

For interconnection with a step-by-step exchange, the register and the decimal sender to which it is temporarily connected are immediately released at the moment digit sending from the subscriber keeps pace with the retransmission of digits by the sender.

Thereafter the subscriber dials directly through the outgoing junction, which repeats the impulses towards the distant exchange.

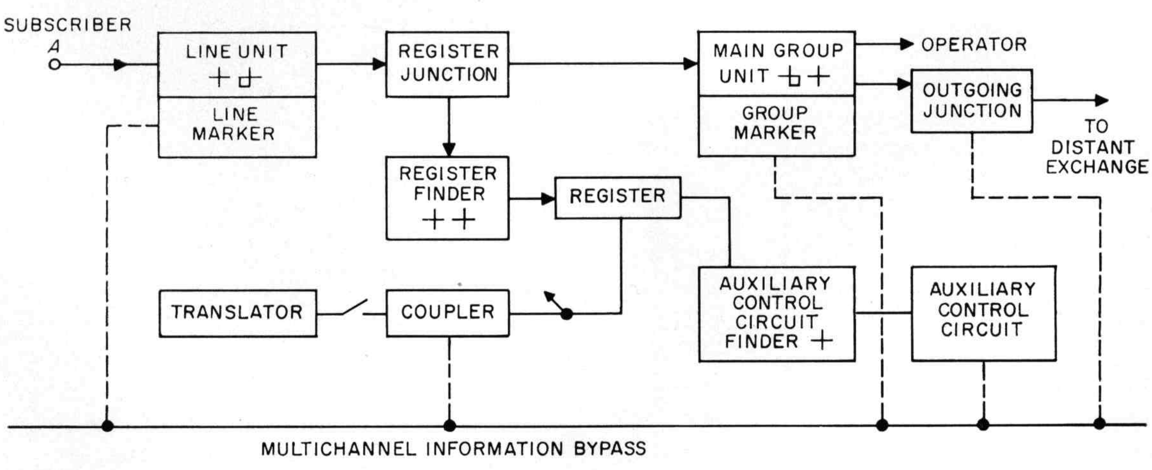


Figure 8—Switching network for outgoing calls.

4.4 Tariff Indication

The charges for connections over any outgoing junction may differ depending on the final destination of each call. If the outgoing junction must control the call charge, the tariff to be applied must be supplied when the register and its auxiliary control circuit have completed the distant selection. At this time, the auxiliary control circuit is released but the register recalls the translator and informs the junction to prepare for recording the tariff from the translator via the multichannel bypass. The register is then released normally; the outgoing junction ensures the functions of current supply, supervision, charge, and release of the engaged selectors.

5. Call Originating from a Distant Exchange

Figure 9 is a block diagram showing the route and the equipment involved in the completion of an incoming call.

5.1 Call from Exchange with Registers

A register is connected to the incoming junction by the incoming junction finder and the register finder, a 2-stage chain of multiswitches. It receives the class of this junction and calls for an auxiliary control circuit adapted to the particular type of signals to be received. The register, after informing the calling register that it is ready, receives the digits required for the selection.

The group and line selections are controlled by the register in the same manner as for a local call. If a large number of incoming junctions employ the same signalling system, as in a large urban network, it may be more economical to provide incoming registers incorporating the functions of the auxiliary control circuits so that the latter may be omitted.

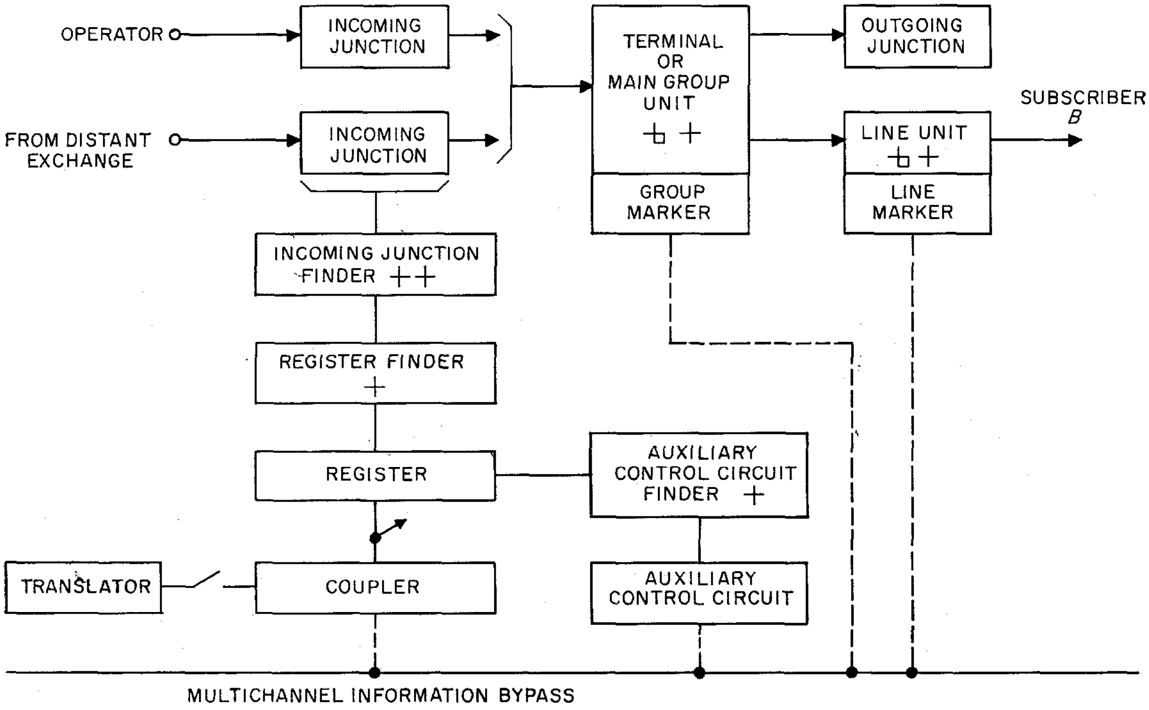


Figure 9—Switching network for incoming calls.

5.2 Call from a Step-By-Step Exchange

The time between the seizure of a junction and the moment the first digit must be accepted may be very short. Consequently, only one stage of finders must be used to minimize the time required for connecting a free register. Furthermore, no time will be available for the register to seek an auxiliary control circuit, so that this must be dispensed with and the register must be arranged to receive the dial impulses immediately. In some cases, it is necessary to record the impulses in the junctions themselves and transfer the digits subsequently to the register in a coded form.

6. Transit Call

This type of call is handled as an outgoing call. See Section 4. An outgoing junction is connected to the incoming junction. If a conversion of the selection code or a regeneration of the dial pulses has to be performed, the register will engage an auxiliary control circuit as in Section 4.2. It should be noted that the register may be connected simultaneously to two auxiliary control circuits, one for adaptation to the incoming signalling and the other for controlling the distant selections.

7. Call to an Operator

Referring to Figure 8, it will be seen that the junctions to operators' positions, in a manual toll exchange or for special services, are connected to the outlets of the group selection units. The selection process is the same as for an outgoing call except that no subsequent selections are to be made.

8. Call Originating from an Operator

As shown by Figure 9, a junction from an operator is treated as an incoming junction. When the operator's position is provided for key-sending, the register will call an appropriate auxiliary control circuit.

9. Multichannel Information Bypass

The multichannel information bypass used for exchanging information among the registers and the various common devices in the exchange consists of a number of conductor pairs. Such units as markers, auxiliary control circuits, and outgoing junctions have access to only one pair, which they can use indiscriminately. They are said to be active units for they seize the bypass themselves, through concentration devices, if necessary. The register couplers are said to be passive units but have access to all paths in the exchange. The routes of the bypass are identified as families that are at the disposal of the various stages of selection. Within each family, identification of any pair is made either by direct-current polarities (plus or minus 48 volts) or by 2-out-of-5 voice frequencies. The holding time of the bypass per call is about 100 milliseconds and 24 000 calls can be handled per hour per pair.

10. Easy Maintenance

10.1 Test Chain

Any subscriber line can be called from the test desk by its directory number. For the 40 lines in each line selection unit in excess of 1000 numbers, an access code is used (digit 11).

10.2 Fault Recording

Selections at each stage have to be completed within a given time. Thus, when each selection begins, the pilot unit starts a time-limiting device. If the selection takes too long, the pilot unit automatically connects a localizer that in its turn calls a fault recorder. All equipment units engaged for this selection will have their numbers recorded, that is, the numbers of the calling subscriber, selection units, register, and outgoing or incoming line. Furthermore, for each of these, the positions of its main relays will be recorded. The fault register will punch this information on a card, together with the time of occurrence. Every call handled by the exchange is thus subjected to constant supervision.

10.3 False Calls

Each subscriber line equipment includes a line lockout arrangement. After a register is seized and dial pulses are received, the line is switched to an analyser that measures the loop and insulation resistances and detects any accidental earth potential. This analysis is recorded on a punched card in large exchanges or is shown on a luminous number display in small exchanges.

10.4 Traffic Observation

Registers, markers, auxiliaries, and junctions are equipped for traffic observations such as the number of seizures and the traffic carried.

10.5 Alarm Supervision

The alarm produced by blown fuses, special currents, et cetera, cause alarm lamps to light on the bay concerned, on the row of bays, and on the centralized supervisory desk; they also operate various alarm bells.

11. Exchange Equipment

The components are mounted on bays accessible from both sides. Assembled on the installation site, the bays stand side by side to form rows of varying lengths to fit the dimensions of the room. Aisles between rows give access at the front of the bays to the selection units and the cable connecting strips and, at the rear, to the internal factory-made wiring. The aisles between the front sides are used more frequently than those at the rear and are therefore the wider of the two.

The multiswitches and relays are housed in metal frames that are either 1 meter or 1.29 meters (39.4 or 50.8 inches) wide, 390 millimeters (15.4 inches) high, and 200 millimeters (7.9 inches) deep.

The wide frame can accommodate a multiswitch equipped with 22 verticals and in addition has 2 vertical holders each mounting 22 relays of the flat type used for positioning the selectors. The narrow frame takes a multiswitch having 17 verticals and a single holder for 22 flat relays. The number of switches in these standard frames can be reduced in favor of additional relay holders as some frames, such as markers, registers, and junctions, do not have multiswitches.

A frame only 235 millimeters (9.3 inches) high is often used at the upper part of a bay to house either 10 flat relays or the connecting blocks for the internal distributing frames of the selection units.

The blocks for connecting the outside cabling are at either side of the frame and as the terminals of the multiswitch operating magnets are at the front, full operation of the multiswitches and testing of the frames may be done without recourse to the rear side. Designation strips at right angles to the connection blocks identify the distribution of terminals among the blocks.

Figures 10 and 11 are front and rear views of a frame of call finders and fifties selectors. Figures 12 and 13 are similar views of a line marker and its distributing frame for a bay 1.45 meters (57.1 inches) wide.

Solderless wrapping is used for all connections inside the frames and between the various apparatus and distributing frames.

Metal covers protect against dust and shock. The frames are supported on uprights of folded sheet iron which house the wiring forms interconnecting the various frames of the bay and the switchboard cables coming from the intermediate distributing frames and other bays. Figure 14 shows this arrangement. The uprights are closed at both rear and front by cover plates that can easily be removed.

The two bay widths of 1.16 meters (45.7 inches) and 1.45 meters (57.1 inches), having a ratio of 4 to 5, correspond to the two standard widths of selector and relay frames. The bay height of 3.47 meters (137 inches) permits

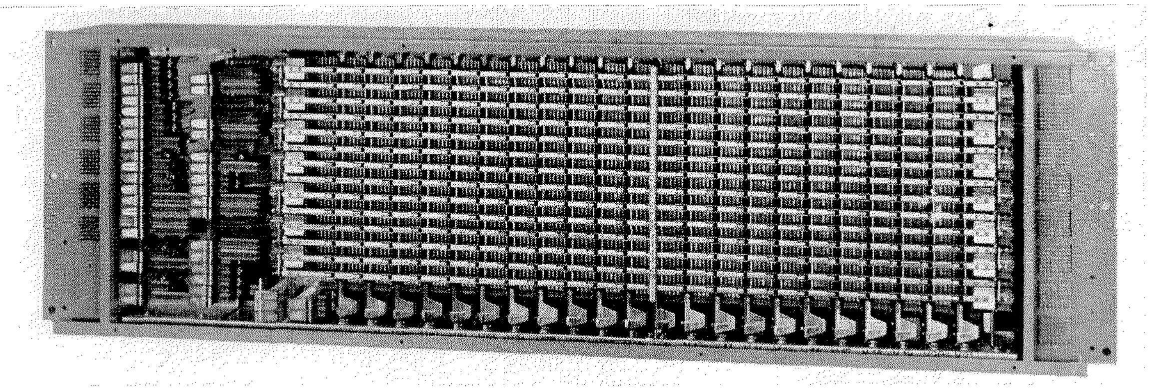


Figure 10—Front of frame of call finders and fifties selectors.

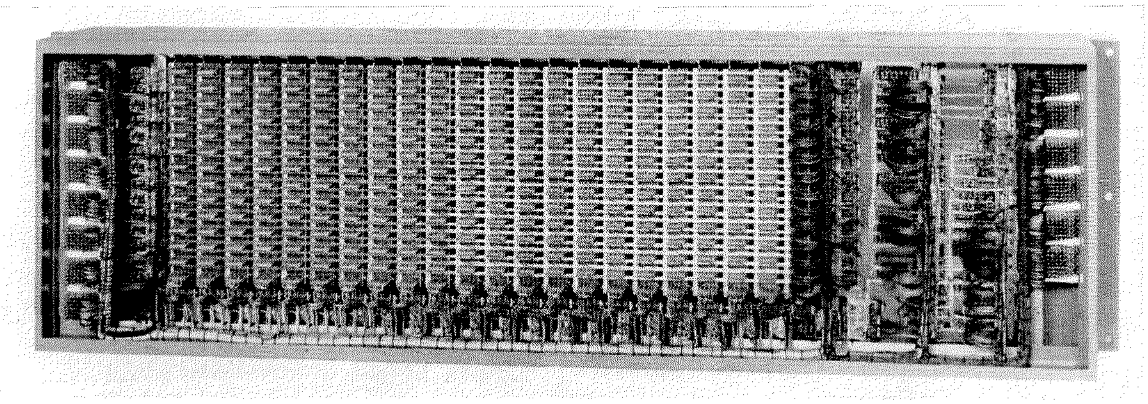


Figure 11—Rear of frame of call finders and fifties selectors.

mounting several frames arranged from bottom to top as follows.

(**A**) Power supply, protecting fuses, and fuse-alarm relays for the 48-volt system and for special currents.

(**B**) Three selector or relay frames.

(**C**) Supervisory panel for alarm and supervision lamps, listening-in and busying jacks, as well as a number of buttons used for maintenance purposes.

(**D**) Four selector or relay frames.

(**E**) If required, a 235-millimeter (9.2-inch) frame may be placed at the top of the bay.

Figure 15 represents a bay of couplers and registers.

If the ceiling of the switch room is too low for standard bays, the bay height may be reduced by mounting fewer selector or relay frames, which are 390 millimeters (15.4 inches) high.

Figure 16 shows the equipment layout of the frames of a 1000-line selection unit capable of handling a traffic of 0.09 erlang per line.

The line selection units are connected by cables to the main distributing frame, the subscriber meters, and the intermediate distributing frame of the register junctions. Jumpers run in this distributing frame permit the ratio of call

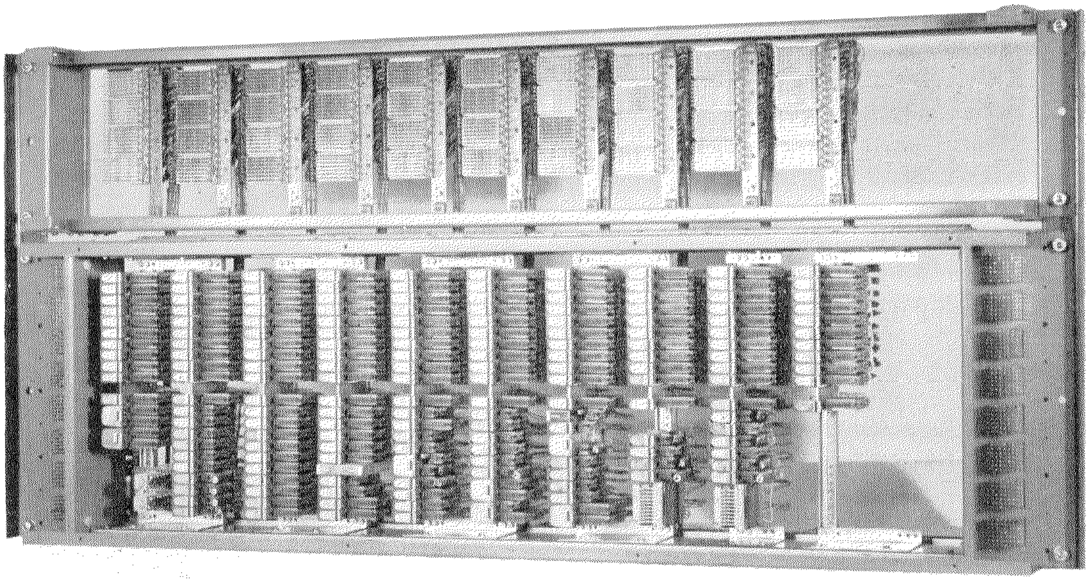


Figure 12—Front of frame of line marker and its associate distributing frame.

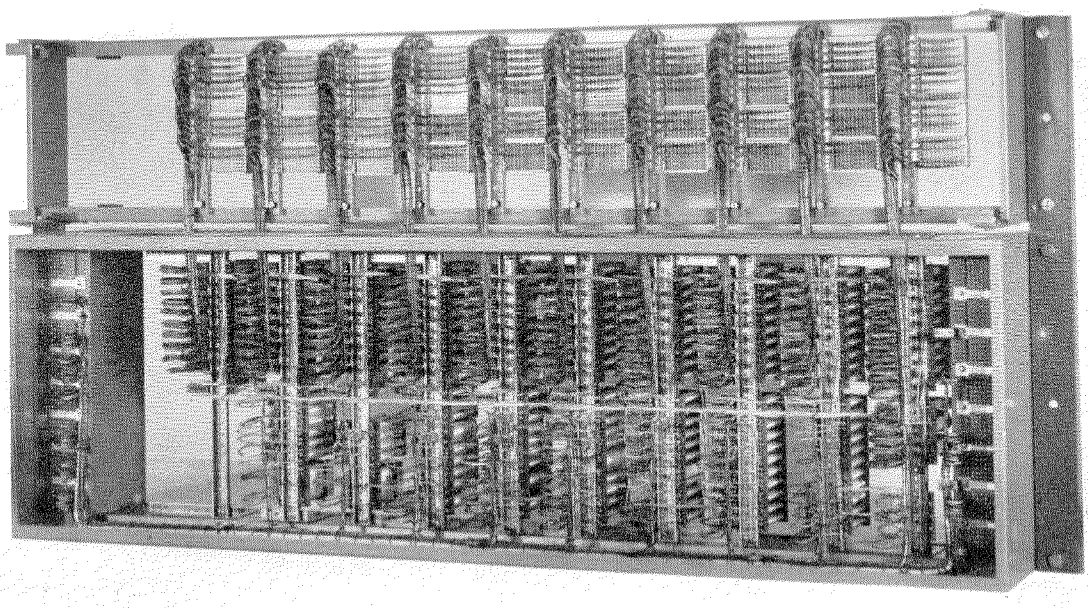


Figure 13—Rear of line marker and its distributing frame.

finders to fifties selectors to be adapted to the outgoing and incoming traffic rates. The assignment of the line relays to the subscribers' lines is made on the markers' distributing frames, which permits partial separation of directory numbers from equipment location for traffic balancing. As the position of each line generally corresponds to its directory number, in most cases this position can be marked by merely interconnecting two adjoining connector tags of the distributing frame. Such interconnections are made at the factory by bridges that can easily be removed when required during service. It should be noted that bridges are also used in the class distributing frames and for the connection of a subscriber's meter to each line.

For a change in traffic, the number of terminal selectors per frame, as well as the number of frames of call finders and fifties selectors, is suitably modified.

For traffics above 0.1 erlang per line, an additional frame that can mount 2 × 11 supplementary selectors is supplied for every two sections of call finders and fifties selectors, so

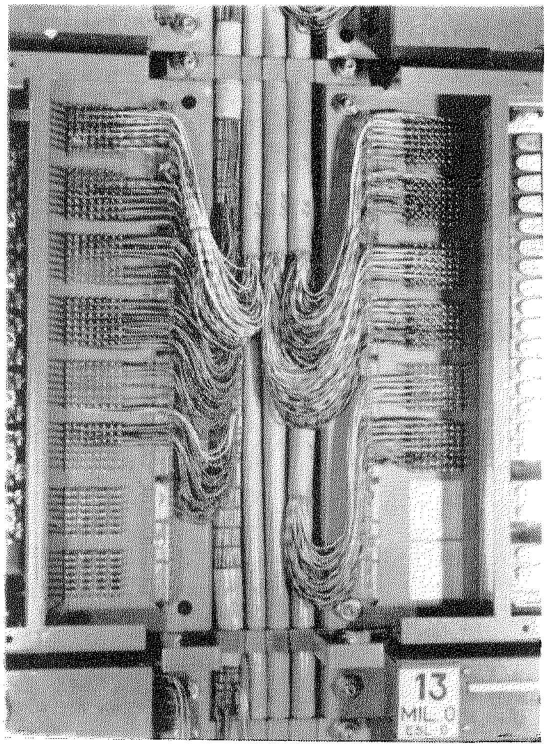


Figure 14—Cable run, connections, and wiring forms.

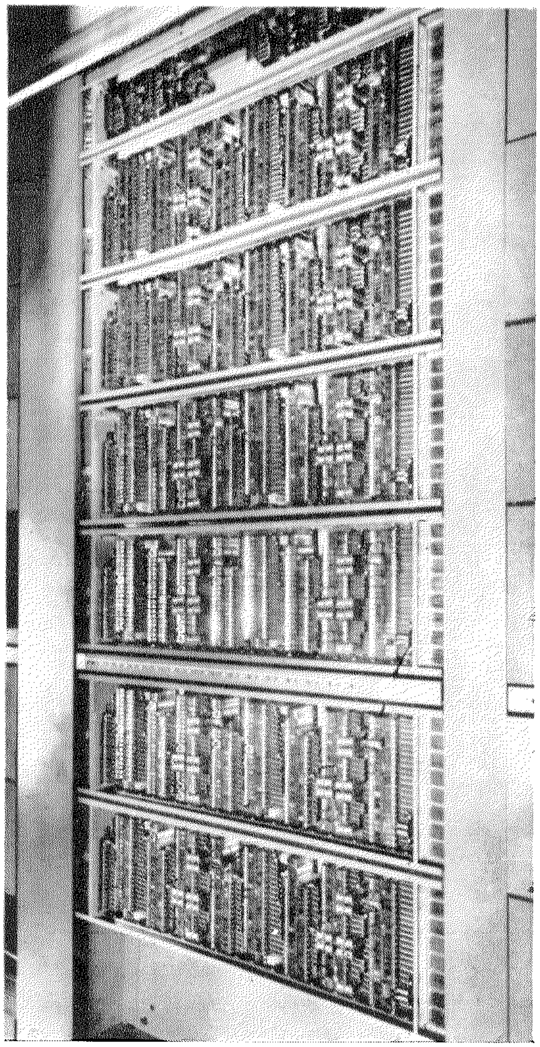


Figure 15—Bay of registers and couplers.

that their total number may be increased to 33 per section.

Figure 17 represents a group selection unit equipped with 1040 outlets. The marker relays associated with a marking distributing frame enable each outlet of the secondary selectors to be assigned to any group of outgoing lines.

The distribution of outlets of the group selection

GNF	GNF		IDF
MARKER 1	MARKER 2	12	PF SECTION 0
00	06	13	PF SECTION 1
01	07	14	PF SECTION 2
02	08	15	PF SECTION 3
S	S	S	S
03	09	16	PF SECTION 4
04	10	17	PF SECTION 5
05	11	18	19
POWER	POWER	POWER	POWER

Figure 16—Line selection unit. *GNF* is group number frame, the frames numbered 00–19 are terminal selectors. *S* is supervisory jacks and lamps, *IDF* is an internal distributing frame, and *PF* indicates call finders, fifties selectors, and entraide selectors.

Figure 17—Group selection unit. The frames numbered 00–19 are secondary selectors, *S* is supervisory jacks and lamps, *IDF* is internal distributing frame, *BP* is information bypass, *PS* is primary selectors, and *ES* is entraide selectors. The supplementary units are at the right.

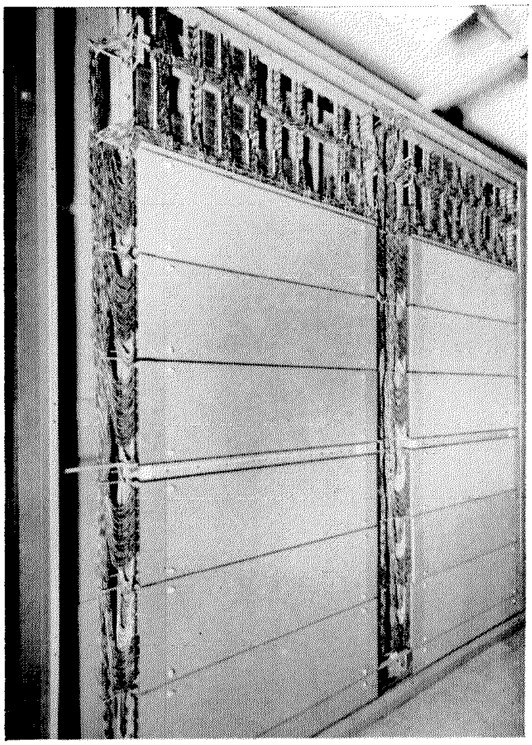


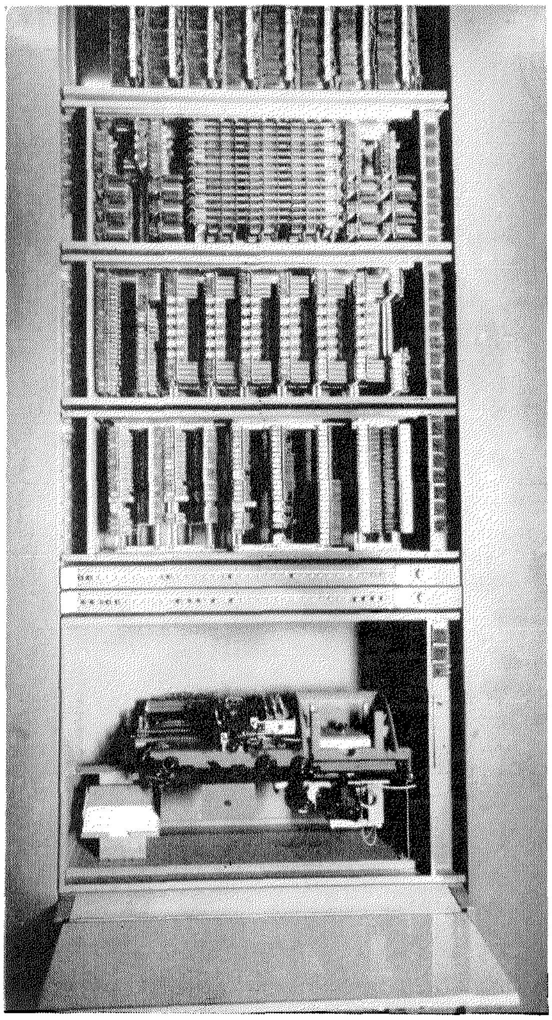
Figure 18—Bays of junctions and register finders.

	IDF	IDF	IDF	IDF	
MARKERS 1 AND 2	MARKER RELAYS 1	BP	MARKER RELAYS 2	PS SECTION 0	PS, ES
00	05	10	15	PS SECTION 1	PS, ES
01	06	11	16	PS SECTION 2	PS, ES
02	07	12	17	PS SECTION 3	PS, ES
S	S	S	S	S	
03	08	13	18	PS SECTION 4	PS, ES
04	09	14	19	PS SECTION 5	PS, ES
				PS SECTION 6	PS, ES
POWER	POWER	POWER	POWER	POWER	POWER

units between the fifties selectors of the line selection units and the junctions to other exchanges and to special services is provided for on one side of a distributing frame, the number of bays of which vary with the size of the exchange.

The distribution between the call finders and the register junctions, on the one hand, and the primary selectors, on the other hand, is effected by jumpers run inside the uprights between the upper distributing frame and the frames of junctions and register finders mounted on each bay. Figure 18 shows this arrangement.

Figure 19—Fault recordings bay with card punch and control relays.



In medium-size offices (4000 to 5000 lines) use is made of group selection units equipped with only one selector stage, entraide selectors being provided in addition. The maximum capacity of the unit then is 6 primary sections with 44 switches giving access to a maximum of 240 outgoing junctions. Such units are housed in two wide-type bays 3.47 meters (137 inches) high.

The frames for information bypass are equipped with multirelay units, each having 20 spring pile-ups so as to simplify internal wiring. These relays are similar to the selectors as regards their vertical multiple arrangement (built-in) and horizontal wiring (layers of bare wires) and to the standard relays as regards their operating magnetic circuit.

The fault-recording bay shown in Figure 19 provides room for a special frame to house the card punch.

A typical floor plan of 10 000-line exchange operated as a single office with a traffic of 0.09 erlang per line is given in Figure 20.

12. Conclusions

These improvements in switching, equipment, and wiring of the Pentaconta system have augmented its original intrinsic qualities of reliability, speed, flexibility, and easy interconnection with other systems including national, continental, and intercontinental dial networks. In addition, space requirements and the time required for its installation have both been reduced.

The 850 000 lines in service or in course of completion in both private and public installations on five continents testify to the success of the Pentaconta system.

J. P. Basset was born in Lyons, France, on 16 October 1925. He is a certificated engineer from the Institut Electrotechnique de Grenoble.

In 1954, he joined the Compagnie Générale de Constructions Téléphoniques to develop circuits for the Pentaconta system. He participated in a series of training lectures on Pentaconta for engineers of the International System.

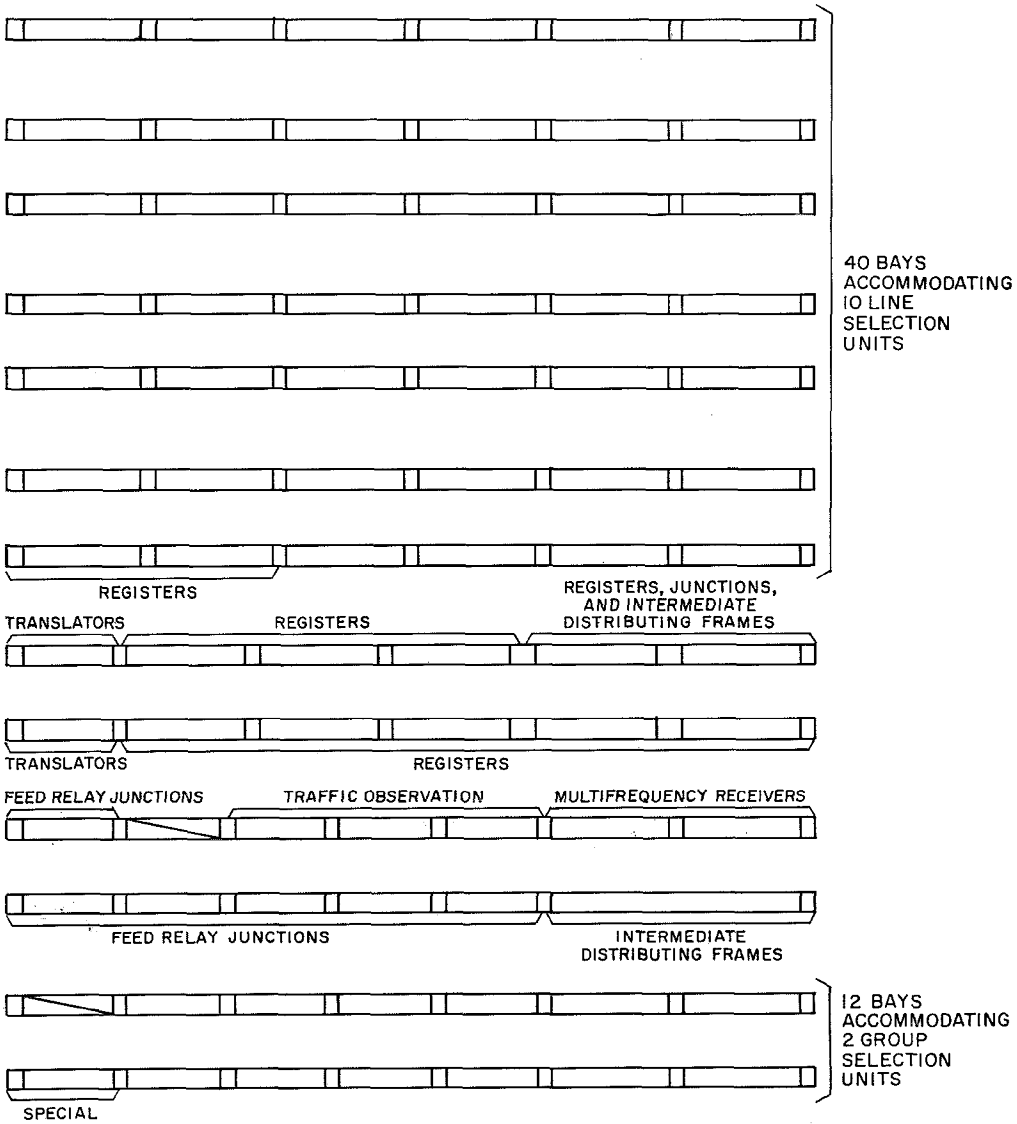


Figure 20—Typical floor plan of a 10 000-line office for a single-office area with a traffic rate of 0.09 erlang per line. The bays are 210 millimeters (8.3 inches) deep. The wider aisles between bay fronts are 900 millimeters (35.4 inches) wide and those between bay rears are 630 millimeters (24.8 inches) wide. The equipment rows are 8.8 meters (29 feet) long and the entire installation can be accommodated in a room 14 by 11 by 3.84 meters (46 by 36.1 by 12.6 feet).

Since 1961, Mr. Basset has been developing circuits for the Pentaconta *1000B,* including its adaptation to the Paris network and its international connections, to 4-wire transit exchanges, and to rural dial switching systems.

Pierre Camus was born on 18 September 1913 at Renwez, France. He received an engineering degree from the Ecoles Nationales d'Arts et Métiers, where he was awarded the silver medal in 1933. In 1934, he received the engineer diploma of l'Ecole Supérieure d'Electricité, Paris.

He served in the military from 1934 to 1936 and from 1939 to 1945.

From 1936 to 1939 and after 1945, he was with Compagnie Générale de Constructions Téléphoniques. He worked on R6 and Pentaconta switching systems. He also was responsible for training courses on Pentaconta for engineers in the International System. He is now chief of the department for Pentaconta development.

An Introduction to Pert

Pert is an acronym for Program Evaluation and Review Technique. It was developed for the management of programs involving many stages of different activities that may take various amounts of time and that are interrelated in the sense that some must be completed before others may be started.

Based on estimates of the minimum, maximum, and probable times that would be taken by each activity stage in a program, the statistical mean and variance of each activity interval are calculated. The earliest possible time at which each stage of activity can be completed is found and the critical path, that series of interrelated activities running from start to finish taking the greatest accumulated time, is determined. By working backward from the termination, the latest time at which each stage must be completed may be found and stages having excess time may be borrowed from to speed up the critical stages. The system is amenable to either manual or computer operation depending on the complexity and size of the program.

This programed learning course presents information, poses a problem based on it, provides several possible answers, and refers the reader to a different page for each answer. If the selected answer is incorrect, the referenced page will state why it is wrong and will redirect the reader to the problem to attempt a new answer or, if the answer is correct, the next item will be introduced.

This programmed learning course is presented on 140 pages measuring 7¾ by 10½ inches (20 by 27 centimeters) that are held between plastic covers by a plastic comb passing through perforations along one edge of each sheet.

It is available from Federal Electric Corporation, 621 Industrial Avenue, Paramus, New Jersey, at $5.95 per copy.

Pentaconta Line Concentrators

A. J. HENQUET
Le Matériel Téléphonique; Paris, France

A concentrator is a switching device used in telephone networks to connect a number of subscribers located in the same area to the parent exchange over a relatively small number of common trunks accessible to all of them when originating or receiving a call.

In the original conception, concentrators were exclusively associated with the subscriber line networks. They are intended to reduce the number of pairs of wires required to connect a group of subscribers' lines to the exchange. They are not part of the exchange switching

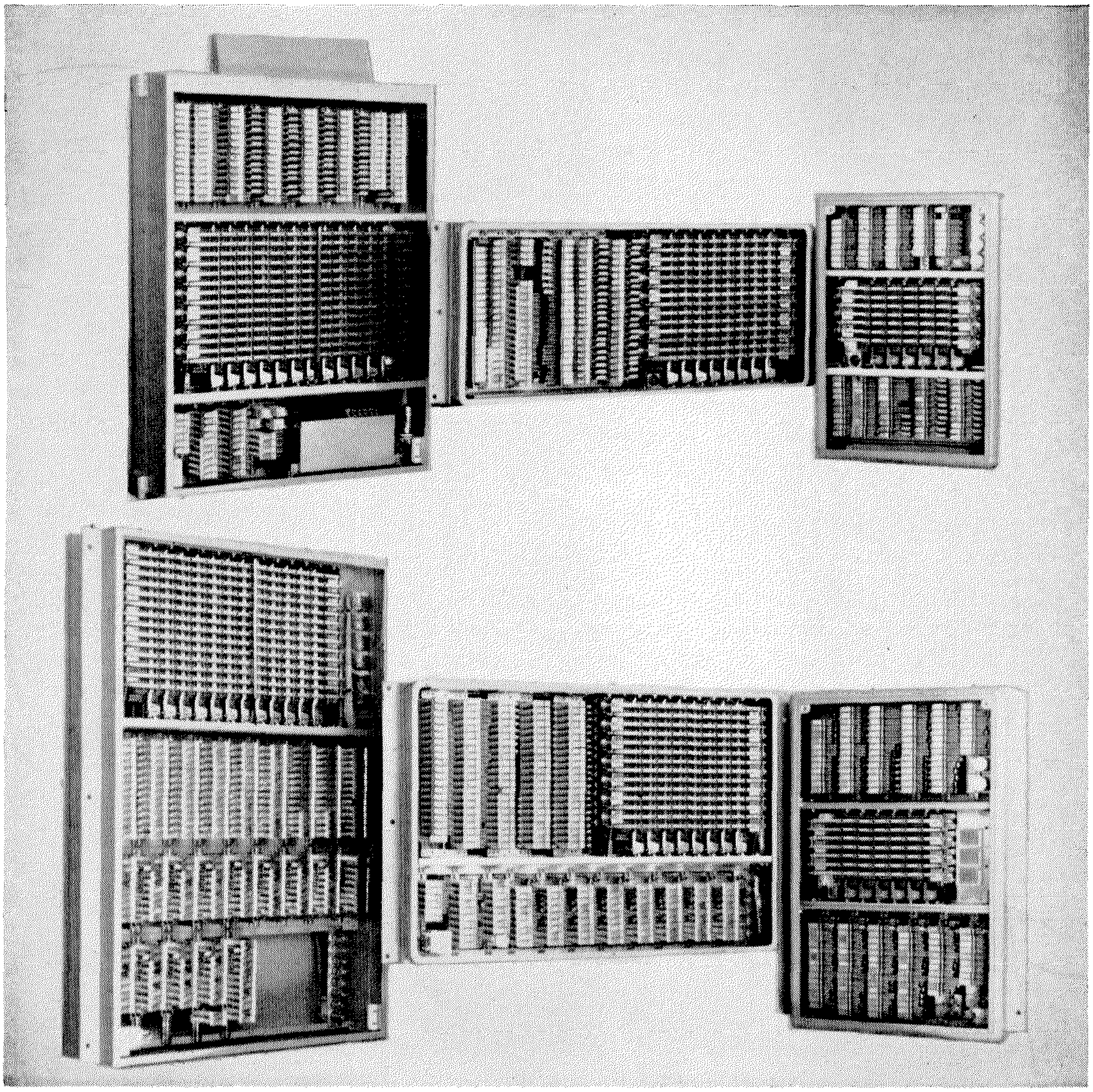


Figure 1—Above are the subscribers units and below the exchange units for, from left to right, the 52×12, 52×8, and 24×6 concentrators.

system through which a particular subscriber's line is selected for service.

A concentrator consists of two switching units, one at each end of a group of common trunks. One unit is in the central office and the other is at the geographical center of the group of subscribers. Each switching unit concentrates and redistributes all incoming and outgoing calls among the group of subscribers. Relays, step-by-step, or crossbar selectors may be used.

Concentrators are no novelty, but the old installations using relays or step-by-step selectors either were too bulky or required maintenance that was uneconomical because the switching unit was distant from the exchange. The development of crossbar multiselectors has renewed interest in concentrators.

1. Pentaconta Concentrators

Pentaconta switches are especially suitable for concentrators [1]. The 14-selection-bar multiselector, using one of its 14 selection bars as a multiplying bar, can serve 52 outlets. Two typical designs have been standardized to concentrate the traffic from 52 subscribers over 8 or 12 speech trunks.

A third version uses the 7-selection-bar Pentaconta multiselector with one bar for multiplying to serve 24 subscribers over 6 speech trunks.

Figure 1 shows the 3 types of Pentaconta concentrators. Their characteristics and sizes are given in Table 1.

Figure 2 represents the junction diagram of a Pentaconta crossbar concentrator connecting 52 subscriber lines to a rotary exchange. The same individual subscriber line equipment is used either for the concentrator or when connected directly to the rotary equipment. It must be pointed out that the third or sleeve wire of the subscriber line circuit must also be connected to the main distributing frame. The line equipment is connected to the concentrator by a jumper at the main distributing frame. The 3 wires of each subscriber line circuit are connected to one of the horizontal levels of the crossbar multiselector of the concentrator connecting unit in the exchange. At the remote unit of the concentrator, the corresponding level of the crossbar multiselector is connected to the 2-wire line to the subscriber's set.

A 2-wire trunk connects, 2 by 2, the corresponding verticals of the two crossbar multiselectors. A control circuit at each end determines the setting of its multiselector and the two control circuits are interconnected by 2-wire control junctions. There are 2 of these control junctions, except in the most recent designs, where only one is required. The orders enabling the control circuits to set the multiselectors are transmitted through these junctions.

TABLE 1
CHARACTERISTICS OF CONCENTRATORS

	52 × 12	52 × 8	24 × 6
Subscribers	52	52	24
Trunks, Traffic	12	8	6
Trunks, Control	2	2	1
Traffic in Erlangs	5.4	2.6	1.6
Subscriber Units			
Inches	39 × 27 × 9	38 × 16 × 7	25 × 17 × 8
Centimeters	97 × 67 × 22	96 × 39 × 18	62 × 43 × 20
Pounds	243	154	84
Kilograms	110	70	38
Exchange Units			
Inches	42 × 30 × 9	38 × 24 × 10	30 × 19 × 8
Centimeters	107 × 77 × 22	96 × 59 × 24	75 × 49 × 20
Pounds	254	198	128
Kilograms	115	90	58

2. General Characteristics

The subscriber's set that is served by a concentrator is connected to the exchange by the same kind of a 2-wire line used for ordinary subscribers.

No supplementary resistance or impedance is introduced either in series or shunt of each wire and ground for connection to the concentrator. Thus the connection established by a concentrator has the identical electrical properties of a normal line connected directly to the exchange and any variations of its electric state may be utilized by the switching system in the exchange including recognition of the different classes of service.

All classes of service may be provided through a concentrator because, up to the main distributing frame, the exchange sees only the normal line equipment. Thus, subscribers grouped on one concentrator can be assigned any directory number. This permits assigning a subscriber to a concentrator without changing his number. Message registers, if used, are connected in normal fashion in the parent exchange.

The number of common speech trunks linking the distant part of a concentrator to its exchange is determined by allowing for a probable number of lost calls equal to or less than that for the terminal selection stages; the reduced

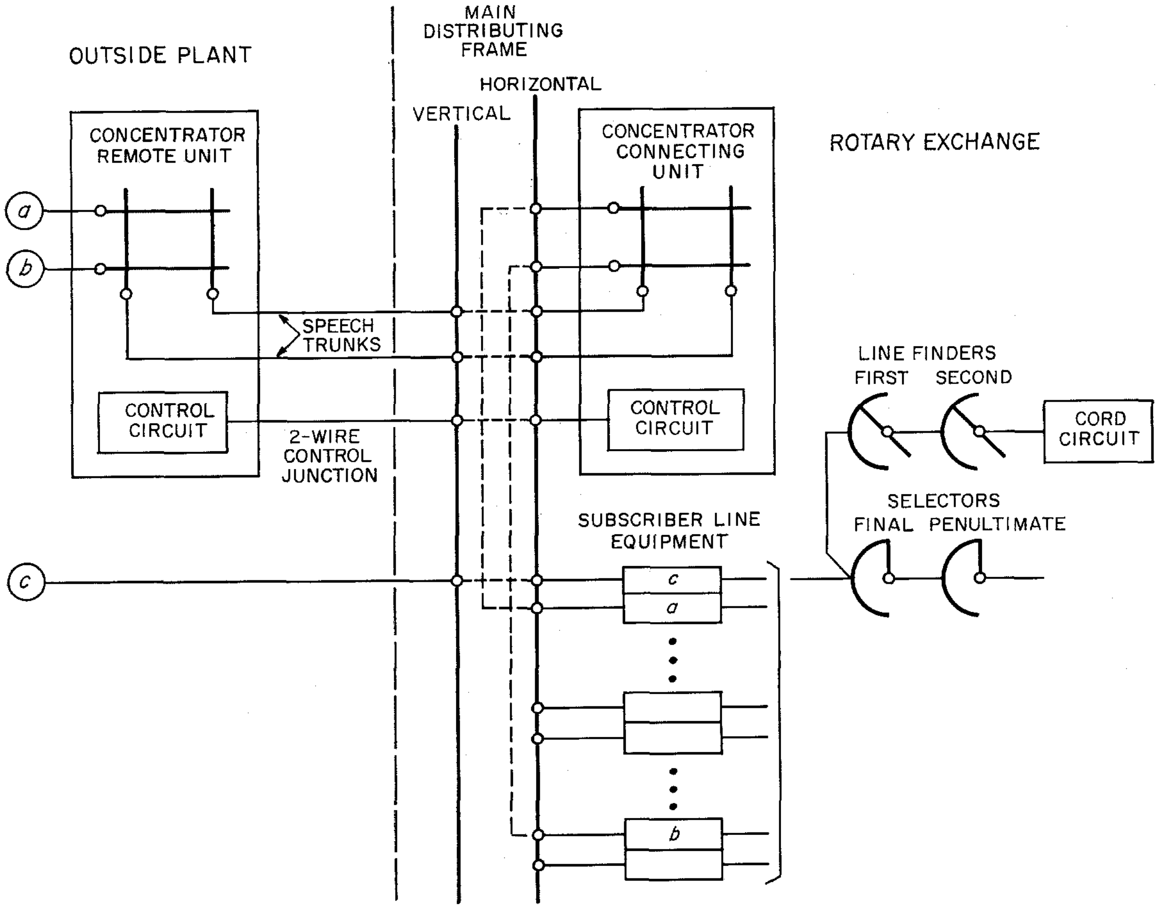


Figure 2—Junction diagram for Pentaconta concentrators working into a rotary switching system.

TABLE 2
Telephone Subscribers and Traffic

Type of Line	Percentage of Total Lines	Percentage of Total Traffic	Average Traffic per Line in Erlangs	Average Use per Day in Minutes
Residential Subscribers	61	15	0.01	7.5
Business, Single Lines	33	37	0.045	30
Private Branch Exchanges	6	48	0.3	100
Total	100	100	0.04	—

quality of service resulting therefrom is not noticeable. This number of trunks is usually larger than would be provided for a small rural exchange of the same capacity.

Finally, the time between the moment a subscriber lifts the receiver and the closing of the loop in the exchange is approximately 800 milliseconds, which also holds for extending a call from the exchange to the subscriber.

Subscribers connected to an exchange through a concentrator receive the same class and quality of service as other subscribers. There is no reason to apply a special subscription rate for this type of connection as the subscribers need not even know about it.

There are several characteristic differences between concentrators and small rural exchanges. In the latter, switching devices participate in the preselection and selection operations of the group to which they are connected. They provide for microphone current to the subscriber's set, for dial-pulse repeating, and for transmitting ringing current. When needed, message registers are generally located in the rural exchange. The subscribers are assigned consecutive directory numbers unless the rural exchange is further equipped with translators of subscriber numbers. Finally, if local connection circuits are utilized, registers or similar simplified circuits must be provided.

The concentrators do not perform any of these functions; their role is limited to extending a 2-wire line from the subscriber's set to the exchange for the duration of each call. Subscribers served by the same concentrator may be interconnected over 2 trunk lines in the concentrator.

3. Economic Factors

The question of under what conditions concentrators prove to be economic has been studied and discussed extensively without providing any definite answer. There would be no value in adding a new study to those already made; it will be sufficient to note that the use of concentrators tends to increase where they are already in service and to be introduced elsewhere.

There are several reasons for the increasing use of concentrators. In countries having high telephone development, the number of lines continues to increase as new categories of subscribers appear. Initially developed for business, the telephone has entered into social and family circles. The number of so-called residential subscribers is increasing and becoming preponderant. Consequently, the number of lines is increasing but, as a counterpart, their utilization rate is decreasing.

Figure 3, which has been prepared from European telephone statistics, illustrates this tendancy. Table 2 gives the breakdown of subscriber lines with regard to traffic and rate of utilization; the figures shown are averages taken from statistics; they can vary rather widely from one country to another.

However, it is relatively expensive to connect a subscriber to an exchange; as is evident from Table 3, which shows a distribution of costs

TABLE 3 Breakdown of Capital Invested in a Telephone Network	Percent
Subscriber's Installation Including Subset	9
Subscriber Lines	60
Switching	25
Trunks	6
Total	100

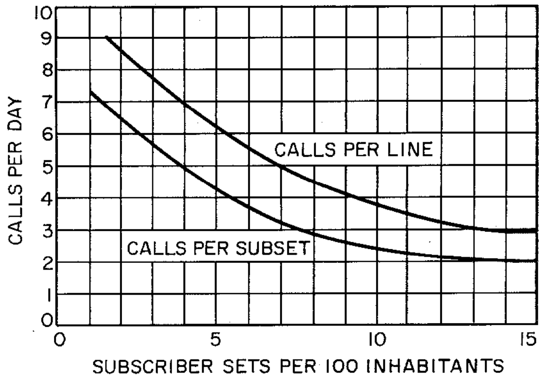


Figure 3—Average number of calls per day for each line and for each subscribers' set as a function of the number of subscribers' sets per 100 inhabitants.

for an automatic telephone exchange and its network.

The connecting of subscriber sets to the exchange represents the largest part of the investment. Considering the rate of utilization of residential lines, there should be intense interest in common connecting devices such as concentrators for groups of subscribers whose total traffic is small and who are located far from the exchange.

A rough estimate shows that if the distance between a group of 56 subscribers and the exchange is approximately 1.55 miles (2.5 kilometers) the cost of material used to connect them is the same, whether one uses 2 overhead distributing cables with 28 pairs of 0.5-millimeter diameter wires or one overhead cable of 14 similar pairs connected to a 52-line 8-trunk concentrator. In this example, means of supporting cables are assumed to exist and the cost of labor to install and lay the cables are considered to be of the same order. In the concentrator case, 4 subscribers have direct connections to the exchange.

Thus, beyond this distance, concentrators can provide an economical means of making connections. Such distances are encountered in rural or provincial areas, in which one exchange serves subscribers in a small town and in the surrounding country.

The usefulness of concentrators is clearly evident in suburban areas around large cities as well as in the urban areas where underground cables are mostly used. In some of these areas, population increases over a few years exceeds the telephone provisions previously thought to be adequate, residential districts rise and grow, and others similarly undergo unanticipated changes in their characters and population. It may not be possible to finance the extension of cables beyond the original plans, particularly if such needs arise at the same time in several places.

In such cases, concentrators give the possibility of creating new spare lines in overcrowded networks by regrouping the traffic of a group of existing residential subscribers on a part of their previous lines used as common trunks.

Savings through concentrators can be evaluated by referring to Table 3. The costs of certain items, switching for instance, are well known in every country. By applying the percentage shown in Table 3, it is easy to calculate the average cost of an average-length subscribers' line. It is interesting to note that the figures obtained in this way provide a good evaluation in France.

When a concentrator is used, the length of the line to be saved is generally greater than average. Thus, the cost of a concentrator and its installation is only a small part of the amount represented by 42 times the average cost. Moreover, the concentrator can be built immediately, which may not always be possible for an extension of the cable network.

On the other hand, it seems difficult to justify the use of concentrators when setting up a new underground network or a new underground cable.

For such installations, the investment in technical studies and in laying cement ducts in the cluttered-up underground of cities or suburban areas exceeds the price of the cable itself. Therefore, the capacity of these ducts and cables is chosen to allow for expansion for many years to come. When these cables are new and all their spare lines are still available, concentrators would provide only additional spare lines.

To summarize, concentrators might economically be used in new networks employing overhead lines and cables in areas having low population density. This is an excellent and inexpensive way of developing new telephone networks in rural or provincial areas. In places having a high population density and where an underground cable network already exists, concentrators mainly are a means of providing immediately for new subscribers. This allows time for selecting the best plan under which the cable network can be extended, thus combining economic management with immediate service to new subscribers.

4. Other Uses for Concentrators

A judicious use of concentrators must take into consideration the total traffic, that is, the average incoming and outgoing traffic, of the subscriber group to be served.

In the preceding section, the expression "residential subscriber" does not mean that subscriber lines for professional use cannot be served by a concentrator; it means only that this type of connection should preferably be reserved for lines having a low utilization rate, that is, comparable to residential subscriber lines.

As there are 8 or 12 speech paths on a 52-subscriber-line Pentaconta concentrator, on the basis of a probability of lost calls equal to 0.005, the total traffic handled during the busy hour by the common trunk group can reach 2.73 or 5.28 erlangs, respectively, which corresponds to an average traffic rate per line of 0.05 or 0.1 erlang. These last figures are not absolute since they are average values and are meant to determine only an order of importance. The traffic on the different lines of the group can vary within rather large limits. However, too heavy a traffic on a line or group of lines may occasion some inconveniences.

These inconveniences can be illustrated by the following example. Let us imagine a group of 50 lines, 4 of which serve a private-branch-exchange group handling approximately 100 incoming and 100 outgoing calls each day. The total traffic of the 50-line group, including the 4 lines of the private-branch-exchange group, is supposed to remain below 5 erlangs, but the traffic of the 4 private-branch-exchange lines during busy hours is more than 2 erlangs. This 50-line group could be served by a 52-line 12-trunk Pentaconta concentrator, but it is much more advantageous to connect the 4 private-branch-exchange lines directly to the central office and to serve the other 46 subscribers by a 52-line 8-trunk concentrator. In fact, in both cases, 14 pairs are necessary for the connection, but in the second case, less money will have to be invested, current consumption and wear of equipment will be lower, and service, particularly that of the private-branch-exchange group, will be of better quality.

Therefore, it is recommended that subscriber lines served by a concentrator have a busy-hour traffic appreciably lower than that of the speech trunks of this concentrator, that is, appreciably lower than 0.34 erlang for the 52-line 8-trunk concentrators and 0.44 erlang for the 52-line 12-trunk concentrators.

The rate of utilization of subscriber lines is often not well known and a check of the number of calls recorded by message registers can give a false idea of their actual traffic. Therefore, if a concentrator is too frequently overloaded, manual or automatic monitoring of the subscribers will determine which lines should preferably be connected directly.

The characteristics of the lines connecting subscriber sets to the remote unit of the concentrator are important. The line relay in the remote unit of the concentrators functions correctly even if the insulation of a subscriber line drops to 20 000 ohms. Theoretically, each subscriber line could present an insulation of 20 000 ohms without affecting the functioning of the concentrator. If this is the case, the battery in the remote unit of the concentrator would have to supply 2.16 more ampere-hours per day to cope with the current leakages occasioned by the poor condition of the lines. The capacity of cadmium-nickel watertight battery in the concentrator would not be sufficient and the charging current it receives through the idle speech trunks is not high enough to handle this additional drain.

If the subscriber connections to the remote unit of the concentrator cause significant leakage, it is necessary either to provide a special pair of conductors from the exchange to supply additional charging current to compensate for leakages, or to provide for a power supply independent of the concentrator, such as 3 motor-car type 12-volt batteries charged from the city electric mains.

5. Installation

The installation of the two units making up a concentrator cannot be handled in the same way. One unit is installed at the exchange and the remote unit is located so that the connections to the individual subscribers will be as short as possible.

In rural areas, it will often be possible to install the concentrator in a building in the community where the subscribers to be served are located and which is already utilized by the operating company. Otherwise, the concentrator will be installed outdoors in a metal cabinet to protect it from weather hazards. The cabinet will be mounted on a concrete base or, where open wire is used, on one of the poles of the network as is frequently done in the United States. Figure 4 shows an outdoor cabinet used by the French administration.

In urban and suburban areas, the pattern of subscriber cables often determines the position of the remote units. In France, for example, the area served by an exchange is divided into zones. Each zone is connected to the exchange by one or several cables with a capacity of 112 or 224 pairs. These cables lead to the entrance to the distributing zone called a junction manhole. Between the exchange and the junction manholes are the main cables. The cables beyond the manholes, called distribution cables, have a decreasing capacity starting from the junction manhole, the smallest cable utilized having a 14-pair capacity. All splices are lead covered.

With these arrangements, concentrators can be equipped near the junction manhole or at the end of the distribution cable.

In the first case, the concentrator makes it possible to delay the extension of the main cables. In the second case, the concentrator also increases the capacity of the distribution network.

When the remote unit of the concentrator is installed near the junction manhole, it can be located in the same building as the manhole if

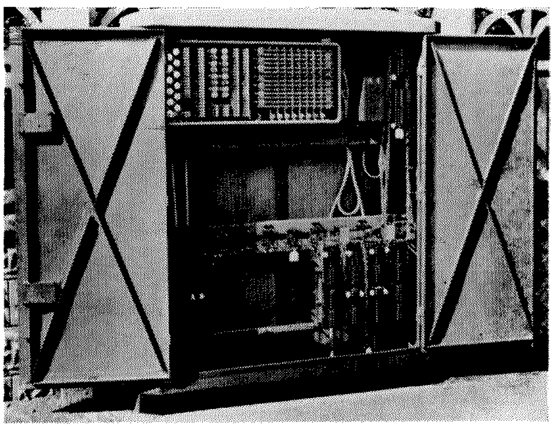


Figure 4—French outdoor cabinet for the remote unit of the concentrator.

the latter is located in a company building. If not, the concentrator is mounted in an outdoor metal cabinet.

When the concentrator is at the end of the distribution cable, it may be installed for example in the basement of the residential buildings where the subscribers reside.

At the exchange, the units are generally on bays in the room housing the main distributing frame. Figure 5 shows an example of this type of installation.

The necessity for connecting units in the exchange certainly limits the use of concentrators. There is usually not much space in the room of the main distributing frame for additional equipment. Unused space in an exchange is scarce or reserved for planned extensions.

6. Concentrators Can Lead to Remote Selection

One may gather that concentrators offer only a provisional solution to network problems. Several writers are of this opinion. Without being so categorical, one must admit that the connecting units increase to an important degree the amount of automatic equipment in the exchange. If only the remote unit of a concentrator were sufficient, this important objection would be removed and the economic advantages of concentrating the traffic of a number of subscribers on a common trunk group would remain. The selecting line unit of the Pentaconta system permits such operation of concentrators. It is possible by using special terminal selection frames to do away with the exchange connecting unit of the concentrators without changing the general operation of the selecting unit and particularly without modifying the marker or the control process.

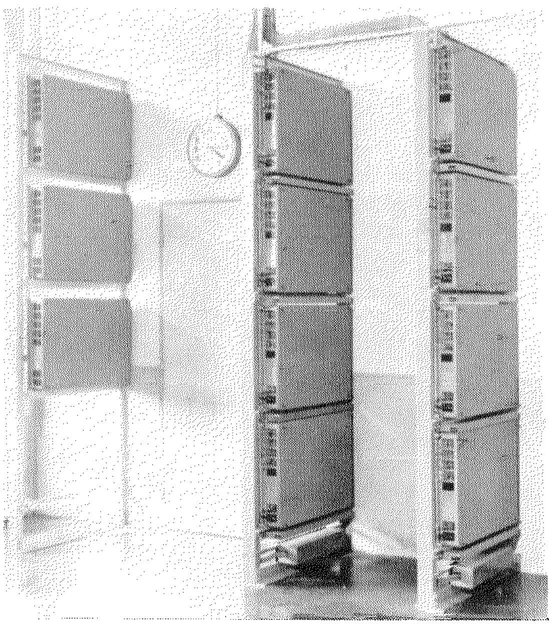


Figure 5—Exchange concentrator units.

In the Pentaconta line selection unit, the normal terminal selection frame includes, in addition to the multiswitch used as final selector, a certain number of relays; such as, line and cut-off relays of the 52 subscribers, selecting relays, and connecting relays to the marker. These are replaced by a special terminal selection frame that will also include the multiswitch used as final selector, the selecting relays and connecting relays to the marker, the cut-off relays of the 52 subscribers, but the line relays will be in the remote unit of the concentrator. Instead, this special frame will include the identifying matrix, common control circuit, pulse generator, and decoding relays that in conventional concentrators are part of the exchange unit.

As the number of relays on this special terminal selection frame is 50 percent larger than that for the normal frame, this new frame is slightly bulkier.

The multiswitch used as a final selector makes it possible to determine at the exchange whether subscribers' lines are busy or idle; it also allows for the connection of message registers and for dealing with the subscriber's category wire as used in the Pentaconta system. The line wires are normally multipled on the switches, but it seems useless to have them connected to the main distributing frame. However, the presence of these line wires in the exchange solves a few problems such as listening in on a busy line, use of message registers at subscriber's premises, et cetera.

Where the 24-line concentrators are used in this arrangement, it is possible to make a special terminal selection frame working with 2 remote 24-line 6-trunk concentrator units.

Although this design of concentrators offers the same operating features as those described, the directory numbers are not so completely independent of the equipment location numbers; the subscriber can be given any number in the thousands group of the line selection unit.

Finally, the cost of such a connection will be half that for a concentrator using exchange connecting units.

A great flexibility results from the fact that the remote units are identical in both types of Pentaconta concentrators. Conventional concentrators can be utilized either to add new subscribers or to meet unforeseen expansion. They may be replaced later by remote selection units.

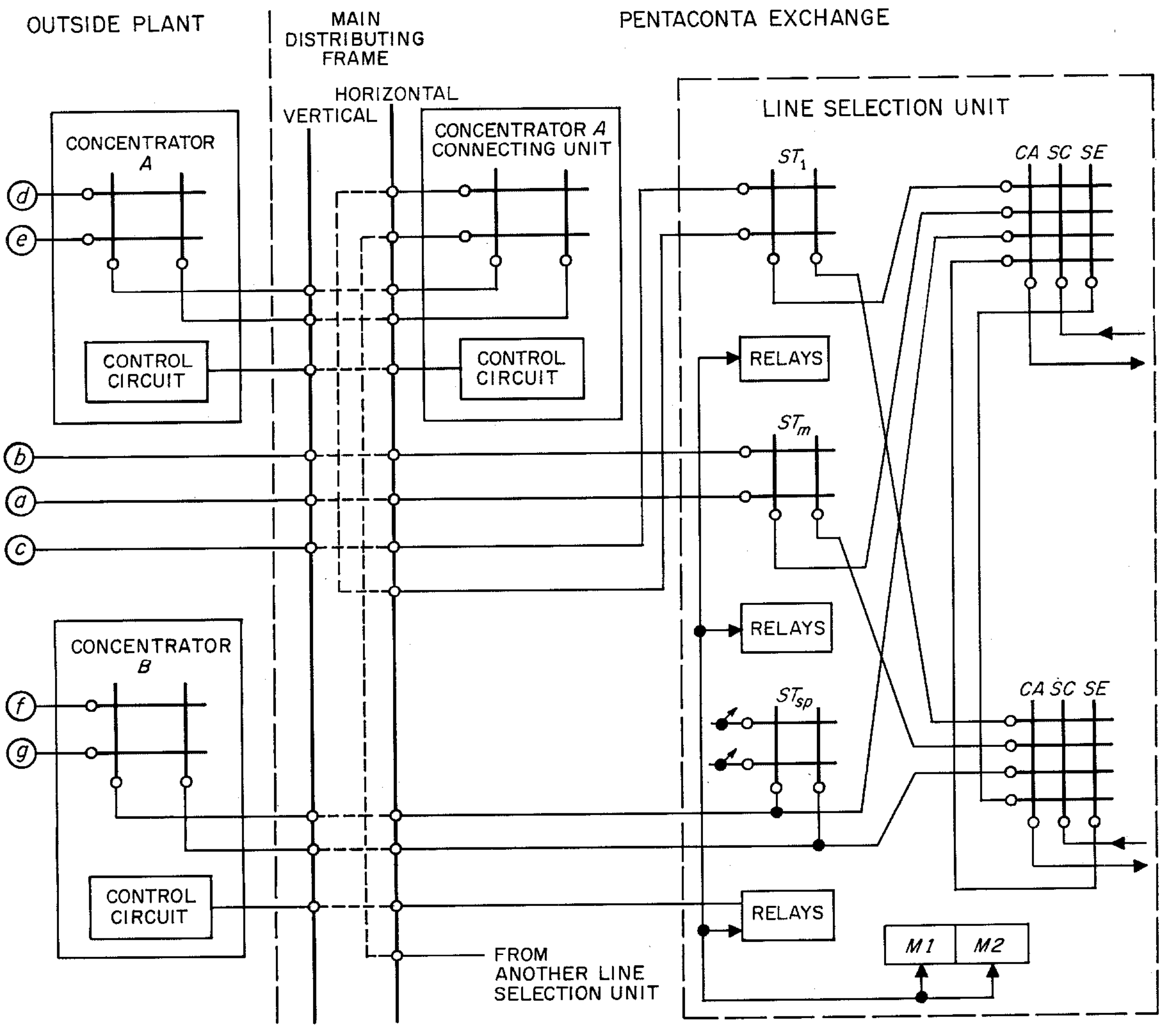


Figure 6—Conventional concentrator and remote terminal selector connected to a Pentaconta exchange.

The exchange connecting unit can then be used for another group.

Figure 6 shows the junction diagram of a Pentaconta line selection unit to which are connected normal subscriber lines *a, b,* and *c;* subscriber lines *d* and *e* served through the conventional concentrator *A;* and finally subscriber lines *f* and *g* served through concentrator *B* used as a remote terminal selector.

Further, Pentaconta concentrators of a capacity beyond 52 lines, capable of serving up to 1000 subscribers' lines, are available. These concentrators are remote line selecting units and are beyond the limits of this article.

7. New Uses of Concentrators

At the very beginning of the study on concentrators, their use with carrier systems was envisaged. It is tempting, of course, to reduce a common trunk group to the single pair of physical conductors needed by a carrier system.

Such utilization is rather far from the original concept of concentrators. The problem is no longer that of providing an entirely metallic path between the subscriber's set and the exchange. A method of supplying microphone and ringing currents, and of repeating dial pulses must be introduced in each speech trunk or channel between the remote end of the concentrator and that of the carrier system. These power supply and repeating bridges can, of course, be part of the terminal equipment of the carrier system. The signalling system used by the carrier current must be able, on the one hand, to transmit the ringing current for calls received by the subscribers served by the concentrator and, on the other hand, to repeat the dial pulses for calls originated by the subscriber. Finally a signalling system as simple as possible must be designed so that the necessary information for control of both ends of the concentrator may be transmitted in both directions.

This type of system, known as "rural carrier system," is rather expensive and its use can be justified only under special conditions; the association of a concentrator with this type of carrier system will increase its field of application.

Prototypes of adaptors based on such an association have been built and tested in the laboratory; field tests are now being undertaken by the International System in the United States and in Italy.

8. Conclusion

Pentaconta concentrators are extremely useful devices for the expansion of a subscriber network. They offer an economical solution to many problems mainly in the development of new networks and the rapid establishment of temporary telephone lines such as those used for exhibitions, meetings, et cetera. Above all in suburban areas they provide a rapid and economic way of meeting unforeseen demands for telephone service by improving the utilization rate of existing cables.

The separation of speech paths and control circuits simplifies the operation of Pentaconta concentrators in association with carrier systems. This leads to future applications of concentrators to connect existing subscribers with conventional subsets to possible time-division-multiplex electronic exchanges of the future.

9. References

1. J. P. Basset and P. Camus, "1000 B Pentaconta System," *Electrical Communication,* volume 38, number 2, pages 196–212; 1963.

2. "Distribution of Telephone Traffic in a German Town with 700 000 Inhabitants," Professor Lennertz, Technical University, Aachen, 1956.

3. "Telephone Policy: The Next Steps," Presented to Parliament by the Postmaster General, Her Majesty's Stationery Office, CMND 436; May 1958.

A. J. Henquet was born in Paris, France, on 15 December 1906. He graduated as a certified engineer in electromechanics in 1926 from the Breguet school.

In 1927, Mr. Henquet joined Le Matériel Téléphonique as a circuit designer and is presently chief engineer of switching developments for the telephone branch.

Applied Cryogenic Engineering

The University of California in Los Angeles presented a graduate-level series of lectures on the properties, characteristics, and utilization of liquefied gases as they are used in space systems. The contents of these lectures will be useful in the development of advanced propellant systems and in other fields involving cryogenics. A compilation of these lectures, edited by R. W. Vance of the technical staff of Aerospace Corporation and W. M. Duke, president of ITT Federal Laboratories, is included in this book. The book is divided into the following 15 chapters and 3 appendixes.

Chapters

1. Basic Theory; R. W. Vance, Aerospace Corporation
2. Cryogenic Fluids—Their Properties and Technology; R. W. Vance and C. H. Reynales, Space Technology Laboratories
3. Mechanical Properties of Materials; R. H. Kropschot, National Bureau of Standards
4. Low-Temperature Thermometry; K. D. Timmerhaus, University of Colorado
5. Fluid Flow and Heat Transfer; K. D. Timmerhaus
6. Low-Temperature Insulation; R. H. Kropschot
7. Liquefaction of Oxygen, Nitrogen, and Hydrogen; A. J. Westbrock, Linde Company
8. Helium Liquefaction—Cryogenic Equipment Applications; A. J. Westbrock
9. Storage and Transfer of Cryogenic Fluids; P. D. Fuller and J. N. McLogan, both of Stearns-Roger Manufacturing Company
10. Safety Aspects of Cryogenic Systems; C. McKinley, Air Products and Chemicals, Inc.
11. Explosion Hazards in Liquid Bipropellants; M. A. Cook, University of Utah
12. Helium: V. Arp, Boulder, Colorado; and R. H. Kropschot
13. Storage of Cryogenic Fluids in Space; M. Adelberg, Space Technology Laboratories
14. Application of Cryogenic Rocket Propellants to Space Vehicles; S. G. Rumbold, Space-General Corporation
15. Future of Cryogenic Fuels for Space Systems; R. D. Long, Aerospace Corporation

Appendixes

A. Properties of Cryogenic Fluids

B. Processing Helium from Natural Gas

C. Contamination Control in Cryogenic Fluids and Systems; Major G. J. Murphy and Captain P. O. Pearce, Air Force Ballistic Systems Division

The book is 9 by 5¾ inches (23 by 15 centimeters) and contains 510 pages including an 11-page index. It is published by John Wiley and Sons, 440 Park Avenue, New York 16, New York, at $17.50 per copy. It is also available from John Wiley and Sons Limited, Glen House, Stag Place, London, S.W. 1, England at £6-11/9d.

Telegraph Transit Exchange Using Crossbar Pentaconta Design

PIERRE SAMUEL

Compagnie Générale de Constructions Téléphoniques; Paris, France

This transit exchange employing crossbar Pentaconta equipment[1, 2] was produced for the Aerial Navigation Department and installed in the central telecommunications north office at Athis-Mons near the Orly airport that serves Paris. Cut over in June 1961, it is a part of the Aeronautical Fixed Telecommunications Network.

In this international network, the telegraph circuits ensure interconnection of the different airports of the world and communication between each airport and services such as for weather forecasting and regional control.

The messages are generally concerned with safety flight plans, meteorological information, and instructions from regional control centers.

Service information is also transmitted and all messages may be directed to more than one party.

In the aeronautical fixed telecommunications network, the circuits employ either voice-frequency wire or radio channels; they are generally long and high in cost. This requires that they handle a maximum of traffic. This is obtained by separating the two channels of each connection to provide for duplex operation.

The preceding considerations lead to the adoption, for a transit exchange, of a method of operation with registration of incoming messages and retransmission over the channel or channels concerned as soon as available. Each incoming channel will then be permanently connected to a receiving device.

1. Transit Exchange

The incoming lines of a transit exchange are connected to receiving devices such as printing reperforators and messages are transmitted over outgoing lines automatically.

In the Orly transit exchange, the tape is perforated without being torn, which avoids its possible mutilation and loss in being manually transferred to an outgoing-line transmitter.

The tape from each incoming reperforator goes directly to an automatic transmitter having access to all outgoing lines. Sufficient space between the reperforator and the transmitter permits an operator to read the routing indications and make the required selection of outgoing line. This is, therefore, semiautomatic continuous-tape operation.

2. Format and Procedure

The continuous-tape method requires a standard composition of each message, which must consist of a heading, routing, origin, text, and end signals.

The heading is provided as a check on the transmission between the two exchanges. Consequently, it is cancelled on reception and replaced by a new heading for the next transmission.

There are only two types of messages: normal messages, which are the business messages for which the system was installed, and checking messages, which are sent at set hours over each outgoing circuit if no normal message is being transmitted.

The normal message and procedure is as follows.

(**A**) Start Impulse—This causes the incoming reperforator in the receiving office to start.

(**B**) Heading—The identification element of a message, usually a serial number for that particular transmission.

(**C**) Routing—The address or addresses to which the message is directed.

(**D**) Origin—The indication of the origin of the message and the priority alarm.

[1] F. Gohorel, "Pentaconta Dial Telephone Switching System," *Electrical Communication,* volume 31, pages 74–106; June 1954.

[2] "M. R. Legare, 'Etude détaillée des circuits des autocommutateurs Crossbar Français: Premiere partie, LE PENTACONTA," Posts and Telecommunications, Paris; 1960.

(E) Text.

(F) End—Indicates the end of the transmission of a message and prepares the reception equipment for the following incoming message.

(G) Tape Advance—This permits separation of messages and is used only for transmission to a torn-tape transit exchange or a local exchange.

The checking messages are transmitted automatically by the outgoing line equipment at determined time periods, say, every 20 minutes, if there is no transmission in process. They are sent to check the correct functioning of the equipment and the condition of the channel. The message consists of the heading, the letters *CK*, and the end.

3. Operation of the Exchange

The operation of the exchange will be described for transit of a message to a single outgoing wire channel, to a single outgoing radio channel, to several outgoing channels, and the case of a message with a faulty address. Reference will be made to Figure 1.

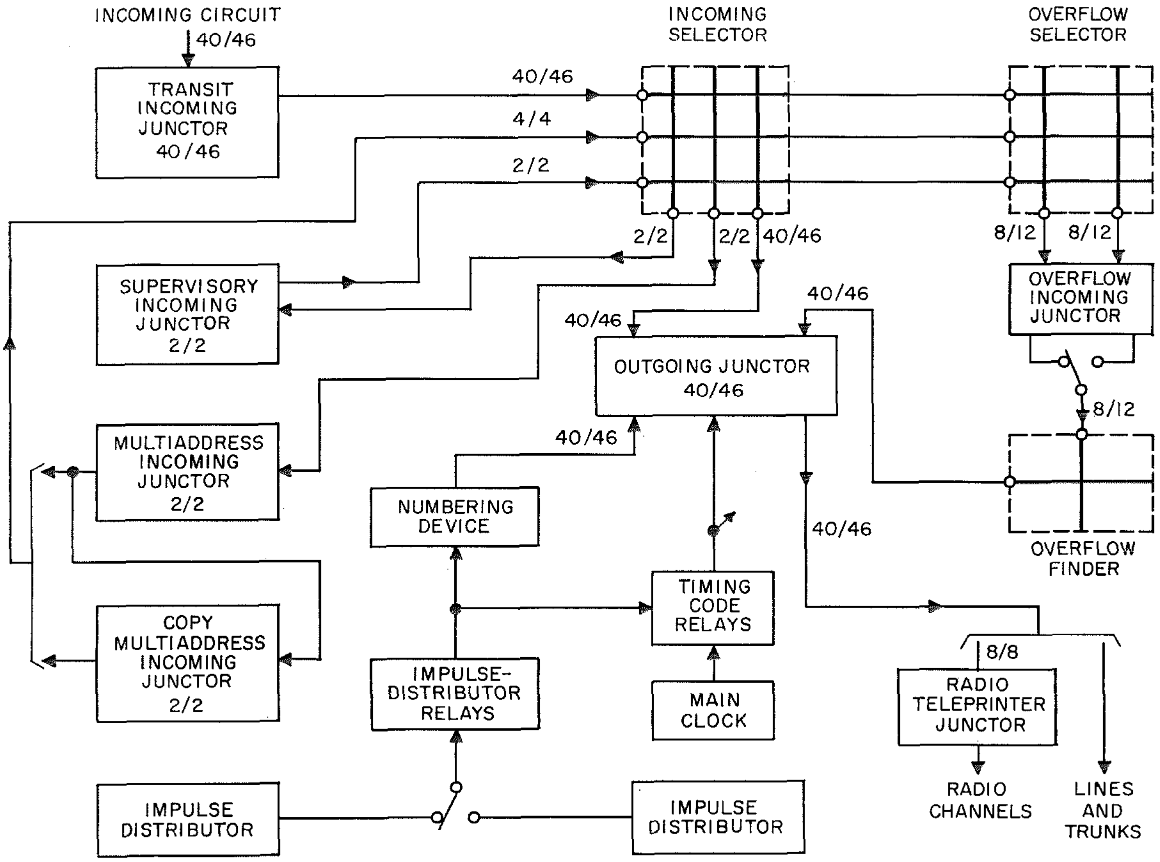


Figure 1—Trunking diagram for Orly telegraph transit exchange. The numbers indicate the initially equipped and ultimate capacities of the various elements. A typing reperforator and transmitting distributor is associated with each incoming junctor except that two such equipments are provided at the overflow incoming junctor.

3.1 Available Outgoing Wire Channel

The message is received on the typing reperforator at the incoming transit junctor, the perforated tape being threaded directly to the associated automatic transmitter. As the tape travels along, the operator checks the serial number in the heading, which under control of the operator is not transmitted.

The operator then reads the address and operates control buttons to select the outgoing channel. When the connection is made, the incoming transit position is connected through the incoming selector to the outgoing junctor. The outgoing junctor will send a seizure signal to the next exchange. After a timed-delay for starting the distant receiver motor, the outgoing junctor, with the aid of the numbering device, the timing-code relay set, and the impulse distributor relays, send a new heading for the message. The end of this transmission is signalled by the outgoing junctor to the incoming transit junctor as an order to transmit the message. The end-of-message signal is detected by the transmitter at the incoming transit position, which then initiates the release of the transit position and the outgoing junctor.

3.2 Available Outgoing Radio Channel

If the message must be routed over a radio channel, it is reperforated before going out of the exchange. Consequently, the heading sent by the outgoing junctor, as well as the message, are received on a typing reperforator at a radio teleprinter position, from which the associated transmitter distributor sends it to the radio transmitter. This storage at the exchange is necessary because of the uncertainties to which radio channels may be subjected.

3.3 Busy Outgoing Channel

If the selection ordered by the operator at the transit incoming junctor is not available through the incoming selector, the call will go to the overflow position through the overflow selector. This automatically operated position is equipped with two sets of typing reperforators and transmitter distributors under control of an overflow incoming junctor. The message is then transmitted from the transit incoming junctor to one of the overflow typing reperforators, which stores it until the required outgoing junctor is available. The overflow position is connected to the outgoing junctor through the overflow finder.

3.4 Fully Busy Outgoing Channel

If no overflow position is available or if the overflow position assigned to the outgoing junction is busy, after automatic reselection, the message is transmitted to a multiple-address position from the transit incoming position through the incoming selector. This is a form of storage to avoid overloading the transit incoming position. The message is then retransmitted by the operator of the multiple-address position.

3.5 Several Outgoing Channels

If the number of outgoing channels does not exceed 9, they can be selected by the operator of the transit incoming position. The message will be retransmitted simultaneously over the different outgoing channels or on overflow positions if the channels are busy. If the number of channels exceeds 9, the message must be sent to a multiple-address position.

3.6 Faulty Address

If the routing indications are incomplete or spurious when a message is received, it must be transmitted to a supervisory position through the incoming selector.

The supervisory position is operated with torn tape to permit reperforation of a message after the correct routing indications are determined. Retransmission over the outgoing channels is done through the incoming selector.

4. Operating Details

4.1 Selection

When the selection sought by a transit or supervisory position cannot be completed, because of busy channels or an insufficient number of available overflow positions, the selection is automatically rerouted after 20 seconds. If this second attempt does not succeed, a multiple-address position is automatically selected. If the two multiple-address positions are busy, the message remains at the caller's position and the operator recommences the selection.

For a call from a multiple-address position, there is no automatic rerouting of the selection. If some selected lines are busy, the message is accepted by the associated copying equipment, thus avoiding the overloading of the normal equipment with messages in wait condition.

4.2 Outgoing Junctors

Each outgoing junctor is assigned to an outgoing channel. It can be connected to the different incoming positions either directly if it is available or through the intermediary of an overflow position that is temporarily allotted to it.

The function of the outgoing junctor is to send the heading before the transmission of a message and at the end of the message to send a sequence of tape unwinding signals if the correspondent is a torn-tape transit exchange or a local station.

Sending the impulses for the transmission of the heading is controlled by an impulse distributor common to all the junctors. There is a second emergency distributor with automatic switching. Identification of the message is done by the numbering device assigned to the junctor, by the common timing-code relay set operated from the clock, and by connections to be made according to other signals that must not change.

On the other hand, the outgoing junctors send the checking messages under control of the timing-code relay set, which requests the available outgoing junctors for this purpose every 20 minutes starting on the hour.

4.3 Timing-Code Relay Set

In addition to supplying identifying time signals and ordering checking messages, the timing-code relay set ensures the return of the numbering devices to zero at 00 : 00 o'clock.

4.4 Incoming and Outgoing Circuits

All outside circuits, incoming and outgoing, are connected to the exchange through telegraph relays so that internal transmission is totally independent of the outside circuits.

4.5 Overflow Positions

The functioning of an overflow position is entirely automatic. On the reception side, the overflow incoming junctor is connected by two selectors in the overflow selector and the two typing reperforators are seized alternately. If one equipment is engaged in receiving, the other can be seized, even repeatedly if necessary.

The two transmitter distributors alternately transmit to the outgoing junctor. The switching is controlled by the detection of the end-of-message signal by each apparatus.

5. Supervision

A page-type receiver monitors the transmission on each outgoing channel.

The supervisory signals from the different circuits operate in the equipment bays. For the outgoing junctors, these signals are also reproduced at the desk of the department chief.

A defect in a circuit engaged in transmission, such as in an outgoing junctor, is indicated to the transit position connected to it.

These signals are transmitted via the connecting selector.

6. Equipment Layout

Switching at the Orly telegraph transit exchange is based on the principles of the Pentaconta telephone switching system and uses its

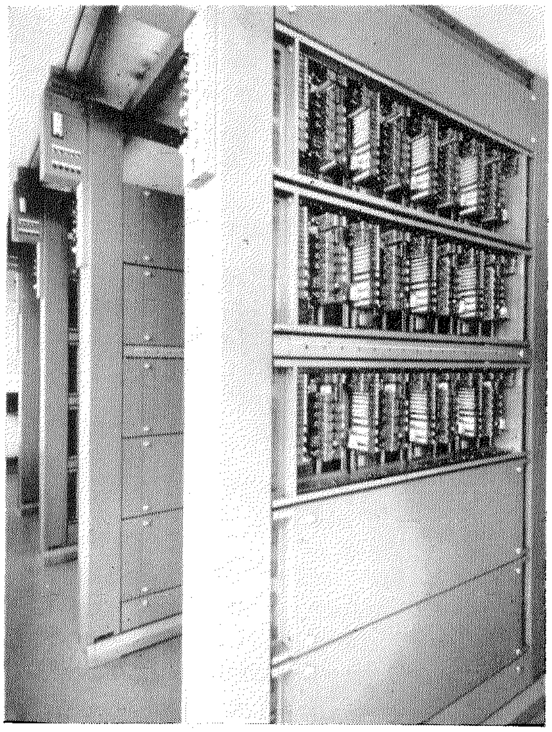


Figure 2—Partial view of the Orly exchange.

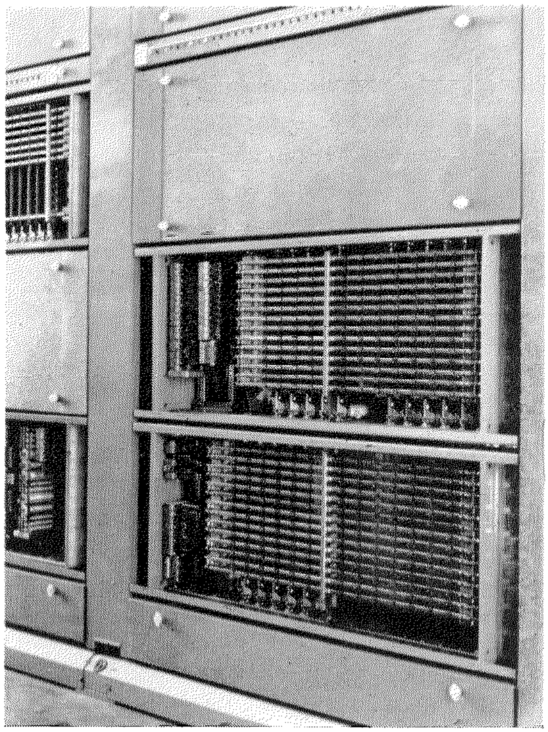


Figure 3—Pentaconta crossbar switches and control relays.

4- or 5-wire multiswitches and relays. The great flexibility of the Pentaconta design and equipment permits its easy adaptation to telegraph installations where its high operational speed and reliability are of prime importance. The exchange is equipped now for 40 incoming and 40 outgoing circuits and may be expanded to 46 circuits of both types.

Figures 2 and 3 are views of part of the equipment, which is installed in 4 rows of bays having a total length of 24 meters (79 feet) and a height of 2.65 meters (8.7 feet). The corresponding area of the room is 54 square meters (581 square feet). The apparatus is mounted in 62 frames.

Consideration is being given to replacing the electromechanical impulse distributors by electronic units to eliminate mechanical wear and reduce maintenance.

7. Conclusion

Since the cut over of the Orly exchange in June 1961, experience has proved that operators previously experienced in the torn-tape method adapt rapidly to semiautomatic continuous-tape operation. This is fundamental as the correct operation of the exchange depends on the total compliance with the message composing procedure.

Every day this transit exchange handles an average of 19 000 messages with peaks as high as 24 000. The mean duration of a message is 55 seconds although some meteorological messages require 300 seconds, which corresponds to 5 meters (16.4 feet) of perforated tape.

The outgoing traffic routed by the overflow positions varies between 28 and 34 percent of the total outgoing traffic.

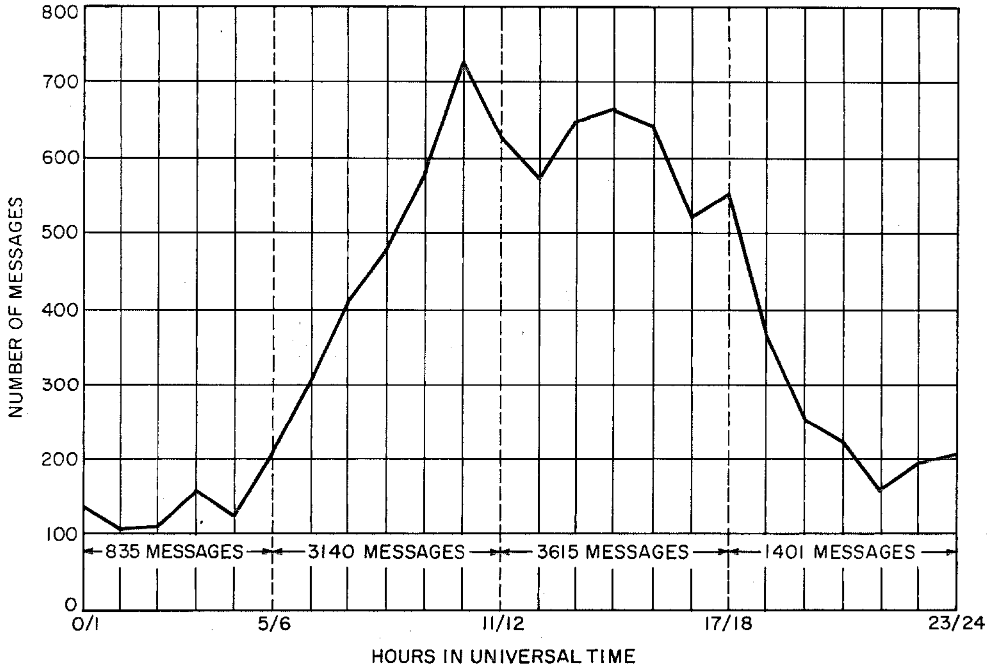
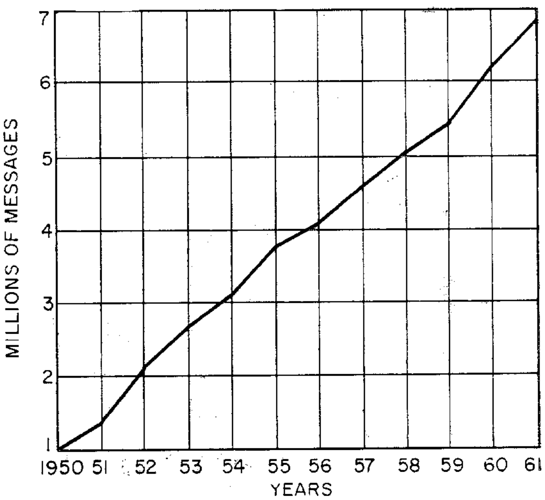


Figure 4—Hourly variations in traffic at the Orly exchange. Each value is for the number of messages handled in the preceding hour.

Figures 4 and 5 show the daily variations of traffic and the steady increase in annual traffic during the past 10 years.

As each transit position may transmit in as many as 9 directions, all messages may be immediately routed by the operators without concentration of traffic in a small number of positions.

Figure 5—Annual growth in traffic at the Orly exchange.



Pierre Samuel was born on 1 March 1928 in Paris, France. In 1952, he obtained a Licence-ès-Sciences Mathématiques from the Université de Paris.

In 1955, Mr. Samuel joined the technical department of Compagnie Générale de Constructions Téléphoniques; he has worked on private telephone equipment and on telegraph installations.

Assistant Type Telephone Set

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H. VAN HOLST
Bell Telephone Manufacturing Company; Antwerp, Belgium

An entirely new series of subscriber telephone sets has been developed jointly by Standard Elektrik Lorenz and Bell Telephone Manufacturing Company. With the requirements of several European telephone administrations in mind, several models were designed and tested [1] by a large number of subscribers in various countries during 1956 and 1957. The majority favored the Assistant set shown in Figures 1 and 2.

Figure 1—Assistant set.

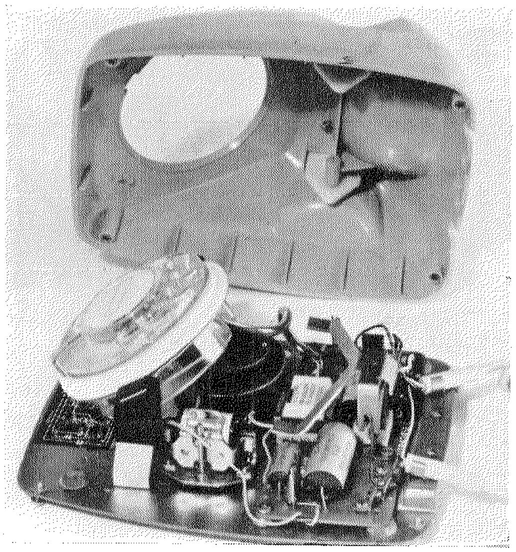


Figure 2—Desk-type subscriber set with cover removed.

1. General Design

For the case, a copolymer of styrene and acrylnitrile combines smart appearance, light weight, and an easily cleanable surface with good impact and scratch resistance. The standard color is grey with ivory mouthpiece and earpiece. The subscriber set is 115 millimeters (4.5 inches) high, 225 millimeters (9 inches) wide, and 200 millimeters (7.9 inches) deep. It weighs 1300 grams (2.9 pounds).

Miniature components are mounted on a printed-wiring board screwed to a metallic base plate, which is fastened to the case by screws. Only the ringer and dial switch do not form part of the printed wiring.

The circuits have been designed for improved performance on all existing feed lines connected to automatic or manual exchanges and to private branch exchanges.

2. Printed Circuit

Most of the wiring is on a rectangular sheet of high-grade glass fiber. The induction coil, gravity switch, capacitors, resistors, varistors, and terminals are automatically assembled and dip-soldered to this board. A 4-wire connector to the dial and a pair for the ringer are also dip-soldered.

The assembled printed circuit is screwed to 4 embossed threads in the steel base plate, which are positioned to support the gravity switch and the board in the region of the screw terminals.

3. Telephone Circuit

To meet the needs of various administrations, 4 different printed-circuit boards are provided.

(A) Circuit with automatic equalization (Western Electric 500 type).
(B) British Post Office Type.
(C) Circuit without equalization.
(D) Bridged circuit (German Post Office).

The printed-circuit board in Figure 3 is the equalized version.

The subscribers set with automatic equalization uses either a ring-armature or a rocking-armature receiver and a conventional transmitter capsule. The circuit includes 2 silicon-carbide varistors. A click-suppressor is mounted on the printed-circuit board.

The circuit that meets the requirements of the British Post Office differs from the equalized circuit in that the 2 matching varistors are replaced by a rectifier stack and a lamp.

4. Induction Coil

The miniature induction coil has about a quarter of the conventional volume. Its small size and weight permit it to be fastened directly to the printed-circuit board by dip-soldering to its wire-type terminals. A special nylon coil former is employed, and the core is of silicon-steel laminations. Its electrical characteristics are comparable to those of the conventional induction coil.

5. Gravity Switch

The gravity switch is also of miniature size and designed for automatic dip-soldering into the printed circuit. It is fixed directly to the base plate by 2 screws. The springs for the 2 make and the 2 change-over contacts are embedded in a plastic compound. A plastic device riveted to the gravity-switch operating arm actuates the spring and at the same time affords protection against dust. Each spring carries twin palladium contacts.

6. Ringer

The single-coil ringer of Figure 4 is a 2-polarity system. The permanent ferrite magnet and the soft-iron core are both contained within the coil.

The permanent-magnet flux path includes the soft-iron core, operating air gaps, armature, and the other pole area. The area of the armature opposite this pole area is large so as to reduce the reluctance of this air gap.

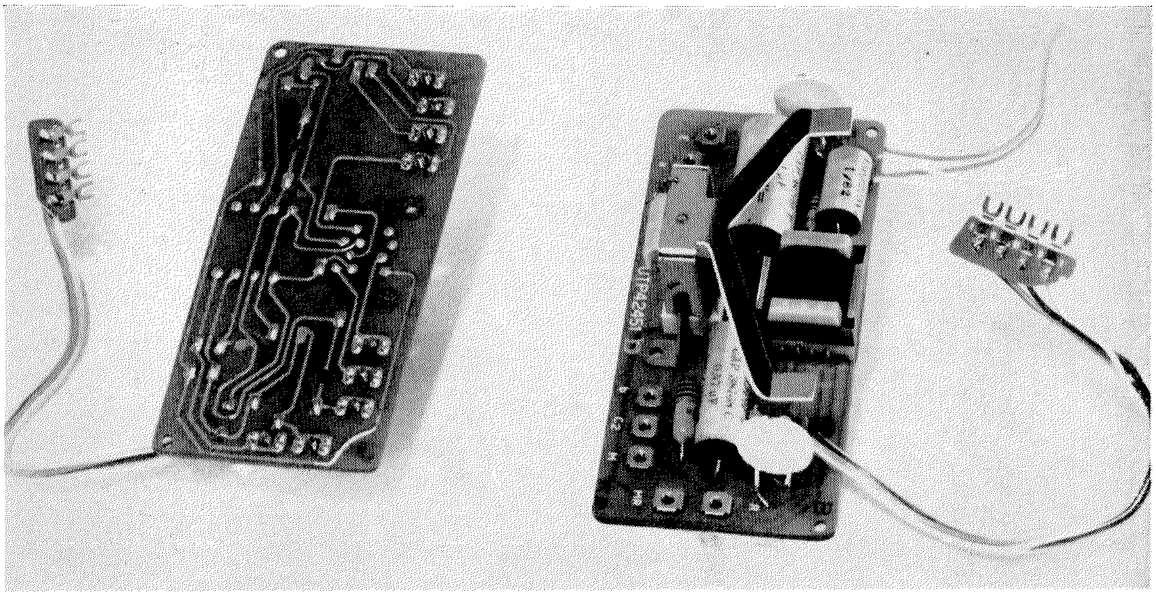


Figure 3—Printed-wiring board equipped with equalizer.

The clapper oscillates between the bell domes and may be laterally biased by an easily mounted spring. A simple knob regulates loudness over a range of about 7 decibels.

7. Dial

The dial, shown in Figure 5, consists of a brass punched base plate on which are mounted the main-spring holder, impulse mechanism, speed regulator, and transparent finger wheel, which are the rotating parts, and the spring nest, finger stop, number plate, and top plate, which are fixed.

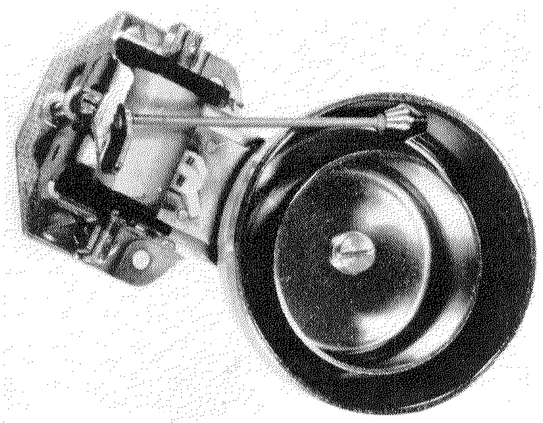


Figure 4—Single-coil 2-polarity ringer.

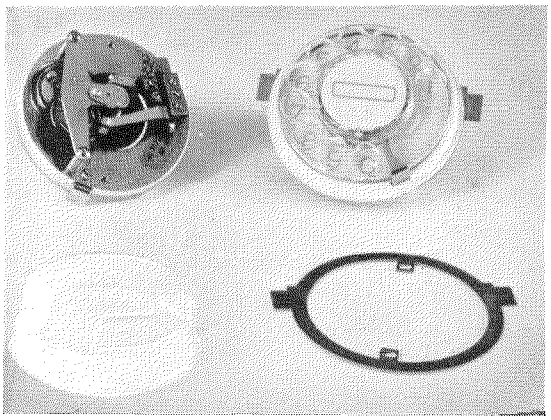


Figure 5—Dial mechanism.

The speed regulator is of the slow-motion type operating at 1000 revolutions per minute. Each of 2 centrifugal weights are controlled by a torsion spring, the tension of which can be adjusted by moving a slider over a graduated sector. Each graduation corresponds to a definite amount of speed variation, and this adjustment can be performed without tools. The regulating action of the centrifugal weights is obtained by the brake effect produced by a bakelised-canvas sector that is part of each weight. The weights rotate in a brass drum.

The impulse mechanism is designed so that the rotation of the speed regulator is started before the impulse cam starts. The impulse contacts are opened by 3 protruding sectors of the impulse cam, which is of the flutter type.

This impulse cam, containing 3 holes for operation with the ratchet springs, is made of polyamide to reduce noise that might be caused by the springs.

As in other designs, the impulse mechanism is provided with a spring clutch. The construction permits easy dismounting of the impulse mechanism.

The helical-type main spring is adjustable and a protecting plate, mounted on the top-plate, prevents any accidental disturbance of the adjustment. The number plate is integral with the outside cover and is of injected acryl.

The dial is acoustically insulated from the base plate by 2 rubber holders and from the case by a polyvinyl-chloride ring, so that noise radiation when dialing is greatly attenuated.

8. Handset

The handset dimensions correspond to recommendations of the Comité Consultatif International Télégraphique et Téléphonique. It is short, thus ensuring a lowered reference equivalent of the sending system and an increase in signal-to-noise ratio. It is shaped to suit the palm and does not tire the fingers. The light weight of the handset causes no fatigue even during long conversations.

To make the transmission advantages of the shortened handset available to as many persons as possible, it is important that the distance between the transmitter and receiver capsules and their angular relations be properly chosen.

Years ago, extensive measurements of the human head were made in various countries [2]. The Comité Consultatif International Télégraphique et Téléphonique selected the head measurements [3] in Figure 6 as average values from which the position of the mouth center was derived. The frequency distribution of the values found in such head measurements [4] as a function of α and δ is shown in Figure 7.

The body of the handset is of a copolymer of styrene and acrylnitrile and is injection molded in one part. Two straight-sided cores that can be withdrawn directly after molding provide for the receiver and the transmitter cavities. The hollow connecting handle is filled with two core pieces that can be withdrawn through the receiver and transmitter cavities.

A disassembled handset is shown in Figure 8. The two capsule supports may differ to accommodate other types of capsules. They prevent acoustic feedback through the hollow handle. These capsules also form defined spaces behind the capsules to improve the acoustic properties of capsules having rear openings for coupling to these air volumes. The capsules are sealed by polyvinyl-chloride rings.

9. Transmitters

The *TMC2046* transmitter capsule in Figure 9 corresponds to the *T1* Western Electric

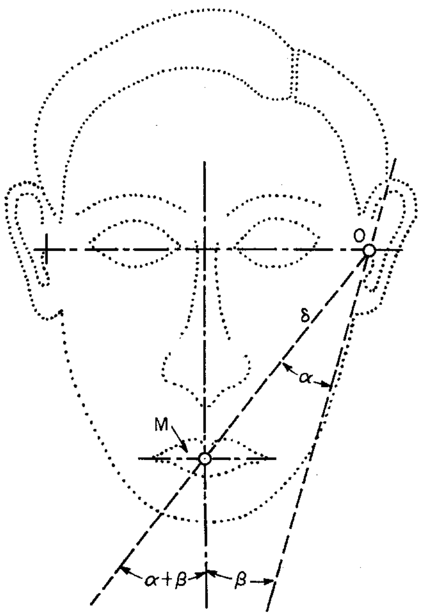


Figure 6—Head standard selected by Comité Consultatif International Télégraphique et Téléphonique. M is the center of the mouth, O is the center of the ear, $\alpha = 22$ degrees, $\alpha + \beta = 34.9$ degrees, and $\delta = 136$ millimeters (5.4 inches).

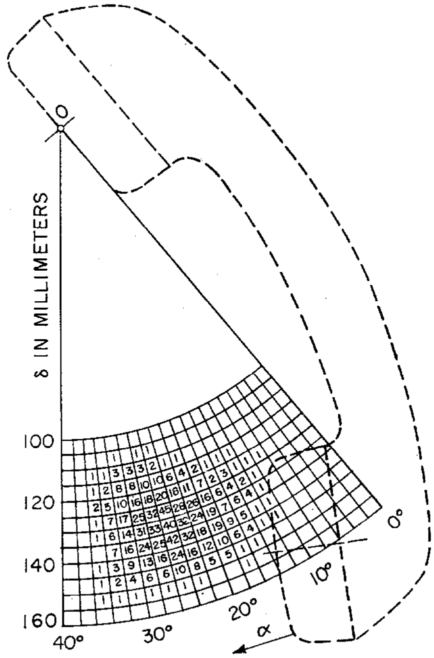


Figure 7—Shape of handset shown on statistical plot of mouth positions with respect to center of ear for 1000 persons.

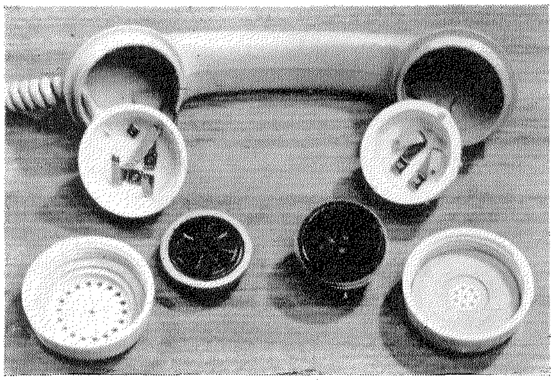


Figure 8—Disassembled handset.

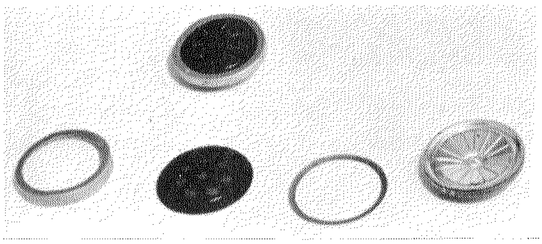


Figure 9—*TMC2046* transmitter capsule.

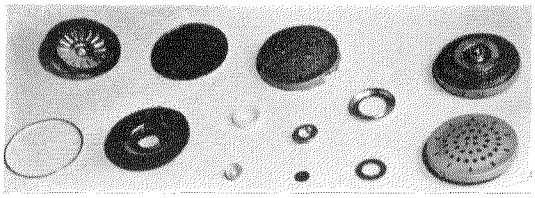


Figure 10—*TMC2047* transmitter capsule.

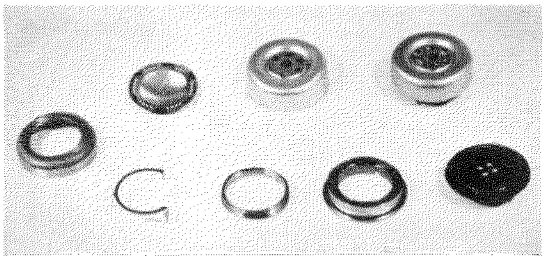


Figure 11—*RCC2687* receiver.

unit. Equalization of response with frequency is aided by three holes in the base that, covered with silk disks of acoustic resistance material, vent the air volume behind the diaphragm into a plastic connecting cup in the handset.

The *TMC2047* transmitter of Figure 10 corresponds to the Western Electric *F1* transmitter in which, however, the damping paper books have been replaced by a metallic separator provided with damping holes. This transmitter is completely sealed against humidity. All transmitters are well protected against corrosion by chromated outside surfaces, a vistanex protecting membrane in front of the aluminum diaphragm, and the use of gold-plated electrodes. Moreover, the electrodes are of spherical shape, thus providing stable performance at various inclinations of the handset.

For use with the Western Electric *500* equalized circuits, the capsules are filled with high-grade pre-aged granular carbon ensuring the high stability of resistance required for adequate operation of the automatic balancing network and for prevention of premature burning with life.

The response of the transmitter capsules are very well equalized with frequency, and approach, in combination with the responses of the receiver, the orthotelephonic response as measured over a 1-meter air path between the human mouth and ear.

The psophometric electromotive-force noise voltage, as measured with the psophometer standardized by the Comité Consultatif International Télégraphique et Téléphonique, the capsules being placed in a soundproof container and supplied with 200 milliamperes, does not exceed 0.02 millivolt.

10. Receivers

One of several suitable types is the *RCC2687A* receiver, which corresponds to the Western Electric U1 ring-armature receiver. As shown in Figure 11, it has a highly coercive alnico circular magnetic system and a dome-shaped aluminum diaphragm that is well balanced between relatively large air gaps by a permendur ring providing a very stable magnetic circuit.

A composite diaphragm permits the central portion to move almost wholly like a piston, making it nearly 100-percent effective.

The shape and level of its response curve make it a high-quality receiver, since it and the transmitter give an over-all response that compensates to some extent for the high-frequency losses of long subscriber lines.

11. Microtelephone Cords

The microtelephone cords are of the coiled type. Their most obvious property is the high extensibility of the coiled part, which can be stretched, by exerting a very slight force, to 5 times its original length. As soon as the stretching force is released, the cord returns to its initial state.

The cords retain the above-mentioned properties, even after repeated pulling and under severe working conditions. The required resilience and elasticity of the material are obtained by a very special production process.

The conductors are made of 7 tinsel wires that are centrally reinforced by a nylon strand, which absorbs the stretching force that otherwise would be exerted on the wires. The conductors are covered with polyvinyl-chloride in such a way as to permit an appreciable sliding of the conductor inside the insulating sleeve. The sleeves are covered by an over-all spirally wound sheeting. The coiled part of the cord has a length of about 300 millimeters (1 foot).

12. Transmission Performance

The absence of automatic equalization permits the *SSB2900A* set to provide more-efficient transmission than the *SSB2900C* on short lines, whereas on long lines their transmission performances are about equal. The reception is weaker than that of the *SSB2900C* and the response is less smooth.

Optimum sidetone suppression is adapted to a 2.5-kilometer (1.6-mile) loop of 23 American Wire Gage cable, but it can be modified for any other loop.

13. Transmission Response

As shown in Figure 12, transmission is measured across a 600-ohm termination of a transmitting system consisting of the subscriber set, subscriber line of either zero or 5 kilometers (3.1 miles) of 26 American Wire Gage cable loop, and a bridged-impedance cord circuit of 2×250 ohms and 48 volts.

The response is referred to 1 volt per dyne per square centimeter as measured with a constant pressure of 30 dynes per square centimeter at the orifice of an artificial mouth before introducing the microphone into the sound field.

14. Receiving Response

The response plotted in Figure 13 is recorded as sound pressure delivered by the receiver capsule to an artificial ear consisting of a calibrated Western Electric *640AA* capacitor transmitter and a 6-cubic-centimeter coupler as recommended by the American Standards Association. The receiver is actuated from a 600-ohm termination across the receiving system, which includes a bridged-impedance cord circuit of 2×250 ohms and 48 volts, a subscriber line, and the subscriber set.

15. Over-All Response

The total or over-all response of two telephone sets connected over two subscribers lines and a central office represented by two bridged-impedance cord circuits, each of 2×250 ohms and 48 volts, is obtained by applying to the transmitting system a constant sound pressure of 30 dynes per square centimeter from the artificial mouth equipment and recording the sound pressure at the receiving system by the artificial ear equipment and level recorder. The

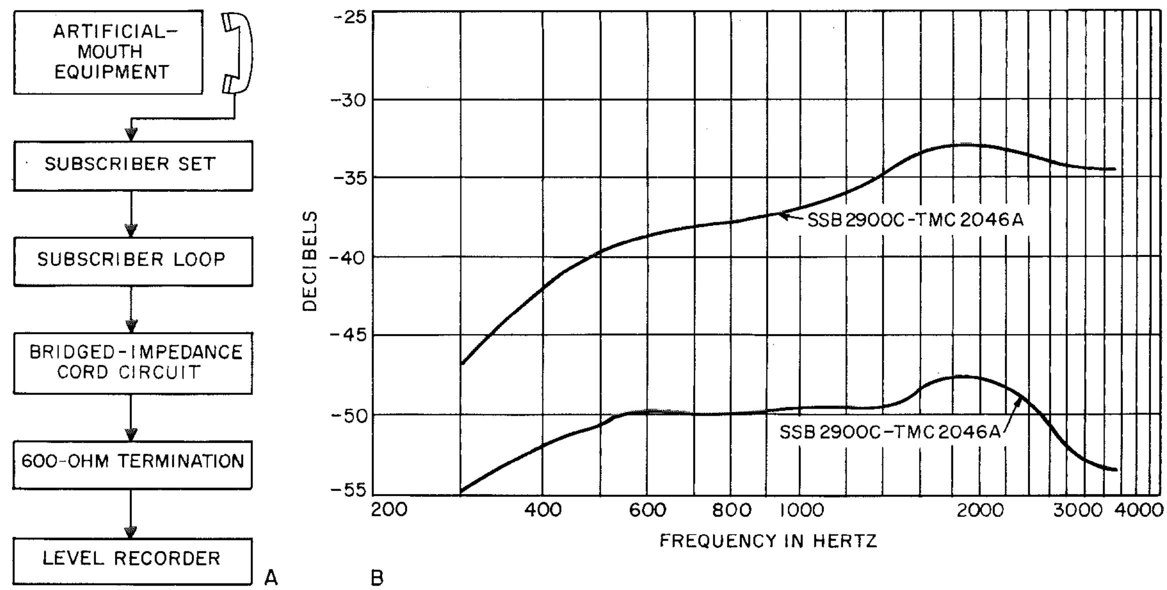
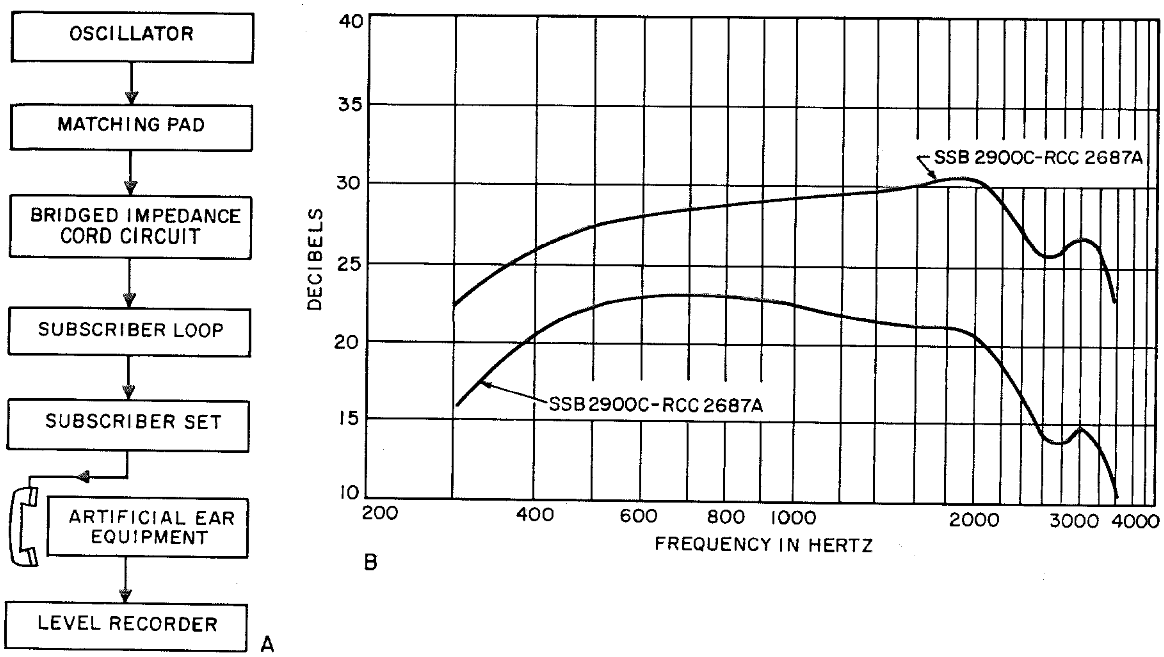


Figure 12—Transmitting response and test circuit. The upper curve is for zero subscriber loop and the lower curve is for an artificial subscriber loop equivalent to 5 kilometers (3.1 miles) of 26 American Wire Gage cable. Response is referred to 1 volt per dyne per square centimeter at the artificial mouth.

Figure 13—Receiving response and test circuit. The upper curve is with zero loop and the lower curve is with an artificial subscriber loop equivalent to 5 kilometers (3.1 miles) of 26 American Wire Gage cable. Response is referred to 1 dyne per square centimeter per square root of 1 milliwatt of available power.



over-all is expressed in decibels referred to 1 dyne per square centimeter per dyne per square centimeter.

16. Wall Set

The *SSB2901* Assistant wall set shown in Figure 15 fills a genuine need for a wall set similar in design to the Assistant desk set. Special attention has been given to standardizing the components of both sets.

The wall set is 185 millimeters (7.3 inches) high, 226 millimeters (9.9 inches) wide, and 76 millimeters (3 inches) deep. It weighs 1400 grams (3.1 pounds).

As in the case of the desk set, the miniature components make possible the use of a printed circuit, which is screwed to a supporting plate. This plate also serves as a support for the dial as is evident in Figure 16.

The housing has been designed so that the

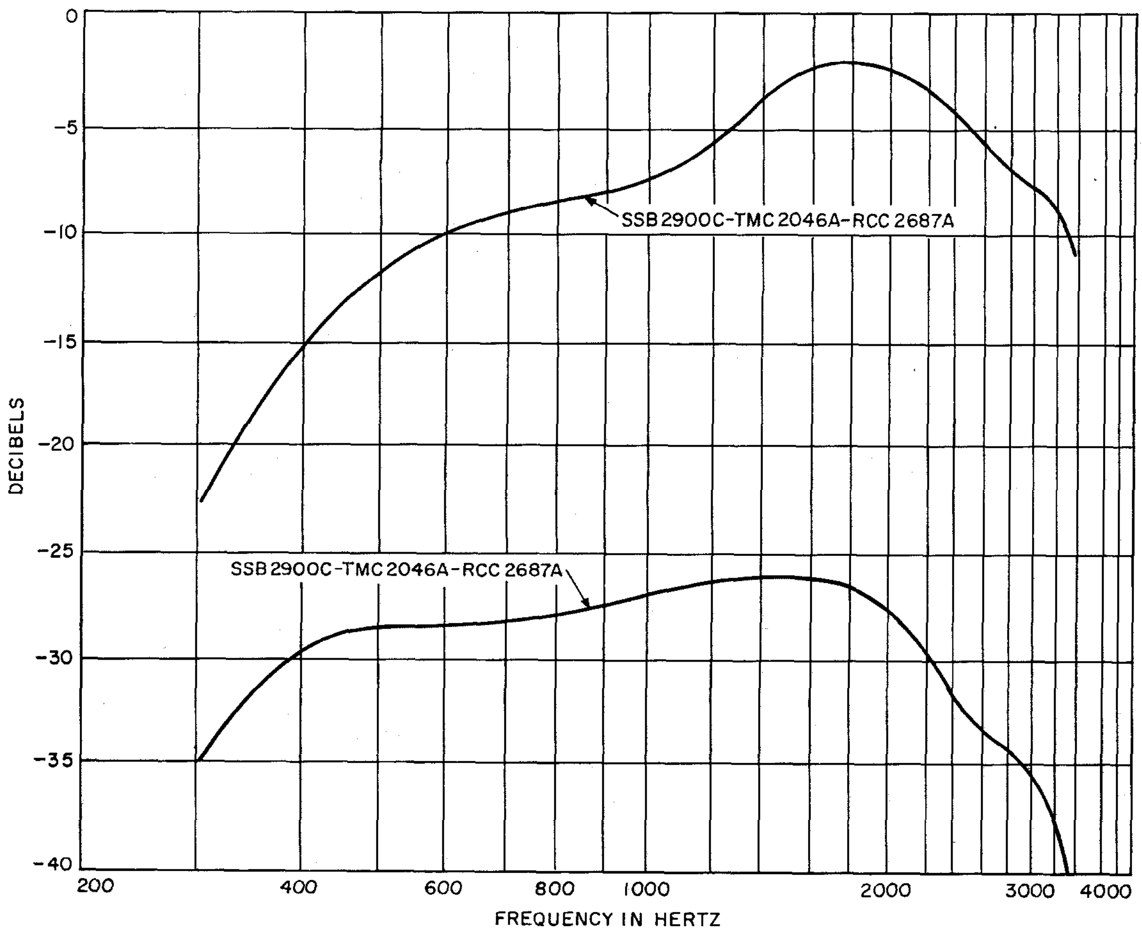


Figure 14—Over-all response using the transmitting and receiving test circuits joining the two bridged-impedance cord circuits to each other. The upper curve is for zero subscriber loops and the lower curve is for two loops or 10 kilometers (6.2 miles) of 26-gage cable. The response in decibels is referred to 1 dyne per square centimeter per dyne per square centimeter.

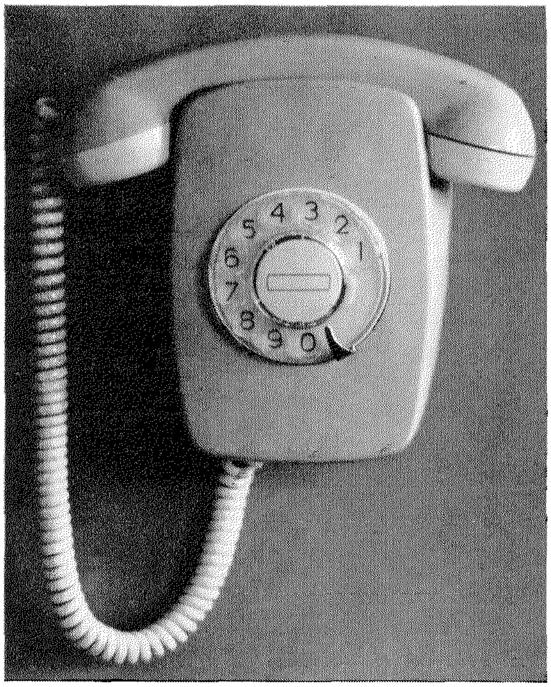


Figure 15—Wall set.

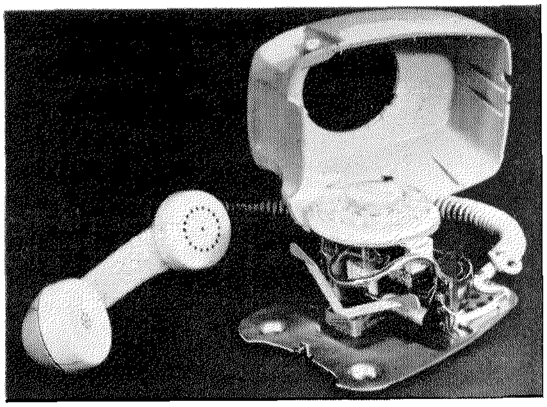


Figure 16—Case removed from the wall set.

handset can be easily suspended from the left- or the right-hand side of the housing without cutting off the line. The indentation in the top of the case (left side in Figure 16) provides for this.

All the essential parts of the desk set, which are the induction coil, dial, ringer, capacitors, resistors, gravity switch, and handset are also used in the wall set.

The various circuits incorporated in the desk set have also been introduced in the wall set and the transmission performance data are identical for both sets.

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5. E. E. Mott and R. C. Miner, "Ring Armature Telephone Receiver," *Bell System Technical Journal,* volume 30, pages 110–140; January 1951.

W. Grüger was born on 28 December 1907 at Friedland, Sudetengau (at present under Czechoslovakian administration). In 1932, he graduated from the engineering school at Bodenbach.

After working for an electrical supply company, he joined the design department of Siemens & Halske in 1936. From 1944 to 1946, he was a prisoner of war.

In 1946, Mr. Grüger was employed by Standard Elektrik Lorenz and is engaged in the development of telephone sets.

Henri Van Holst was born on 27 August 1926 in Mainxe, France. He received the degree of civil engineer from the University at Ghent, Belgium, in 1954.

On graduation, Mr. Van Holst joined the acoustical laboratory of Bell Telephone Manufacturing Company. Since 1958, he has been in charge of the group developing subscriber sets.

Fehlerortungen, Ihre Messverfahren in Fernmelde und Starkstromkabeln (Fault-Location Measurements for Telecommunication and Power Cables)

Erwin Widl of Standard Elektrik Lorenz is the author of this book. It is divided into the 12 following chapters, a bibliography, and an index.

1. Introduction
2. Theoretical Principles
3. Types and Effects of Faults
4. Methods of Locating Faults
5. Location of Insulation Faults
6. Location of Breaks in Wires
7. Equipment for Conventional Measurements
8. Location of Crosstalk Faults
9. Location of Internal Reflections
10. Characteristics of Fault Location in Power Cables
11. Examples of Fault Location in a Large Municipal Power Cable Network
12. Comparison of Measuring Methods

The book is 17 by 23.5 centimeters (6.75 by 9.25 inches) and contains 166 pages and 130 illustrations. It is published by Dr. Alfred Hüthig Verlag, Heidelberg, Germany, at DM 28 per copy.

Intercommunication Telephone Sets

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The standard telephone subscriber's set while amply fulfilling its intended functions, does not provide for all possible needs, particularly for certain types of intercommunication within offices, buildings, industrial plants, houses, and stores. Special intercommunication systems have, therefore, been designed both for connection to the public telephone networks and for private installations not so connected.

1. Intercommunication Sets Connected to Public Exchanges

The design of intercommunication telephone sets that are also connected to the public telephone network has been undertaken by Bell Telephone Manufacturing Company in Antwerp and Standard Electrik Lorenz in Stuttgart. These systems are characterized by their substantially larger number of switching elements compared with normal subscribers' sets. This emphasizes the need for small components and for combining components such as the equipping of a switching key with a signal lamp, which has the added advantage of unmistakably associating each key with its signal lamp.

To provide a full line of telephone equipments in the style and construction of the Assistant subscriber's set, two larger housings capable of accommodating additional switching elements were developed. They permit the construction of any type of telephone set, as for example sets for intercommunication and secretarial systems and for answering stations for small private-branch-exchange systems incorporating call-metering facilities, monitoring, et cetera. An assortment of these will be illustrated by some examples.

1.1 Intercommunication Systems

An intercommunication system consists of a master station and a number of extensions. Each extension is equipped with the switching elements necessary to establish a connection. Units common to the entire system, as for example the feed choke and the ringer, are accommodated in the junction box that is associated with the master station. The power supply, which consists of a mains rectifier, is also at the master station. Such systems are economically attractive especially if all stations are within a relatively small area and thus do not require an extensive line network.

Small intercommunication systems for one exchange line and 2 to 5 extensions, coded $1/5$, share a common party-line connecting link. Each set has a red and a green key, for access to the exchange line, and 5 line keys for internal calls. When a set engages the exchange line, its green key is lighted and the red keys of all the other sets are lighted. If one of the line keys at the engaged set is depressed for a call-back, the exchange call is held, the green key is released but its green lamp stays lighted, and throughout the call-back, its red key also is lighted. If the green exchange key of the other extension is depressed to take over the exchange call, the green light on the originating set extinguishes and the handset may be replaced.

Each extension of an intercommunication system having several exchange lines, for example installations with 2 exchange lines and 5 to 10 extensions (coded $2/5$ to $2/10$), is provided with an individual internal connecting link. To enable interruption of an exchange call without replacing the handset, for example during a broker's call, a cutoff key is provided on each set. Figure 1 shows an extension set of the $2/5$ system.

In areas using time-and-zone metering with metering pulses transmitted to the subscriber, rate meters for toll calls are increasingly demanded to keep records of long-distance calls and assign charges to the individual extensions. The master stations are equipped with one rate meter per exchange line. In systems without caller identification, every long-distance call has to be set up with the assistance of the master station which, notified by a visual or aural signal, records the rate at the termination of the call.

In systems with caller identification, each non-restricted toll-dialling extension is able to set up long-distance calls without requiring the assistance of the master station. On termination of the call, the toll supervision lamp for the exchange line and the identification lamp for the calling extension both light, thus permitting proper charging.

1.2 Secretarial System

Secretarial systems normally consist of an executive and a secretary station that are connected to 2 private-branch-exchange lines. Incoming calls are answered at the secretary station and transferred to the executive whenever necessary. Furthermore, outgoing calls for the executive may be set up by the secretary.

The only distinction between the executive and secretary stations is in the key arrangement. Both are similar to Figure 1 without the 3 center keys in the top row. The circuit of a

Figure 1—Extension set of system having 2 exchange lines and 5 extensions.

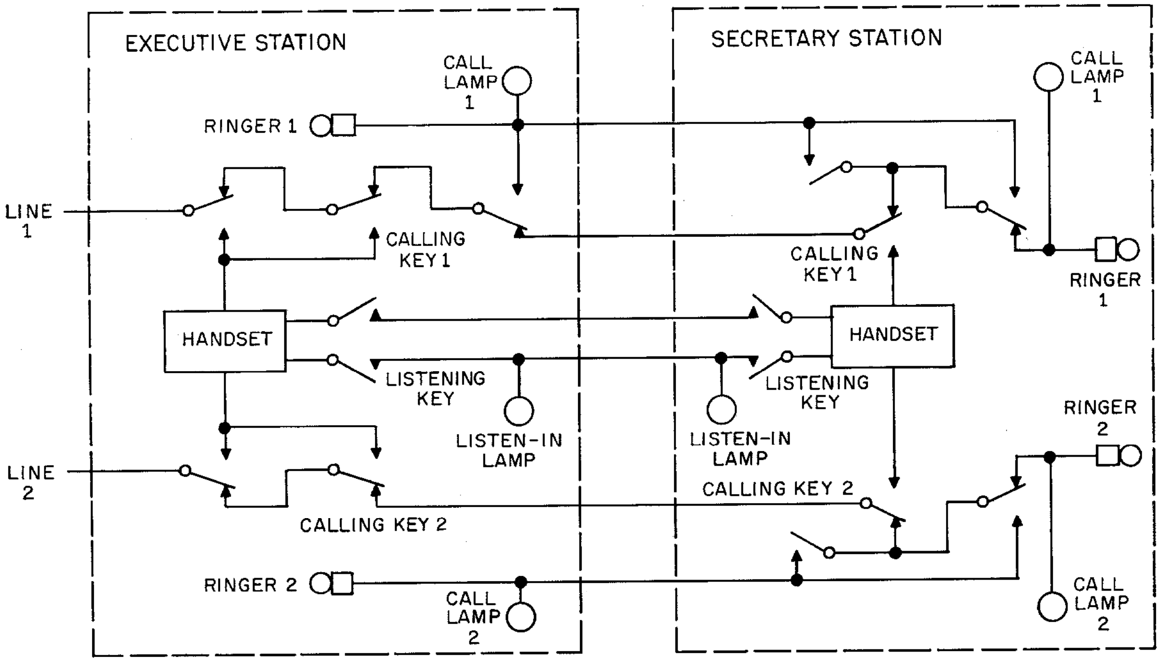


Figure 2—Circuit arrangement of secretarial system.

Figure 3—Intercommunication set having both handset and loudspeaker for connection to a private automatic exchange. The 5 buttons in the top row are for direct selection, camp-on-busy, transfer, staff locator, and loudspeaker. In the bottom row are buttons for microphone short-circuit, press-to-talk, and release.

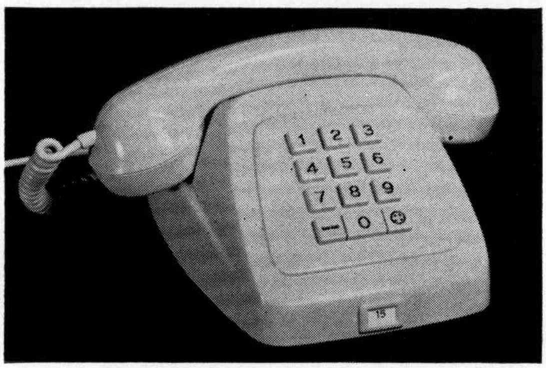


Figure 4—Set with extra facilities limited to press-to-talk and staff-locator buttons.

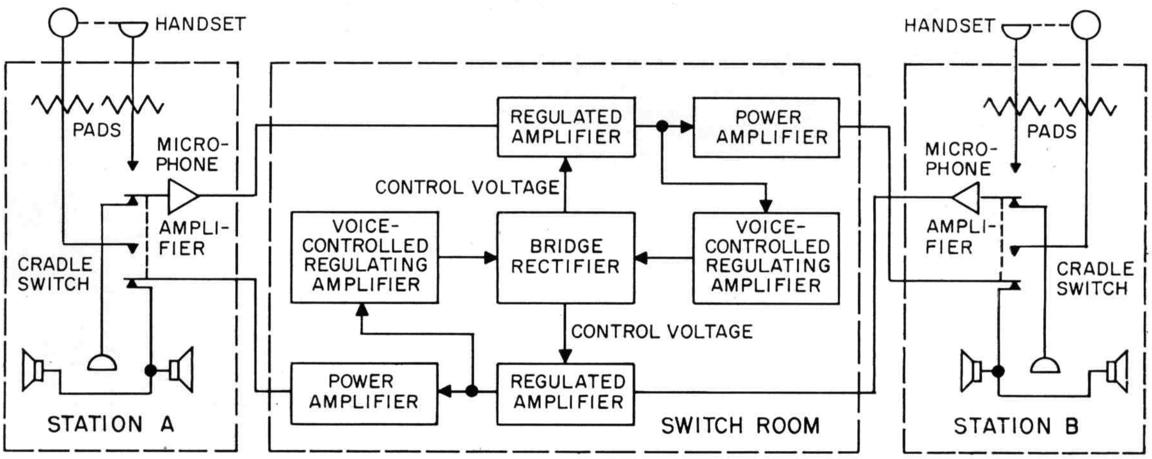
secretarial system is shown in Figure 2. Incoming lines 1 and 2 are looped over the executive station to the secretary station where they are terminated by the ringer. Both have equal access to the lines. However, it is possible to arrange that the secretary use one line predominantly and the executive the other. Finally, another variation is to loop only one line over both stations and provide each station with a separate second line. In this case, 3 private-automatic-branch-exchange lines are required.

2. Intercommunication Sets Not Connected to Public Exchanges

2.1 Large Capacity

Large-capacity intercommunication sets not connected to the public telephone network and using loudspeakers have been developed by Standard Radio & Telefon of Stockholm. They are designed for offices, industrial plants, buildings, and so on. The core of the system is a private crossbar exchange equipped with two-way amplifiers. Direct-current signalling is by push-buttons over 4 wires to the switching equipment.

Figure 5—Speech circuit showing method of controlling amplifiers to prevent howling.



The design is based on modern crossbar and semiconductor techniques and provides a maximum of conveniences, such as, handsfree operation, direct selection, staff location, transfer, camp-on busy, priority call, and group hunting.

2.1.1 *Intercommunication Sets*

One of 3 types of intercommunication sets is shown in Figure 3. It has both a handset and a loudspeaker for handsfree operation. A second design supply omits the loudspeaker. Both have signalling push buttons for all facilities, while certain facility buttons have been excluded from the set, in Figure 4, which has only a handset.

The loudspeaker systems consist of a rocking-armature microphone, a microphone amplifier, and a pair of 75-millimeter (3-inch) loudspeakers.

The axes of the loudspeakers are at right angles to the microphone axis, and the microphone is located midway between the loudspeakers. This arrangement greatly reduces the acoustic coupling between the loudspeakers and microphone.

The pilot lamp indicates that a connection is established. During conversation, the lamp shows a steady light. However, it also indicates the transfer condition by flashing, and the busy-for-called-subscriber condition when extended waiting is forced by operation of the camp-on busy button.

The system operates at 48 volts of direct current for both speech and switching.

2.1.2 *Speech Transmission System*

The speech transmission system is shown in Figure 5. The microphone amplifiers are incorporated in the sets and the main amplifier is in the switchroom. All amplifiers use transistors and are mounted on printed circuit boards.

The speech transmission path is from the microphone in station *A*, via its microphone amplifier, over the line to the main amplifier, and then to the loudspeakers in station *B*. The cradle switch disconnects the loudspeakers and set microphone and connects the handset when the handset is lifted. The set microphone is of the rocking-armature type with an impedance of 2000 ohms at 1000 hertz, which is suitable for the input transistor in the grounded-emitter connection.

The main amplifier is in the cord circuit of the exchange and is assembled on 5 printed circuit boards having connecting plugs. This amplifier has two identical channels. A voice-operated regulating circuit controls the speech direction by increasing the gain of the active channel and decreasing the gain of the passive channel by a larger amount. This prevents howling. Each channel has a 3-stage amplifier providing a maximum output of 0.5 watt. A high noise level makes use of the loudspeaker unsatisfactory. This is due to the masking effect of noise on speech, resulting in poor intelligibility. In this case, handset operation is recommended. However, in an occasionally noisy room, automatic voice-switching may be replaced by manual control using the press-to-talk button for switching.

2.2 Restricted Capacity

Loudspeaker sets for a limited number of stations in a network not connected to the public system have been developed by Standard Telephon und Telegraphen of Vienna. In addition to providing for normal telephony, their loudspeakers offer additional useful services.

There are two basic Dirigent systems: Dirigent in star connection has a master station connected individually to a number of substations, which cannot communicate with each other, and Dirigent universal, which provides unlimited intercommunication among all stations.

2.2.1 *Dirigent in Star Connection*

Dirigent master stations are available for operating with a maximum of 1, 5, or 10 substations. The latter being shown in Figure 6. Master stations are also available without handsets.

Figure 6—Dirigent master station for working with 10 substations in the star connection. The substations cannot communicate with each other.

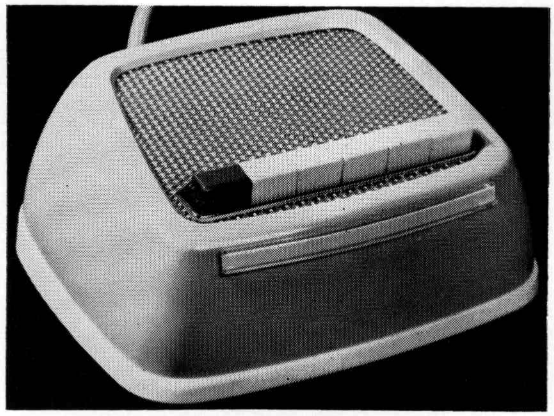


Figure 7—Dirigent universal station, which is one of 6 stations that can intercommunicate among each other without limit.

In addition to the transducer and amplifier, the master stations include a nonlocking button for talking and 1, 5, or 10 locking line buttons to the substations.

The substations are identical for all systems. They do not require an amplifier and in addition to the sound transducer they are provided with a nonlocking button for talking and a locking button for listening.

If there is more than one substation, the connection is made at the master station by pressing the line button of the desired substation. The substation can be called immediately by voice. For answering, the talking button of the called substation must be pressed and a two-way conversation can then be conducted with alternate actuation of the nonlocking talking buttons during speaking. When the conversation has been terminated, the locked line button at the master station is released.

When the self-locking listening button in the substation has been pressed, no further operation is required for the remote listening to the master station.

A call may be initiated from a substation by pressing the talking button and directly calling the master station by voice. If the master station is already busy, the call will not be received and thus disturb the established conversation.

2.2.2 Dirigent Universal

The Dirigent universal system may be assembled in networks of a maximum of 6 and 11 stations, each of which can be connected as desired to any other station in the system. A 6-station unit is shown in Figure 7. A single station unit may be connected as one of these substations but will be able to work with only the station to which it is connected.

The number of conversations is limited only by the number of stations. Conference conversations, whereby all stations connected for conference can hear each other, can also be conducted. In view of the necessary conversation discipline, it is recommended that conferences be limited to 4 stations.

Rudolf Bayer was born in Vienna, Austria, on 17 April 1907. After graduating from college in Vienna in 1925, he attended the Technical University in Vienna for 3 years.

He worked for some years in the broadcast receiver industry. In 1939, he joined the engineering staff of Standard Telephon und Telegraphen AG., Czeija, Nissl & Company where he developed carrier systems, public-address apparatus, and intercommunication equipment.

Rudolf Beith was born in Berlin, Germany, on 9 November 1920. He received a degree as a telecommunication engineer.

In 1950, he joined the Berlin works of Standard Elektrik Lorenz, where he developed small private automatic branch exchanges, telephone sets, and special switching equipment. He was head of the technical department from 1957 to 1962, when he was transferred to the Hanover office as sales manager.

Evert Ekbergh was born on 16 May 1928, at Härnösand, Sweden. He graduated from the Telecommunication Administration school for technical clerks in 1950 and received the degree of Master of Science in electrical engineering in 1954 from the Royal Institute of Technology of Stockholm.

After nearly 8 years with the Telecommunication Administration, where he was employed on administrative work, system evaluation and planning, and traffic analyzing, he joined the engineering staff of Standard Radio & Telefon in 1956 as assistant chief switching engineer. He became chief switching engineer in 1961.

Mr. Ekbergh is a member of the Swedish Association of Engineers and Architects.

David Eklöv was born near Uddeholm, Sweden, on 27 March 1918. He received a radio engineering degree in 1945. He was in the receiving laboratories of the Centrum Radio Company from 1939 to 1949 and was then transferred to the telecommunications department as head of the electronics laboratory. He joined the Sinus Company in 1952, where he was in charge of the electronics laboratory. He there invented the 2-way amplifier that made it possible to mass produce intercommunication equipment for handsfree operation. He also developed the Wegephone set.

He joined Standard Radio & Telefon in January 1962 as head of the electroacoustics department.

Matrix Multiplication in Search for Alternate Routes *

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This paper is concerned with routing in a line-switched communication system, that is, the problem of choosing a suitable path to connect on demand the originating switching point with the destination switching point. In more-mathematical language, the problem is to choose a path in a net consisting of nodes and links[1] that connects the originating node with the destination node.

The following two extreme approaches can be taken in connecting two switching points whenever a demand arises.

(A) Complete determination of the path at one location (either at a single central location or at the originating node).

(B) A link-by-link establishing of the path, where the decision as to which link of several specified choices should be taken next in the path[2] is made at the node where the last link in the tentative path terminated.

Approach (A) presupposes that either the control center, where each request for connection is sent, or each node is informed about the status of each link and each node in the net. This information has to be updated at very-short time intervals so that a link or a node that has become unavailable, even temporarily, is not traversed in the path proposed to serve a demand for the connection. A rather-frequent condition that a link is unavailable arises whenever all the trunks in the trunk group constituting the link are busy with traffic.

Maintaining such rapidly updated status information is a difficult undertaking in a net consisting of a large number of links and nodes. For this reason, approach (B) is usually taken in large systems. In the simplest version of this approach, control circuits (route translators) in any switching point, be it at the originating node or at an intermediate node, attempt to establish a path to a given destination along a specific link, determined by memorized instructions. If this link is busy or out of action, the route translators step through a predetermined sequence of attempts to establish the path along alternate links, until an available link is found. If the sequence of attempts is completed without success, a trunks-busy signal is returned.

This version is simplest, since no information is carried about the links already traversed from the originating node to the intermediate node. In other words, the route translators at a given switching point do not differentiate between a request originating at this switching point and a request originating elsewhere and for which this switching point is an intermediate node. This version is discussed in what follows, except for a modification described in the last paragraph of Section 4.

The sequences used by the route translators, taken for the whole net, constitute the alternate routing pattern. By virtue of the fact that connections can be made avoiding some unavailable links, the routing pattern need not be changed when some links become busy or if one or two links are not functioning. But when major changes occur in the communication system, such as large-scale damage, it is imperative to establish quickly a new routing pattern to obtain maximum use from the surviving system. The present paper gives a computational method that constitutes a useful tool in determining alternate routes in a communication net, in connection with setting up new alternate-routing tables. Updated information about the system is assumed to be available to the computer for the purposes of this computation.

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* The work was carried out under United States Army Signal Corps Contract DA-36-039-SC-78806 while the author was resident-visitor at Bell Telephone Laboratories in Whippany, New Jersey.

[1] Still another terminology, which will not be used here, is vertices and edges.

[2] Or, if the system has back-out capacity, to subtract a link from the path when a dead-end is encountered.

1. Statement of the Problem

The following problem is discussed here. Given a communication net consisting of a number of nodes connected by links, find through the use of a computer procedure the preferred (first-choice) route and alternate routes (second-, et cetera, choice) between any pair of nodes.

Finding the route consists of determining

(A) The link on which the proposed path leaves node i.

(B) The total distance along the proposed path from node i to node j.

Each link has a weight (number) associated with it that denotes its length or its more-general figure of demerit, such as delay, noise, or cost of use. The first-choice route is to be understood as the *shortest* path measured along links between nodes i and j (here and in what follows, the word shortest means of least demerit quantity, which characterizes the links and which adds up for the links traversed). The second-, third- . . . choice means the shortest path between nodes i and j, *with the following conditions*:

(*A*) Provision that links that were used as initial links out of the node i in previous choices are not traversed.

(B) Provision, during the computation, that the path taken from the first intermediate node m to j *is* the shortest.[3] Note that under certain conditions the node m can coincide with the destination j.

Because of these provisions, the problem of determining alternate routes in general is quite different from the problem of determining the next-to-shortest, et cetera, paths between pairs of nodes. It should be realized that the above criterion, even though its definition is somewhat laborious, represents exactly the simple and intuitive approach to the problem of finding alternate routes under the principle of link-by-link establishing of the path in a communication net, where the choice of next-link-in-path is decided at the node i where the last link terminated. As a first choice, the link originating at i and corresponding to the most convenient path i-j, is taken. The first choice for any particular destination is memorized by the route translators. But when this link is busy or temporarily not functioning, the route translators take an alternate link, which corresponds to the most convenient path i-j not using the first-choice link.

The proposed computer procedure can be used in the central control facility of a communication net. This facility would, (A) receive periodically status information for the whole network, (B) compute, when necessary, the new optimum routing for the whole network, and (C) send the pertinent part[4] of the solution to each node, where the new route translators are simultaneously implemented for the whole network. It should be understood that once the route translators are given new memories, so to speak, each switching point is again in full control of routing any call that reaches it.

The automatic method proposed here for computing alternate routes, utilizes the approach of matrix multiplication developed by Shimbel.[5] To facilitate the presentation

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[3] This provision is made even though some calls will overflow at some node along this shortest path m–j to the second-, et cetera, choice link. This is the simplest assumption to make, and of course a very large portion of the traffic will follow the shortest path.

An alternative criterion for a routing pattern could be along the following lines. Define an optimum operation of the system as when the sum of the products (link occupancy) × (demerit figure of the link), summed over all links, is a minimum. The problem of finding a routing pattern to achieve this optimum operation is extremely difficult. Solution in the form of a convenient computation procedure is not available.

[4] The ith rows of the computed routing matrices are sent to the node i. See later discussion.

[5] A. Shimbel, "Structure in Communication Nets," *Proceedings of the Symposium on Information Networks*, Polytechnic Institute of Brooklyn, New York, 1954.

of the method, Shimbel's dispersion-matrix calculation is first briefly presented.

2. Calculation of Shimbel's Dispersion Matrix

The matrix listing all the least-path lengths of a net is called by Shimbel the dispersion matrix of the net. Using his own rules, Shimbel calculates the dispersion matrix through successive multiplication of the structure matrix of the net.

The elements α_{ij} of the structure matrix as used by Shimbel denote the length, or some more-general property, of the link between the node i and the node j. When no such link exists $\alpha_{ij} = \infty$. The transmission demerits in opposite directions may differ, and then $\alpha_{ij} \neq \alpha_{ji}$. The diagonal terms α_{ii} represent the distance of the node from itself and all are therefore zeros. A small net and its structure matrix are shown in Figure 1.

Shimbel's procedure to find the dispersion matrix involves matrix multiplication under special rules in place of ordinary multiplication and addition of terms. Shimbel's arithmetic is as follows: For any arbitrary real finite or infinite numbers x and y

$$x \cdot y = \text{the algebraic sum of } x \text{ and } y \quad (1)$$

$$\infty \cdot x = x \cdot \infty = \infty \quad (2)$$

for any x, including infinity,[6] and

$$x + y = \min(x, y). \quad (3)$$

Definition (matrix product): If A and B are any two square matrices of the same order having only zero, positive, or infinite entries, then their product AB is defined as the ordinary matrix product with the proviso that the above-defined arithmetic be substituted for ordinary arithmetic.

[6] Infinity can be represented in an actual computer program by a fixed very-large number.

If S is the structure matrix of a net, then the product of S with itself, namely S^2, is a matrix giving the least distances between nodes, given that the path from one node to another *may* lead through a node. This, as Shimbel shows, holds true, because the term β_{ij} of S^2 is given in terms of α_{ij} of S as follows

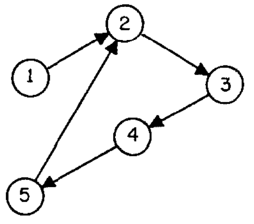
$$\beta_{ij} = \sum_{x=1}^{k} (\alpha_{ix} \cdot \alpha_{xj}) \quad (4)$$

where k is the order of the matrix, that is, the number of nodes in the net. In Shimbel's arithmetic $\alpha_{ix} \cdot \alpha_{xj}$ is the algebraic sum of α_{ix} and α_{xj}. The symbol Σ denotes the operation of choosing the least term. Thus β_{ij} is actually the shortest "one-link" or "two-link" path from node i to node j. The possibility of a one-link route arises since under the summation sign the term $\alpha_{ij} \cdot 0 = \alpha_{ij}$ appears. (This term appears actually twice, the second time in the form $0 \cdot \alpha_{ij} = \alpha_{ij}$.)

It follows that S^m is a matrix giving the shortest paths from node to node given that up to $m - 1$ intermediate nodes are traversed. For any S there exists an integer n such that $S^n = S^{n+1}$, where $n \leq k - 1$, k being the number of nodes. The dispersion matrix of S will be the matrix S^n such that $S^n = S^{n+1}$. The dispersion matrix is designated D in what follows.

3. Computer Procedure for the Alternate-Routing Problem

The procedure for computing alternate routes in connection with setting up new routing tables requires as the input to the



0	1	∞	∞	∞
∞	0	1	∞	∞
∞	∞	0	1	∞
∞	∞	∞	0	1
∞	1	∞	∞	0

Figure 1—Small net and its structure matrix.

computer an updated status report for the system, that is, the computer has knowledge of the pattern of interconnection of nodes and the weights of the links. This knowledge is in the form of a structure matrix of the system.

As the output, a set of routing matrices is obtained: first-choice routing matrix, second-choice routing matrix, et cetera. The matrices are square of order k. The index m, appearing as the element in row i and column j of the *first*-choice routing matrix, indicates that route translators at node i will be instructed, on a call to destination j, to attempt *first* the link i-m. Similarly, the second-choice routing matrix indicates the link for the *second* attempt if the first attempt is unsuccessful, et cetera.

As a second output, a set of distance matrices can be obtained: first-choice distance matrix (which is identical to the dispersion matrix), second-choice distance matrix, et cetera. These are again square matrices of order k. The significance of the dispersion matrix has been explained. The element ij in the second-choice distance matrix denotes the distance on a path from node i to node j provided the second attempt out of node i is successful and all first attempts out of subsequent nodes are successful. Similarly for the third-choice distance matrix, et cetera.

The procedure here consists of multiplying a modified structure matrix by the dispersion matrix. Computation of the dispersion matrix by Shimbel's technique is the initial step in the calculation, this matrix being designated by D with elements δ_{ij}. An order of procedure is now described.

First, modify the structure matrix, as used by Shimbel, replacing the zeros on the diagonal by ∞. The modified matrix will be referred to as the M matrix with elements γ_{ij}. Thus all elements $\gamma_{ij,\ i \neq j} = \alpha_{ij}$, and $\gamma_{ii} = \infty$. Next, examine the formation of the product $M \cdot D$. Multiply row i of M by column j of D. Shimbel's terms $\gamma_{ix} \cdot \delta_{xj}$, that is, γ_{ix} plus δ_{xj}, are formed, where x ranges over all nodes. Since the term $\gamma_{ii} \cdot \delta_{ij} = \infty \cdot \delta_{ij} = \infty$, it is eliminated from the competition for being the minimum, second-to-minimum, et cetera, term. Thus x is effectively limited to all nodes except i.

The terms $\gamma_{ix} \cdot \delta_{xj}$ are now compared, the minimum term $\gamma_{ix_1} \cdot \delta_{x_1j}$ (which, of course, equals δ_{ij}) representing the length of path i–j on the first-choice route. The index x_1 corresponding to this smallest value of $\gamma_{ix} \cdot \delta_{xj}$ indicates that the first-choice route out of i on a call to j is on link ix_1. The index x_1 is entered as the ij element of the first-choice routing matrix, and the term $\gamma_{ix_1} \cdot \delta_{x_1j}$ is entered as the ij element of the first-choice distance matrix.

The second-to-smallest term $\gamma_{ix_2} \cdot \delta_{x_2j}$ is now determined. This term corresponds to the shortest path i–j in which the initial link i–x_2 is other than i–x_1. The distance δ_{x_2j} corresponds to the shortest path from the first intermediate node, x_2, to j. Thus the two provisions specified for the alternate route are met, except in the case where the shortest path x_2–j transverses the node i. In this case, the path i–x_2–j under consideration loops back to i and leaves node i for the second time on link i–x_1, thus violating provision (A).

The shortest route from x_2 to node j passes through node i if

$$\delta_{x_2j} = \delta_{x_2i} \cdot \delta_{ij}. \qquad (5)$$

The computer program checks for this condition and if it exists, x_2 is disqualified for the second-choice route and the next-smallest term $\gamma_{ix} \cdot \delta_{xj}$ is sought. In most instances

$$\delta_{x_2j} < \delta_{x_2i} \cdot \delta_{ij} \qquad (6)$$

which indicates that the shortest path x_2–j does not pass through node i. The index x_2 is entered as the ij element of the second-choice routing matrix and the term $\gamma_{ix_2} \cdot \delta_{x_2j}$ is entered as the ij element of the second-choice distance matrix. And so on for subsequent choices, up to the number of alternate routes desired. Of course, whether the desired number of alternate routes will be found from all nodes depends entirely on the character of the net.

4. Route-Stability Examination

In link-by-link routing, the danger arises of route instability, which is often called "ring-around-the-rosie." This means that the connection loops back to a node previously traversed. Once back in this node, the call takes the same looping path and this process is continuously repeated until an all-trunks-busy condition is introduced on one of the links in the loop. In the routing scheme arrived at by the procedure described above, ring-around-the-rosie *may* occur if *more than once* in setting up a connection a first-choice link is busy.

It is suggested that inherent stability of the multialternate routing scheme can be achieved if the allowed connections will result in the call getting always closer to its destination in terms of distances (weights) along the links in the net. In the computations outlined above, it is easy to check whether the routing is an allowed routing or not. The necessary and sufficient conditions for an allowed routing on a call to destination j from i to an intermediate node x is that the distance along the shortest path i–j in the net be larger than the distance along the shortest path x–j

$$\delta_{ij} > \delta_{xj}. \tag{7}$$

The stability is achieved at the cost of eliminating some possible paths for establishing a connection. The resulting scheme is certainly not exhaustive; that is, a busy signal may be returned even if an available path i–j exists. The list of links on which attempts to connect are made can be extended beyond the allowed links without the danger of instability by resorting to some message coding. When all the allowed links are busy, route translators can be permitted to attempt setting up the connection to intermediate points x of "last resort" that violate the above equation. The permission to try such a link will be given to calls that have not previously tried last resorts in their quest for the final destination. Thus, virgin messages will have a bit in the address position that will be converted to zero the first time the route of last resort is taken. If a connection loops back to a node previously traversed, it is stopped there (call incomplete).

5. Actual Computer Program

The procedure for finding alternate routes has been programmed on an IBM 704 computer by Miss G. C. Watling. The program for a net consisting of 18 nodes took approximately 1 minute running time.

6. Conclusions

A procedure for determination of the alternate routing pattern in a communication net by a computer has been presented. The method seems to be especially useful when a communication network has been damaged. When the status of the surviving network is reported to the central supervisory facility, it is obviously important to compute the new routing pattern reliably and quickly so that the functioning parts can be put into optimum use with minimum delay.

7. Acknowledgment

Very helpful comments of Eric Wolman are gratefully acknowledged.

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Theoretical and Practical Aspects of Telephone Traffic

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1. Introduction

Calculation of the minimum quantities of telephone exchange equipment required for satisfactory service is possible because the traffic created by subscribers has certain characteristic features and shows regularities notwithstanding the fact that each subscriber station is used in an independent manner. Although telephone users have different occupations, interests, and habits, it has been observed that as a group they originate, within certain limits, about the same number of calls during corresponding periods of each working day and that the interoffice traffic flows show similar aspects.

Probability theory is applied to switching problems under certain generally accepted assumptions of a random arrival and duration of calls. Based on these assumptions and consideration of the manner in which traffic is handled by specific switching arrangements, equations have been developed to guide the telephone engineer. In evaluating these equations, the extent to which these assumptions agree with the corresponding types of traffic met with in practice must be determined.

It is equally important that the methods used to evaluate actual traffic yield quantities that, when inserted in the equations, give reliable results. The choice of a correct measurement period leads to a statistical concept of the busy hour, which subject will be considered later.

For practical purposes, the observation and evaluation of actual telephone traffic is generally restricted to the collection of data pertaining to the occurrence of numbers of calls during certain periods of time, to the number of calls in progress simultaneously, to the interoffice traffic flows, and to the holding times of the connections. They serve to establish the calling rate per line and all other data needed to calculate the quantities of telephone equipment required. It is implied that satisfactory agreement exists between the theoretical and the actual traffic flows. The number of studies made on the observation and verification of the characteristic features of actual telephone traffic is restricted.

The fact that most of the present telephone plant operates satisfactorily from a quantitative point of view during most of the time is insufficient proof of agreement between theory and practice as, in accordance with well-established engineering usage and to care for future growth, the basic traffic data are generally made to include a safety margin, and later plant extensions are based mostly on experience during years of operating the particular plant.

The object of this paper is to outline in general terms the means and methods by which actual traffic may be measured, to review the principal concepts of theoretical traffic, and to discuss their effects on the interpretation of the busy hour and on the choice of the busy-hour-traffic data. For the sake of clarity, the results of applying several well-known theories have been presented in concise form.

Finally some consideration is paid to the problem of deriving values for the traffic offered to a switching arrangement from observations of the traffic carried by it.

This paper does not deal with sampling studies that are possible from the observations made.

2. Theoretical Telephone Traffic

A flow of theoretical telephone traffic is fully defined by the distribution function of two independent random variables, one relating to the holding time of calls and the other to their arrival time or their coincidence.

2.1 Duration of Calls

For the duration of the calls, it is usually assumed that the holding time is either constant or it is variable and follows a negative exponential law.

The distribution function of the latter type of holding time expresses the probability that a specific call does not terminate within the period t or, in other words, by the probability $p\ (>t)$ that the holding time exceeds a time t. If the average duration of the calls is denoted by h, the function reads

$$p(>t) = e^{-t/h} \qquad (1)$$

where $0 < t < \infty$.

The evaluation and verification of this holding-time distribution against that of actual telephone traffic requires appropriate testing equipment but otherwise it offers no difficulties.

The measurement of many thousands of telephone connections has demonstrated a persistent deviation from the negative exponential law given in (1). Figure 1 indicates the general shape of an observed distribution curve; the exponential curve has been added to show the general trend of the deviation. This phenomenon can be explained by the following considerations.

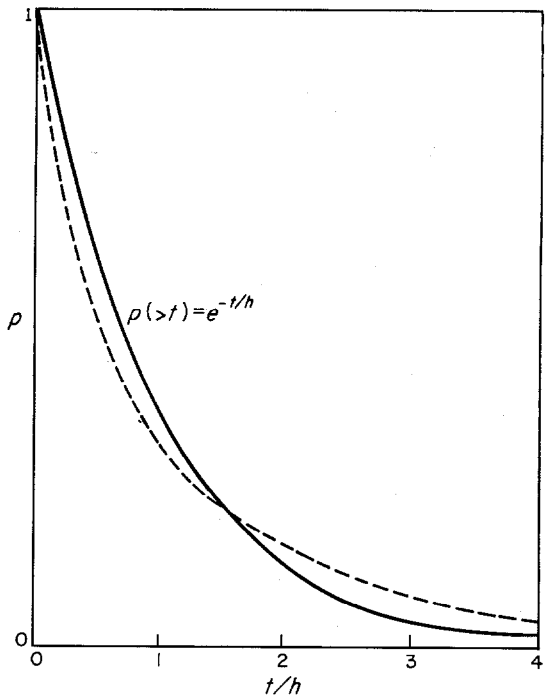

Figure 1—The broken line is an observed distribution of holding time and the solid line is the calculated exponential curve.

If the variation of the holding times of the calls of two traffic flows is expressed by the functions $p(>t) = e^{-t/h_1}$ and e^{-t/h_2}, h_1 and h_2 indicating the respective average holding times, and if the two flows combine or merge, the distribution function of the holding times of the merged calls is

$$p(>t) = \frac{n_1 e^{-t/h_1} + n_2 e^{-t/h_2}}{n_1 + n_2}. \qquad (2)$$

n_1 and n_2 represent the average number of calls of the flows.

A merged traffic flow comprises every call of the merging flows. It has been assumed that the merging process causes no change in the individual holding times of the calls. This is a simplification of what actually happens in a telephone exchange where dialling, selection, and hunting demand some time. As, in general, the difference is less than half a percent and of some random nature, this simplification does not affect our conclusions.

Consideration of the above equations reveals that the holding time of the combined traffic flow follows the simple negative exponential law comprising one term, only when $h_1 = h_2 = \cdots h_n$. Actual traffic rarely satisfies this condition as in many instances the average holding time depends on the destination of the flow. The group selectors of a telephone exchange direct their traffic to local subscribers, exchanges located in the suburbs, special services, and distant locations reached via rural and toll lines. Each of these classes of calls has a characteristic average holding time. Special-service calls distinguish themselves by a short average holding time, calls between residential subscribers tend to be longer than business connections, while the average duration of rural calls is rather long.

From the manner in which the distribution functions of holding times add and from the observation that different traffic flows often show distinctly different average holding times, it follows that the simple exponential law, which is frequently adopted for theoretical studies, is applicable only in rare instances and that in general the actual distribution function of the holding time is better expressed by a function comprising a number of exponential terms.

This phenomenon is of special importance when dealing with delay problems in which, as is well known, the variation of holding time plays a critical role. The generally observed deviation is such that the theoretical delays based on a simple negative exponential distribution function are too optimistic.

It may be concluded from theoretical investigations made by Palm (1938) that the loss equations in general and the Erlang loss equation in particular are valid for any holding-time distribution. In Section 3, we shall revert again to this subject.

2.2 Arrival of Calls

For the variable describing the arrival of calls, a variety of distribution functions result depending on a number of assumptions made. For instance, the number of sources that create the calls may be assumed to be either finite or infinite. The latter assumption is generally preferred in practice as it leads to more-manageable equations.

When the traffic is unhampered by any switching arrangement causing loss or delay, when the calls may commence at any moment of the period considered, when no relation between the calls can be demonstrated, and with an infinite number of sources, the following Poisson function describes the probability of the arrival of precisely x calls during an observation period t.

$$P_x(n, t) = (nt)^x e^{-nt}/x!$$

where

$$x = 0, 1, 2, \cdots, \infty; \qquad (3)$$

$0 < t < \infty$; and n is the average number of calls arriving during the unit of time. In the following section, we shall refer to this class of equations as time distribution functions.

The intervals between successive calls are characterised by the arrival of no new calls. Then (3) transforms to

$$P_0(n, t) = e^{-nt} = p(> t). \qquad (4)$$

The probability $P_0(n, t)$ indicates that no calls arrive during the period t and it is equal to the probability that the length of the interval between successive calls exceeds t.

Many thousands of intervals have been measured in a public and a private exchange with the consistent result that the interval between successive calls closely follows the negative exponential law. The minor deviations show no persistent tendency so that in this instance one may conclude that there is agreement between theory and practice. The influence of repeated trials appears to be negligible if it exists at all.

When independent flows of telephone calls that satisfy (4) merge, the distribution function for the merged traffic is obtained by the multiplication of the functions of the individual flows. If, for example, the variations of the two flows are characterized by $p(> t) = e^{-n_1 t}$ and $e^{-n_2 t}$, n_1 and n_2 being the average numbers of calls per hour, the combined flow will follow the function

$$p(> t) = e^{-(n_1+n_2)t}. \qquad (5)$$

Consequently the average number of calls of the combined flow is obtained by the straight addition of the averages of the merging flows. A similar rule holds good when traffic divides. There seems to be a discrepancy between actual and theoretical traffic in that the observed expectation n varies during the day whereas the n appearing in (3) is of a constant nature. This fact and the desire that theory and practice agree in the closest possible manner, leads to the concept of the busy hour, a problem discussed in Section 6.

Instead of (3), which pertains to a sequence of events, we may measure telephone traffic by call coincidence. The equations then express the probability of a specific number of calls being simultaneously in progress. In the following equation of Poisson, y is the average of the variable x.

$$P_x(y) = y^x e^{-y}/x \tag{6}$$

where $x = 0, 1, \cdots, \infty$ and $y = \mathrm{nh}$.

Section 3 discusses the relationship between these two classes of equations, where the latter will be referred to as space distribution functions.

When two traffic flows that obey (6) merge, the distribution function of the combined flow is

$$\sum_{1=0}^{x} P_i(y_1)P_{x-1}(y_2)$$

where the suffixes 1 and 2 distinguish the two flows. Elaboration leads to

$$(y_1 + y_2)^x e^{-(y_1+y_2)}/x! \tag{7}$$

which is $P_x(y_1 + y_2)$.

From this follows the previous conclusion that, when independent traffic flows merge, the average traffic value of the merged flow is obtained by the straight addition of the averages of the merging flows.

The multiplication theorem does not apply to interdependent traffic flows as will be shown by the following example. When hunting over a group of junctions in a sequential order always starts from a fixed home position, the distribution function of the intervals between successive calls picked by the first junction is

$$p(> t) = \frac{1}{1-y} e^{-nt} - \frac{y}{1-y} e^{-t/h}, \quad y \neq 1.$$

$$p(> t) = e^{-nt}(1 + nt), \quad y = 1$$

in which

$$y = nh \quad \text{and} \quad 0 < t < \infty.$$

The traffic offered to the group is assumed to obey laws (1) and (3). The corresponding function of the calls overflowing the first junction is, according to Palm (1943),

$$p(> t) = \frac{a^{1/2}}{a^{1/2} + b^{1/2}} e^{-bt/h} + \frac{b^{1/2}}{a^{1/2} + b^{1/2}} e^{-at/h}$$

in which

$$a^{1/2} = \tfrac{1}{2}[(4y + 1)^{1/2} + 1]$$
$$b^{1/2} = \tfrac{1}{2}[(4y + 1)^{1/2} - 1]$$
$$y = n \cdot h$$
$$0 < t < \infty.$$

If the multiplication theorem mentioned above applies, the product of these two functions should be equal to e^{-nt}, the distribution function of the interval between successive calls offered to the group. Evidently this is not the case, because the two functions relate to interdependent traffic. Calls flow over the first junction only when it is engaged.

Traffic changes its character after having passed through a switching arrangement. If, for example, the arrangement consists of a limited group of N junctions, the traffic peaks exceeding N calls are cut off. They may either be lost or delayed. O'Dell has introduced the term smooth traffic for that part of random traffic that has passed through such a limited group, while the traffic that has been rejected by the group during periods of congestion is called peak traffic. When such traffic is directed to another group of outlets it is called overflow traffic.

When any call has access to any of the outlets at any moment (full availability), the Erlang distribution function describing the number of calls in progress simultaneously is

$${}_1E_x = \frac{P_x(y)}{\sum_{i=0}^{N} P_i(y)} \tag{8}$$

where $0 < x \leqslant N$.

Here x is the random variable associated with y, the average traffic offered to the group and expressed in erlangs. The calls that are not served are lost.

When the calls that are not served immediately are delayed, the distribution function of the traffic carried by the group is expressed by the second equation of Erlang.

$$ {}_2E_x(y) = \frac{P_x(y)}{\sum_{i=0}^{N-1} P_i(y) + \frac{N}{N-y} P_N(y)}, $$

$$ x = 0, 1, \cdots, (N-1). \quad (9A) $$

$$ {}_2E_N(y) = \frac{\frac{N}{N-y} P_N(y)}{\sum_{i=0}^{N-1} P_i(y) + \frac{N}{N-y} P_N(y)}, $$

$$ x = N. \quad (9B) $$

The symbols in (8), (9A), and (9B) refer to (6). Equations (9A) and (9B) assume that the holding time follows the negative exponential law (1). Equations (8) and (9) may serve for the verification and evaluation of observed telephone traffic but (8) is apt to present difficulties in this respect, as explained in Section 7.

3. Relationship Between Time and Space Distribution Functions

In the preceding section, it has been explained that a traffic flow can be described by two distribution functions. The first of these relates to the holding time, for which no definite function is adopted in this section. The second relates to the calls and two expressions are used which pertain to

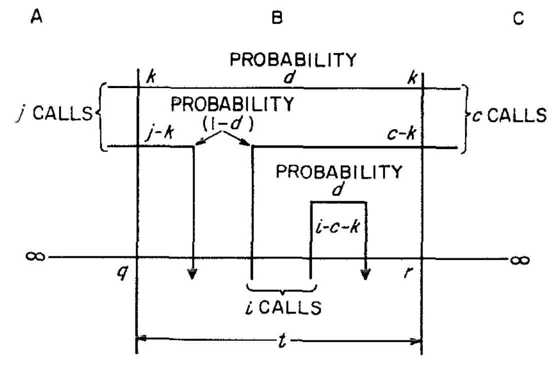

Figure 2—Events and probabilities.

(A) The probability that at a moment j calls are found simultaneously in progress, which we represent by the symbol ${}_2X_j(n, t)$.

(B) The probability that i calls arrive during a following period t, which we represent by ${}_1X_{i,j}(n, t)$, under the condition that j calls were in progress at the beginning of the period. i and j are positive numbers and range from 0 to ∞.

As these two functions relate to the same traffic flow, the average number of calls arriving during the average holding time must be equal to the average number of calls in progress simultaneously. In other words, the t's of both symbols represent equal periods, in the one instance t represents the average observation period and in the other the average holding time.

These two conceptions are distinguished here as time and space distribution functions. For their discussion, reference is made to Figure 2, in which the horizontal line indicates time, three periods being distinguished: A that extends from ∞ to the moment q; B that is limited by the moments q and r and has a duration t, the average holding time; and C that extends from the moment r to ∞.

A call in progress at r must have been originated either during the period A or B, to which events we attach the probabilities d and $(1-d)$.

A call that started during B must end either during B or must continue past r. As the probability of the latter event equals $(1-d)$, that of the former must be equal to d. As already stated, the average number of calls arriving during B is equal to the average number of calls in progress at the moment r.

By similar reasoning, we find that the probability $(1-d)$ also applies to a call existing at the moment q and terminating during the period B. The latter can also be demonstrated by interchanging the moments of birth and death of the two kinds of calls that have the probabilities $(1-d)$.

We suppose that at the moment r exactly c calls exist, k of which are included in the j calls existing at the moment q and $(c - k)$ are among the i calls originated during the period B. Consequently $(j - k)$ calls of the j calls terminate during B and $(i - c + k)$ calls of the i calls terminate during the same period.

The probability of finding c calls in progress simultaneously at r is consequently composed of an infinitely large number of partial probabilities as follows.

$$
{}_2X_c(n,t) = \sum_{k=0}^{c}\sum_{j=0}^{\infty}\sum_{i=0}^{\infty}\binom{j}{k} d^k(1-d)^{j-k}
\times {}_2X_j(n,t)\binom{i}{c-k}(1-d)^{c-k}d^{i-c+k}{}_1X_{1,j}(n,t).
$$

There is no need to consider the effect of the limit $i + j \geqslant c$ as combinations having negative lower numbers are equal to zero.

Using similar symbols throughout, we have

$$
{}_2X_c(n,t) = \sum_{k=0}^{c}\sum_{j=0}^{\infty} B_k(j,d)\,{}_2X_j(n,t)
\times \sum_{i=0}^{\infty} B_{c-k}(i,1-d)\,{}_1X_{i,j}(n,t). \quad (10)
$$

In this equation, B stands for the Bernoulli law. It delineates the general relation that exists between the three distribution functions mentioned. One would deduce from this that the space distribution function depends in any case on the time and the holding-time distribution functions. There are, however, exceptions. If the time function obeys the Poisson law, the same law also applies to the space function without any postulate for the holding-time function.

When introducing

$$
{}_1X_{i,j}(n,t) = P_i(y)
$$

and

$$
{}_2X_j(n,t) = P_j(y)
$$

into (10), an identity appears and no condition exists in this instance that the holding time distribution function should satisfy. We then have for (10)

$$
{}_2P_c(y) = \sum_{k=0}^{c}\sum_{i=0}^{\infty} B_{c-k}(i, 1-d)
\times P_i(y)\sum_{j=0}^{\infty} B_k(j,d)P_j(y).
$$

It can be demonstrated that the following equation is of general validity.

$$
\sum_{j=0}^{\infty} B_k(j,d)P_j(y) = P_k(d\cdot y). \quad (11)
$$

Introduced, we obtain

$$
{}_2P_c(y) = \sum_{k=0}^{c} P_k(d\cdot y)P_{c-k}[(1-d)y]
$$

or

$$
{}_2P_c(y) = y^c e^{-y}/c! \times \sum_{k=0}^{c}\binom{c}{k} d^k(1-d)^{c-k}
$$

which is an identity as the above $\Sigma = 1$.

The above method may be applied to other types of distribution functions, but care should be exercised when dealing with limited groups, as in such cases part of the i calls must necessarily be lost.

4. Artificial Traffic

Besides telephone traffic created by subscribers and the variety of theoretical forms of traffic discussed in Section 2, there exist various kinds of simulated traffic produced by mechanical or electrical means such as traffic machines or computing machines.

The complete simulation of traffic requires, as stated in Section 2, two appropriate random mechanisms, one for imitating the random arrival of calls and the other for the distribution function of holding time. Simulation of the arrival of calls presents no great difficulties and several equipments provide for this but a holding-time mechanism incorporating any specific random character has not yet been developed. The precision of such instrument should be good.

A reliable traffic machine should include means for checking the amount of traffic offered or the number of calls carried by the equipment with their average holding time. This check is required to verify correct operation of the machine during every test and the necessity for it increases with the accuracy to which measurements are made, which should range between 1 and 0.1 of 1 percent. Lacking such a check, there is no knowledge of the variation of traffic about the desired average and no possibility of eliminating faulty tests. With constant holding time, such a check is fairly easy as knowledge of the number of calls carried and lost suffices, but for variable holding time, matters become more complicated in that the durations of calls that may be simultaneously in progress have to be added.

With the roulette principle invented by Kosten, two independent random variables are used, one indicating the beginning and the other the ending of the calls. This method implies the adoption of the negative exponential distribution function for holding time with the result that machines based on this principle abandon the only means for checking for correct operation during the various tests.

The same principle is also employed in computing machines creating series of random numbers and placing the calls via some switching network in suitable memories. Such application has the inherent disadvantage, noted in the preceding paragraph, that no precise knowledge of the traffic offered or carried is produced so that faulty tests cannot be eliminated. As each test requires a new program, possible bias is difficult to discover and eliminate. The more so, as programming engineers are not supposed to possess sufficient experience to be aware of the pitfalls in the creation of random phenomena.

5. Traffic Measurement

Based on the description given for theoretical traffic, actual telephone traffic is measured in three distinct manners.

With the first method, lengths of periods are measured and such observations serve for gathering information on holding times of connections, intervals between successive calls, periods during which groups of circuits are blocked, et cetera. A contact-closing clock or a simple interrupter may be used as a timing device. The error committed thereby amounts to about half the interval of the basic timing period. (See Rabe, 1949.) The measuring equipment also includes a number of counters operated in series with a switch that steps in synchronism with the impulses produced by the timer.

With the second method, a count is made of the number of calls that arrive during consecutive equal periods. The test equipment may be simply a lamp that flashes each time a call arrives but there may also be included means of counting the number of call arrivals.

The drawback of this method is that it must be accompanied by observations relating to the holding times of the calls, whereas, as previously stated, no separate information on holding time is essential in case of lost-call switching system arrangements.

With the third method, the numbers of calls simultaneously in progress are noted. It has the advantage of being a direct measurement of the traffic expressed in erlangs. It dispenses with the tedious method of counting calls and of measuring their holding times.

The observations are generally made at equal time intervals that exceed the average holding time. Equal spacing, however, does not seem to be a stringent requirement as from a theoretical point of view the observation moments may also be chosen at random. Neither would it appear necessary to limit the interval to a minimum value as the numbers of calls in progress simultaneously can also be obtained, and even more precisely, by using a recording ammeter in series with an individual resistance per circuit. In this case the moments of observation may be considered to lie infinitely close together. However, in view of the method described in the next section of determining the busy hour and the busy-hour traffic, a standard uniform interval between the successive observations is recommended.

Even the stipulation *simultaneous* need not be taken too strictly. Should an observer have no test equipment to indicate the instantaneous number of simultaneous calls, he may still proceed by observing in succession the condition of the circuits in the various groups but he should continue his busy count even if changes occur in the condition of the circuits already passed over.

By merely walking through an exchange and noting in a leisurely manner the number of outlets in each of the various groups and how many are busy, one can obtain a fairly accurate picture of the traffic the equipment carries and can conclude whether there is any danger of abnormal congestion.

6. Busy Hour and Busy-Hour Traffic

The subject of the busy hour was touched on in Section 2 in connection with the constant nature of the mathematical expectation n appearing in (3) and y in (6).

Busy hour was introduced in the early days of the telephone art to ensure that the traffic data underlying the computation of the equipment quantities were chosen sufficiently large to cover the traffic at any period of the day.

The definition of the busy hour contained in British Standard Specification 204 is in line with the above but does not recognize its statistical character. In the pertinent literature, the concept of the busy hour is but rarely referred to and is even sometimes called "vague."

This situation induced us in 1937 to propose a concept of the busy hour through which agreement between theory and practice would be ensured in the best possible manner. It was subsequently recommended by the Comité Consultatif International Télégraphique et Téléphonique (volume VI, page 16; 1954) for the evaluation of the international busy-hour traffic.

Realization of this agreement is aided by the application of a guided choice among the data observed and is based on three characteristic features of the theoretical traffic distribution function. These features are best explained by using the Poisson equation (6). The parameter y is of a constant nature and represents the average number of calls in progress simultaneously, taken over a period of unlimited duration. We may divide this period into H subperiods, each of 1 hour, as shown in Figure 3, and to make in every hour an arbitrary number of 10 equidistant observations.

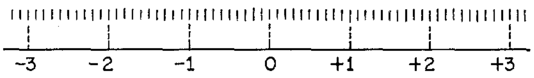

Figure 3—Division of observation period into subperiods.

The three characteristic features referred to are:

(A) We cut the above period into H subperiods each of 1-hour duration and arrange the numbers of simultaneous calls observed in the following manner, (+1.9) representing the number of simultaneous calls observed at the moment +1.9.

.	.		.	.
.	.		.	.
.	.		.	.
(−2.9)	(−2.8)	···	(−2.1)	(−2.0)
(−1.9)	(−1.8)	···	(−1.1)	(−1.0)
(−0.9)	(−0.8)	···	(−0.1)	(0.0)
(+0.1)	(+0.2)	···	(+0.9)	(+1.0)
(+1.1)	(+1.2)	···	(+1.9)	(+2.0)
(+2.1)	(+2.2)	···	(+2.9)	(+3.0)
.	.		.	.
.	.		.	.
.	.		.	.

The observations are now arranged in 10 columns each containing an infinitely large number of H data. The average for each column amounts to y, the average number of simultaneous calls. The subperiod of 1 hour is representative for the busy hour and the above demonstrates the constant nature of the mathematical expectation during the busy hour.

When considering the H observations of each of the above 10 columns, we would further find that they contain the same proportions of 0, 1, 2, $\cdots$, simultaneous calls. This demonstrates the principle of the statistical equilibrium introduced by Erlang, which may also be expressed by stating that the probability of finding a specific number of simultaneous calls is independent of the time. The principle of the statistical equilibrium is, therefore, directly associated with that of the constant nature of the mathematical expectation. If the latter is dropped for one reason or another, the principle of the statistical equilibrium must be revised.

(B) The variation of the observed numbers of calls in progress simultaneously is expressed by (6).

(C) Equation (7) demonstrates that arithmetical addition and subtraction of the average numbers of calls in progress simultaneously must be applied when unhampered traffic flows either merge or divide.

The features (A) and (C) pertain to theoretical traffic that satisfies (6). They also appear to be properties of traffic that satisfies the distribution function

$$p(x) = \binom{s}{x} t^x (1 - t)^{s-x} \qquad (12)$$

where $x = 0, 1, 2, \cdots, s$. The number of sources is denoted by s.

On these three properties of theoretical traffic that satisfy the functions (6) or (12) rests the following statistical method for determining the busy hour and the busy-hour traffic.

Suppose we have at our disposal extensive statistical data for a specific group of outlets operating on a full-availability basis and with a negligible loss or delay. These data pertain to the number of busies observed at the same moments of the day, for example, at the hours 0.0, 0.1, 0.2, $\cdots$, 23.8, 23.9, and for a sufficiently large number of working days. The data pertaining to exceptional days such as Sundays and national holidays are discarded. The larger the number of days, the greater the degree of accuracy will be. The number of 10 days mentioned in the recommendation of the Comité Consultatif International Télégraphique et Téléphonique referred to in the above, should, therefore, be considered as a minimum.

When plotting the averages for each of these times of the day, a well-known fluctuating curve will be obtained that remains fairly flat between the hours of 9:00 to 12:00 and 14:00 to 17:00 o'clock. The period located at the point of culmination is now chosen for the busy hour and its ordinate for the value y of the busy-hour traffic. Consequently it is assumed that the traffic flow is caused by a "calling potential" that remains stable at the same hours of the different days, which stability applies to the subscribers individually and collectively.

In so doing, the value obtained for y is in close correspondence with characteristic (A). A minor variation of y during the busy hour seems acceptable.

Characteristic (C) is met by choosing, possibly with a few minor exceptions, the same busy hour for all the traffic flows in an exchange or area. This seems quite normal as exactly the same calls that contribute to the busy-hour traffics of merging groups will also be found among the merged traffic of the combined group.

Practice shows that a displacement of the busy-hour period by a quarter of an hour causes no appreciable change in the average value of y, so that coincidence of the various busy hours of the groups can readily be arranged. The traffic peaks that possibly appear outside the adopted busy-hour period contribute to the average of the hours outside this period and, of necessity, to a lower average traffic value.

Characteristic (B) leads to a simple check of the variation of the observed numbers of simultaneous calls around the average adopted for the busy hour chosen. Equation (6) or (12) may serve for this purpose.

A different and widely spread interpretation of the concept of the busy hour and the determination of the busy-hour traffic is to use the average of the individual traffic peaks of the days observed, which peaks may occur at different hours. The value y thus obtained will be greater than that found in the manner proposed by us and as random hours are used a theory was developed permitting subtractions when traffic flows merge or additions when they divide. In Section 2, however, we have demonstrated that for both (6) and (12) the theoretical traffic obeys the simple law of straight addition or subtraction of the average traffic values, so that the latter interpretation of busy hour and busy-hour traffic are not in agreement with the theoretical concepts underlying the well-known distribution functions.

Directly associated with the busy-hour problem is that of the quality of service. At the present moment, it is a common understanding that the grade of service determined by $P = 0.001$ is very good, by $P = 0.01$ permissible, and by $P = 0.10$ rather poor. It might be suggested that we completely abandon the busy-hour concept and base the switch calculations on traffic data extending over the full period of 24 hours. The consequence of this suggestion would be that new standards of service would have to be introduced and the probability equations now in general use would have to make place for others based on variable expectation. The principle of statistical equilibrium would no longer apply and some function expressing the variation of the mathematical expectation would have to be adopted. For normal circumstances, such a function would have to acknowledge that the value of expectation would be negligible for some 12 hours of the day, increase during 3 to 4 hours, and remain about constant for approximately 8 to 9 hours. We know however, that only the last group of hours contributes to delay or to lost traffic so that the adoption of a variable expectation would in fact lead right back to the equivalent of a busy period. Thus, the use of traffic data relating to the full period of the day does not appear to be very attractive, useful, or necessary, and no better solution than the present busy-hour concept seems to exist.

For the great majority of cases, the busy-hour traffic obtained as indicated satisfies the three characteristic features of the theoretical traffic concept. In several instances, however, and especially in automatic long-distance service, matters are complicated by the difference in standard time that may exist between the interconnected areas. As no guiding rule is available, the solution of such cases must remain with the traffic engineers who are acquainted with the full facts.

7. Deriving Traffic Offered from Traffic Carried

If the groups of outlets are sufficiently large so that the loss is of minor value, the traffic offered may be assumed to be equal to the traffic carried by the group. The error thus committed is negligible both for the purpose of verification and measurement. If on the contrary the switching arrangement causes an appreciable loss, special methods are needed because the observations are of the traffic carried by the group whereas the usual loss equations include traffic offered as a parameter. Consequently the traffic offered must first be derived from the observed data by checking the specific numbers of calls simultaneously in progress against the probabilities calculated by (8).

In the following paragraphs, four distinct methods that have some theoretical basis are described.

7.1 Method 1

From the lost-call equation of Erlang (8), the following proportions can be obtained

$$y = ip(i)/p(i-1)$$

where $0 < i \leqslant N$.

Each of these N proportions provides a theoretical value for the traffic offered to the group. By calculating these proportions from the observed data, we obtain N values for y. Their average is equal to

$$y' = \frac{1}{N}\sum_{1}^{N}\frac{ip'(i)}{p'(i-1)}.$$

The primes indicate the measured and derived values, which correspond with their theoretical counterparts. A disadvantage of this method is that the proportions calculated do not have the same degree of accuracy as the numbers that are found in the neighborhood of the average group occupation. These are larger and have greater likelihood of being correct. It seems therefore necessary to weight the observed proportions with a suitable factor that is a function of the various numbers observed, the sum of which must be equal to 1. A reasonable assumption is to adopt factors that are in direct proportion to the observed proportions $p'(0)$, $p'(1)$, et cetera. The manner of weighting used may be supplemented by others, perhaps more suitable, depending on the judgment of the analyzer.

An advantage of this first method is that all observed proportions are utilized for the computation of the traffic offered to the group.

7.2 Method 2

This method is based on a comparison of the observed and the theoretical values of $p(\leqslant x)$, the probability of finding a maximum of x calls in progress simultaneously. From the observed data, $N+1$ values for $p'(\leqslant x)$ are calculated while the corresponding theoretical values have to be computed for the necessary sequence of traffic values.

The comparison exists in finding among the theoretical traffic values the one that most closely approaches the observed $p'(\leqslant x)$. The $N+1$ values for the traffic offered found in this manner may be averaged with or without weighting.

7.3 Method 3

The lost traffic is in direct proportion to the time during which the group is fully engaged. The measured portion of the busy hour during which the group is fully engaged is compared with the corresponding data as, for example, those contained in the tables prepared by Palm (1947). In this manner, only one value for the offered traffic is obtained.

The disadvantage of this method is that only one of the numbers observed is utilized for the evaluation of the offered traffic. Application of this method to the other frequencies may lead to anomalies.

7.4 Method 4

This method is based on the comparison among the various values of $p'(x)$ calculated from the observations and their theoretical counterparts as these have been listed in the tables prepared by Palm (1947). For a sequence of traffic values estimated to cover the range of the traffic offered, the differences $p'(x) - p(x)$ are calculated. Calculation of the standard deviation and skewness from these differences provides two values for y', the one when the standard deviation is a minimum, the other when the skewness equals zero.

When the calls of the observed group of outlets that are not served immediately are delayed, the traffic carried by the group is equal to the traffic offered, at least from a theoretical point of view. It would appear, therefore, that the problem dealt with in this section does not exist for switching arrangements causing delays. In such instances, however, it is advisable to proceed with care as groups of outlets that are underswitched cause a strangling effect on the offered traffic. The subscribers know by experience that such a situation exists and consequently use other means of communication instead, such as the telegraph or even the mail. Instances can be cited where with manual toll service the lines of a certain direction were doubled and redoubled while each time the delay, after a temporary drop, climbed back to its original value.

Several other influences may render a reasonable forecast difficult, such as a change in the structure of the rates, the changing from flat rate to measured rate, the introduction of cheaper night rates, and the change from 3- to 1-minute rate units for toll calls. Such changes exercise an unpredictable effect on the importance and the characteristic features of telephone traffic.

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Since 1953, he served as assistant technical director of International Standard Electric Corporation and now acts as a technical consultant to International Telephone and Telegraph Europe.

Slow-Wave Structures for Millimetre-Wavelength Backward-Wave Oscillators

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1. List of Symbols

ω = angular frequency
v_p = phase velocity
v_g = group velocity, $d\omega/d\beta$
c = speed of light
β = propagation constant, ω/v_p
p = pitch of slow-wave circuit
α = attenuation constant
E_z = radio-frequency electric field in the direction of the beam velocity
P = power propagating along the circuit
K = interaction impedance, $E_z^2/2\beta^2P$
I_0 = direct-current beam current
V_0 = direct-current beam voltage
C = Pierce's gain parameter, $\{K(I_0/4V_0)\}^{1/3}$.
η = efficiency

2. Introduction

Microwave electron-beam devices may be classified as to whether the interaction is confined to one or a series of short regions or whether it takes place over extended regions. In the first type, the interaction effect is enhanced by the use of resonant cavities, which may be regarded as effecting a repeated use of the same packet of electromagnetic energy. In the second type, a large effect is obtained by allowing the interaction to continue for a long time, corresponding to many periods of the wave. For this class, which includes the travelling-wave tube, backward-wave oscillator, carcinotron, and linear accelerator, the electromagnetic wave must be guided by a slow-wave structure in which the wave velocity closely matches the speed of the electrons.

Whereas in general it is a relatively simple matter to decide on the desiderata in the case of cavities, in which a single parameter, the shunt impedance, could in many instances be regarded as a figure of merit, in the case of slow-wave structures the situation is considerably more complex. One important characteristic is described by the interaction impedance, which is a measure of the intensity of the useful electric field per unit power propagating along the structure [1]. This impedance corresponds roughly to the shunt impedance of a resonant cavity. In addition one must, however, also consider the bandwidth over which the slow-wave circuit can operate, the attenuation, the ability of the circuit to dissipate large powers, and the ease with which it can be matched to a waveguide over its operating frequency band. Inevitably compromises must be sought, and the weight placed on any one of the desired properties depends on the application. At millimetre wavelengths, the relative importance of various factors is totally different from that which obtains at longer wavelengths. In particular, the minimization of the attenuation becomes of primary importance. To illustrate this point, consider a backward-wave oscillator as indicated in Figure 1. The radio-frequency current along the beam varies approximately sinusoidally, the amplitude of the wave on the circuit approximately cosinusoidally [2]. The radio-frequency power is generated primarily where both the current and the field are strong, that is, in the middle of the tube. This power must then pass through half the total attenuation of the tube before reaching the output guide. It is not uncommon at millimetre wavelengths for the attenuation to amount to 20 decibels whereas at a wavelength of a few centimetres it is not likely to be very significant. It can be shown [3] that if the attenuation of the slow-wave circuit is too high, it is not possible to obtain oscillation, irrespective of the length of the circuit.

The main purpose of this paper is to present an approach to the design of slow-wave circuits for the particular circumstances encountered at millimetric wavelengths and to describe some of the circuits that have been studied. For reasons of available space, we present the work without the mathematical analysis on which it is based but wherever possible appropriate references have been included. Section 3 presents some of the considerations that govern the choice of the group velocity of the slow-wave circuit. Since both the interaction impedance and the attenuation are inversely proportional to this velocity, it is a very-critical design factor. An outline of an analysis aimed at the determination of the actual losses is also included. Section 4 deals with the possibilities of utilizing slow-wave structures that extend in three dimensions. In Section 5 some results relating to particular millimetric slow-wave circuits are discussed.

3. Choice of Group Velocity

In a backward-wave oscillator a certain relation must be satisfied between the circuit loss α and the gain parameter C before oscillations will commence. The larger α, the larger the required value of C. α depends on the material of the circuit, its geometry, and the group velocity v_g of the wave on the circuit. C depends on the beam impedance and the interaction impedance, which in turn depend on the geometry of the circuit, the group velocity of the wave on the circuit, and the phase velocity v_p of the wave component interacting with the beam. In designing a tube for a specific application, many of these factors may be largely prescribed; for example, the beam impedance and phase velocity may be determined by the power level required and by the highest perveance considered practicable for the electron gun. However, we have to decide whether to aim for a high or a low group velocity. If we require a tube that is tunable over a wide range, there is no choice; a high group velocity is inevitable. If, on the other hand, oscillation is required over only a narrow frequency band we are free to consider whether there is any advantage in reducing the group velocity. Since K is inversely proportional to v_g, an increase in the interaction impedance is effected and so C is increased (C^3 being inversely proportional to the group velocity). However, when we remember that the circuit loss α is also inversely proportional to the group velocity, it is not obvious whether we shall gain or lose by so doing.

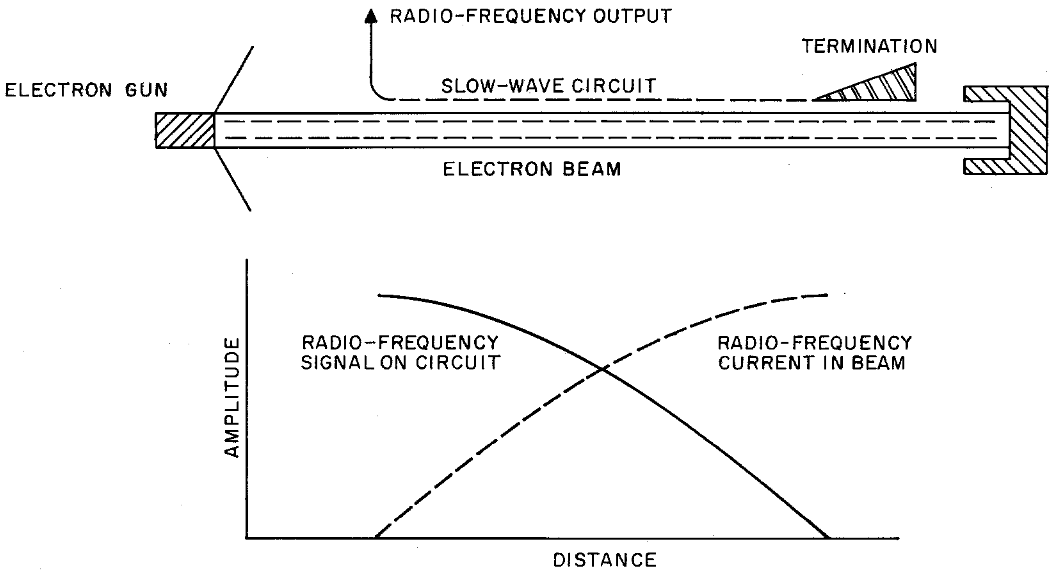

Figure 1—Variation of radio-frequency signal and beam current in a backward-wave oscillator.

If we let $\alpha = k_1/v_g$ and $C^3 = k_2/v_g$, we can summarize the situation with a single curve in which $N/(k_1/k_2)^{1/2}$ is plotted against $v_g(k_1^3/k_2)^{1/2}$, where N is the minimum length of circuit measured in guide wavelengths necessary to obtain oscillation. The numerical evaluation of the expression obtained required a knowledge of the starting conditions for a backward-wave oscillator in the presence of loss. This information is to be found in a paper by Johnson [4] and was used in the computation of the curve in Figure 2. It is seen that there is a minimum value for N and hence an optimum value for v_g. Although k_1 and k_2 do not contain v_g explicitly, they are dependent on the geometry of the circuit that in turn controls the group velocity. Thus if we attempt to change the group velocity, in order to optimize its value, the values of k_1 and k_2 will also change so that an iterative procedure is called for. Nevertheless, we have established a criterion that indicates in which direction the group velocity should be changed and how far it is from optimum.

So far we have only considered the conditions for start of oscillation and, when trying to work at the very-highest frequencies, this must be the first consideration. Eventually, however, we shall become interested in the efficiency and want to know how to optimize it with respect to group velocity. Grow and Watkins [5] have given an approximate expression for the efficiency of a backward-wave oscillator $\eta = C\exp[-0{\cdot}115\,N\alpha]$. In deriving this expression they have assumed that the interaction is sufficiently vigorous for the radio-frequency current in the beam to reach saturation and, provided this is achieved, there is no optimum value of N; the shorter the circuit the better. The group velocity that gives maximum efficiency can, however, be shown to be equal to $0{\cdot}345\ k_1N$, which is not the same as that giving the minimum starting length. To design for maximum efficiency, we must fix the starting current, relative to the working current, so that radio-frequency beam saturation is ensured. Then N and v_g must be selected to satisfy the condition for optimum efficiency and simultaneously the condition for start of oscillation given by Figure 2. The starting current is used to calculate k_2 so that N and v_g correspond to a point on the curve of Figure 2, although this will not now be the point of minimum N.

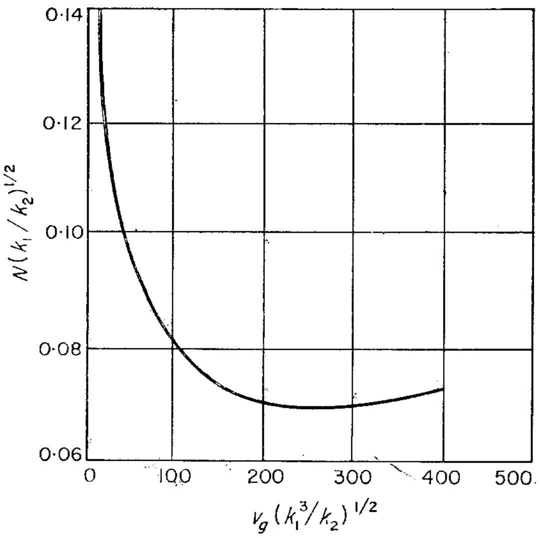

Figure 2—Relation between starting length, loss, and group velocity.

To use these expressions, we must be able to calculate α and the interaction impedance, which in turn give us k_1 and k_2. In general this is not an easy problem because of the difficulty of determining the field distribution in slow-wave structures. However, Fletcher [6] has provided a solution to this problem for structures that comprise (or may be approximated by) arrangements of parallel bars of rectangular cross-section, and interaction impedances may be readily obtained by this method. In principle it also permits the loss of such structures to be calculated, but in practice this is more difficult. Whereas in the calculation of impedance it is necessary to determine the total current flowing along a bar of the structure, to obtain the loss the square of the current has to be integrated over the surface of a bar. Difficulties arise at the corners of the bars where the field solutions are approximate and where in the idealized model a current infinity occurs. The latter gives rise to some mathematical difficulties in the loss calculations but these can be overcome. However, since the loss is dependent on the way the current is distributed over the surface of the bar while the impedance depends only on the total current, the approximations in the field solution have a much greater effect on the losses than on the impedance. Nevertheless, values of α have been computed for a wide range of circuit geometries and it is considered that these are sufficiently accurate to provide a considerable measure of guidance in calculating the optimum group velocity.

The importance of this problem of optimum group velocity can be illustrated by showing how its value changes with wavelength for a typical circuit. In the case selected the circuit is of molybdenum, the beam current density is 1·5 amperes per square centimetre, and a fundamental backward wave is assumed. The optimum values of c/v_g and N to minimize the starting current at a particular frequency are given in Table 1. From the figures it can be

TABLE 1

λ in millimetres	c/v_g	N
5	70	12
2·5	20	29
1·25	6	69

seen that at a wavelength of 5 millimetres the optimum group velocity is embarrassingly low but at 1·25 millimetres it is very high so that for a non-dispersive circuit ($v_p = v_g$) the beam voltage for interaction would be 7 kilovolts.

Thus we can see that the design of a millimetric backward-wave oscillator for a narrow band requires a balance between the demands of high interaction impedance and low circuit loss. The optimum design can be established provided these two quantities can be calculated and this can be done for ladder structures by an extension of Fletcher's analysis.

4. Multiple Slow-Wave Circuits

In the previous section we discussed the choice of group velocity to optimize the efficiency of a backward-wave oscillator. Even with this optimum choice, and with a circuit configuration having the highest attainable interaction impedance, the maximum output power is still severely limited by the heat-dissipation ability of the circuit. At millimetre wavelengths, the fields decrease so rapidly with distance from the slow-wave circuit that, for example, for a tube operating at 6 millimetres wavelength and a beam voltage of 2·6 kilovolts, it is only the current within 0·1 millimetre of the circuit that makes any appreciable contribution to the power. The presence of thermal velocities in the beam and the fact that the available focusing field is limited, means that the beam edge must be ill defined; some interception of current is therefore inevitable. This problem is particularly acute at millimetre wavelengths for yet another reason. To obtain enough interaction, it is essential to use very-high current densities in the beam. To attain these, the current from the cathode must be compressed. This has the effect of raising the effective electron temperature, so that the edge of the beam is far less well defined than one would expect in a tube operating at longer wavelengths.

One way of obtaining greater powers would be to use several tubes in parallel. This would, however, involve considerable difficulties in coupling and probably insuperable difficulties in ensuring phase coherence between the separate oscillators. A far-more-elegant and promising approach is to combine several slow-wave circuits internally to form one multiple structure. A single electron-optical system can then provide the electron beam that interacts with the whole array. This principle is illustrated diagrammatically in Figure 3 for the case of ladder structures (to be discussed in the following section). In principle there is no limit to the number of circuits that can be combined in this way. In practice there are, of course, limitations arising from the difficulty of joining all the circuits to a single output waveguide and also arising from the need to ensure that all the circuits oscillate in phase.

The conditions that must be met in a multiple structure to achieve phase coherence among all its constituent parts have been analysed and studied experimentally in a number of papers [7, 8, 9]. The conclusions reached in these studies may be summarized by saying that the tolerance errors on the various subcircuits must be held to very-tight limits, but that at wavelengths above about 3 millimetres these limits should be attainable. A second conclusion is that the problem of phase coherence is eased as the efficiency of the tube is increased. This means that the chance of successful multiple-circuit operation is greatest in a tube in which the current density and power output on each circuit are as high as technological limits will permit.

The question of greatest interest is naturally how much can be gained by resorting to the multiple-structure idea. If we incorporate M slow-wave circuits in a multiple array, we would expect to be able to get at least M times the power output obtained from a single circuit. In fact the possible improvement is much greater than suggested by this consideration. The improvement factor that can be anticipated has been investigated by a number of authors [10, 11] and the results depend to some extent on the assumptions that are made in the comparison. However, for the circumstances that apply in the case of a millimetre-wavelength backward-wave oscillator, the result [11] is as indicated in Figure 4. It is seen that the output that can be expected per circuit relative to that provided by a single isolated circuit depends on the distance between the circuits in the array. The improvement reaches a maximum value of just over 3 at a critical spacing and beyond this spacing falls rather rapidly to unity. On this basis one would therefore expect that the power output from M circuits would exceed that from a single circuit by a factor $3M$. Although the result, Figure 4, is based on a somewhat idealized model, a factor of around $2{\cdot}5M$ can be anticipated. We see therefore that quite a moderate number of circuits in a multiple array can lead to substantial increases in power output. So far, there have not been any reports of true multiple circuits operating at millimetre wavelengths. The advantages that can be anticipated are, however, sufficiently great to encourage attempts to realize such circuits. It is for this reason that our efforts to devise suitable circuits for the millimetre band have been concentrated on the ladder type, as this has a geometry that is particularly suitable for assembly into multiple arrays.

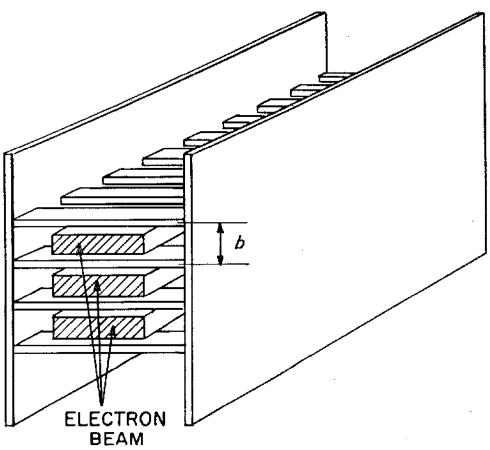

Figure 3—Multiple ladder structure.

5. Ladder Circuits

Figure 5A illustrates a simple ladder structure, the prototype of a class, which has a number of desirable features for use at millimetre wavelengths. In the first instance, it is a very-well-cooled structure. Under normal conditions, the spacing between the sidewalls is of the order of ½ free-space wavelength, so that no point on the circuit is more than ¼ wavelength away from a substantial metallic heat sink. The question of how much power can be safely dissipated on such a circuit has recently been analyzed [12] by solving the appropriate heat-flow equations. The problem is complicated by the fact that we are concerned with large temperature differences, so that effects due both to radiation and to the variation of conductivity with temperature may be important. It was, however, possible to obtain useful approximations to the non-linear equations, and thus to derive quantitative results for the power dissipation capability. Applying these results to the case of a backward-wave oscillator centred at a 6-millimetre wavelength and making a number of plausible assumptions, one is led to the conclusion that beam power densities of 100 kilowatts per square centimetre should be attainable. This figure is several orders of magnitude higher than would apply to the case of a simple helix.

The possibility of stacking ladders to form a multiple array has already been mentioned; however, the ladder has yet a further appeal for the millimetre band; it is relatively easy to fabricate. It has already been mentioned that the ohmic loss of a slow-wave structure is inversely proportional to the group velocity, and that losses tend to be a dominant factor. There is another kind of loss that may become significant; this is a statistical random reflection loss due to irregularities in the structure. It can readily be shown that this loss also is inversely proportional to the group velocity. The avoidance of small errors is therefore of great importance at millimetre wavelengths, and this discourages any kind of complexity in the choice of structure. A completely planar circuit such as the ladder is amenable to a number of constructional techniques that work satisfactorily for small dimensions. Among these are precision winding, photoetching, and spark erosion machining. We have experimented mainly with the latter two and believe that good circuits can be made with their aid, at least down to 2 millimetres wavelength.

So far we have not mentioned one vital disadvantage of the ladder: in its simplest form, as shown in Figure 5A, it does not propagate a slow wave. If one regards each rung of the ladder as a resonator, it is at first sight surprising that an array of such resonators, which are certainly coupled to each other, do not give rise to a frequency band over which propagation is possible. The explanation that emerges from analysis is that the resonators are indeed coupled, but both magnetically and electrically, the effects being equal and exactly opposite. This also gives a clue to how a pass band can be obtained. It is necessary only to alter either the electric or magnetic coupling, in almost any manner, and propagation over some band will become possible. The simplest way of perturbing the basic ladder was first suggested by Karp [13], who added conductors adjacent to the ladder, either in the centre or at the edges (Figures 5B and 5C). These circuits have been described and analyzed by a number of authors [14, 15] and they have been remarkably successful in practice. They are used in many commercial tubes and have led to the first successful oscillator below 2 millimetres wavelength. They are not, however, suitable for the purpose that formed our primary aim, which is the realization of structures that can be stacked to form multiple arrays. The necessity of providing adjacent conductors would prevent the assembly of more than two ladders.

Our aim has then been to devise modified ladder structures that propagate by virtue of their

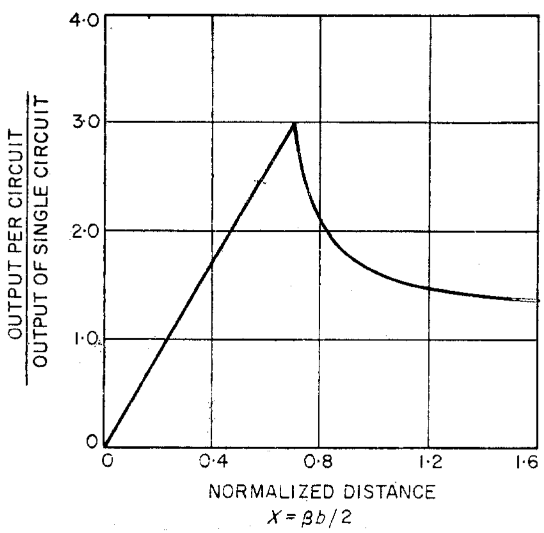

Figure 4—Normalized output and ladder separation.

own topology rather than by the addition of external conductors. The circuits may be divided into two groups according to whether they are suitable for broad- or narrow-band operation, where we will choose the dividing line at bandwidths of 20 per cent.

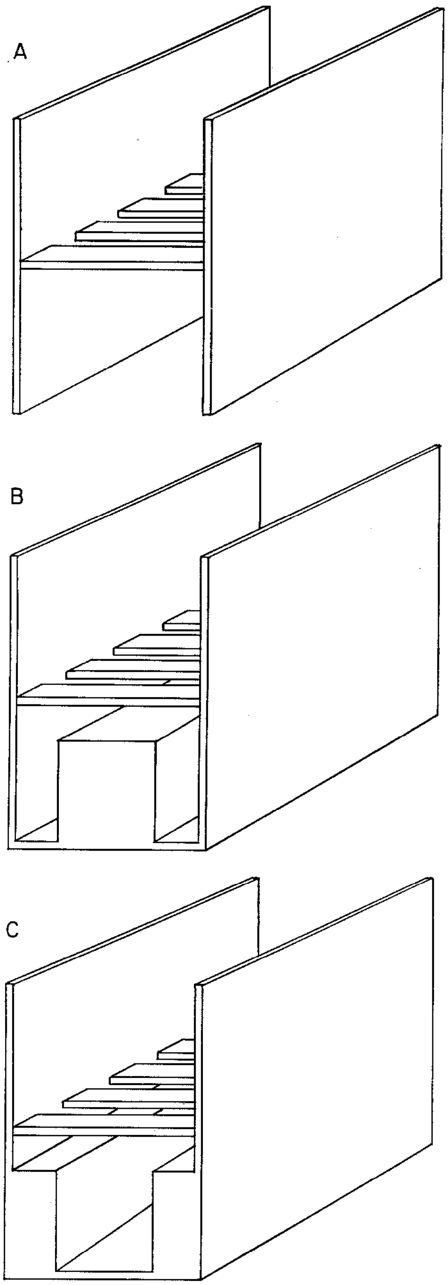

Figure 5—A, simple ladder structure; B, Karp structure; and C, Anti-Karp structure.

5.1. Narrow-Band Ladder Circuits

A very simple perturbation of the basic ladder has been described by White, et al. [16]. Here the slots extend over only a portion of the distance between the two planes, and this produces the dispersion curve *a* shown in Figure 6. The essential point is that a fundamental forward wave results and a negative space harmonic could be used in backward-wave operation. Unfortunately, the effective bandwidth is rather small, particularly at relatively low voltages (say below 10 kilovolts). This circuit is not therefore very attractive for our purpose, although it is probably a very good one for a narrow-band forward-wave tube operating at high voltages.

By far the most successful structure in the attainment of the highest powers at the shortest wavelengths has been that described by Mill-

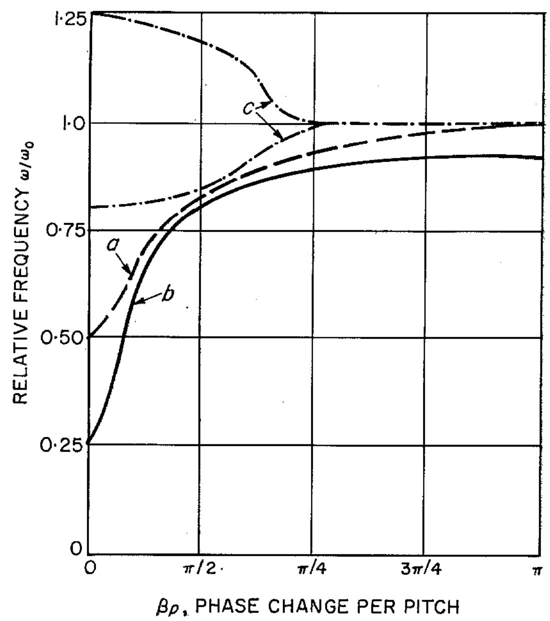

Figure 6—Dispersion curves for *a*, modified ladder; *b*, vane type; and *c*, crossed-wire circuit.

man [17], shown in Figure 7. This again is a very-simple modification of the basic ladder; in fact, it is half of such a ladder with the addition of a ground plane. Here it is the fringing field between the ends of the rungs and the ground plane that provides the perturbation that leads to the existence of a pass band. A typical dispersion curve is shown in *b* of Figure 6. Here again a backward space harmonic is required to provide backward-wave interaction. The available bandwidth is rather small—typically of the order of 10 per cent—but over a narrow band tubes using such a structure have given outputs of over 1 watt at a wavelength of 2 millimetres and have oscillated at wavelengths below 1 millimetre.

Yet another variant of the basic ladder is shown in Figure 8. Here the necessary perturbation has been obtained by skewing the rungs. If the rungs of a single ladder are skewed, very little pass band is obtained. However by utilizing two ladders with complementary angles of skew, a very-much-wider pass band is produced. This circuit was amenable to analysis, by using an approximate model in which the ladders are replaced by inhomogeneously conducting sheets. Using a variational method, the dispersion equation could be derived. A typical dispersion curve is shown in *c* of Figure 6. This circuit has both a forward as well as a backward fundamental mode. The existence of a backward fundamental mode means that the circuit will have a high interaction impedance when used in a backward-wave oscillator. Experiments at *X* band showed that oscillation over a 10-per-cent band was possible. These experiments were carried out with a very-weak electron beam in a demountable vacuum system. With a properly designed gun, somewhat greater bandwidths would result. The method of alternating the angle of skew can be extended to more than 2 circuits to form a larger multiple circuit. Analysis shows that this leads to some increase in the bandwidth. Experiments with up to 5 circuits and 3 beams carried out at *X* band demonstrated that multiple operation with this circuit was possible, and there appeared to be no difficulties with the excitation of spurious modes. These circuits have not yet been tried out at millimetre wavelengths, but it is felt that for a narrow-band multiple circuit they should provide a high performance.

5.2. Broad-Band Ladder Circuits

For a number of purposes, of which the provision of tubes suitable for a broadband waveguide communication system might be cited as an example, it would be very desirable to have an oscillator capable of covering a much-wider

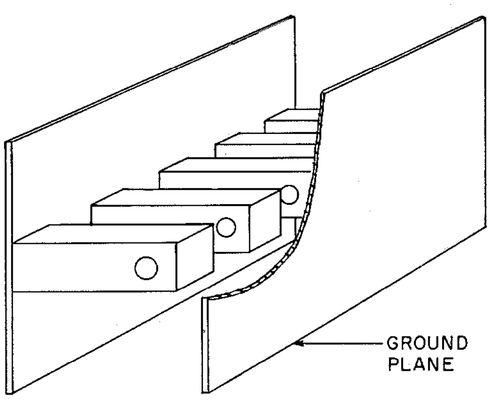

Figure 7—Vane-type circuit for narrow-band backward-wave oscillator.

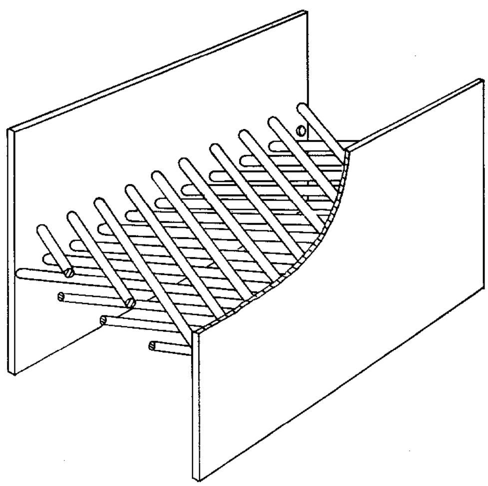

Figure 8—Crossed-wire circuit.

band than the circuits previously discussed. One circuit that will give such broad-band performance is the helix, but this has a very-poor thermal dissipation capability. A second possibility is the interdigital line, which is superior in this respect. However, this is mechanically very-much harder to make, and especially as there are free fingers that are not directly restrained, the necessary tolerances are difficult to attain.

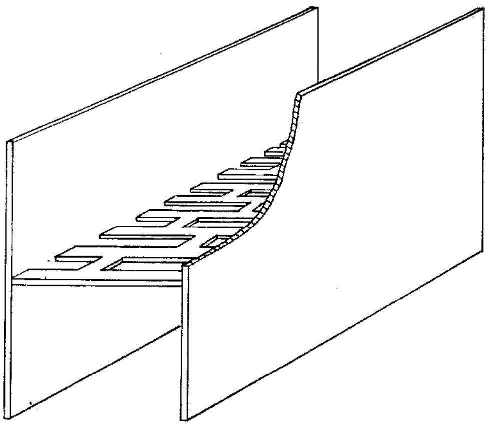

Figure 9—Stub-supported meander line.

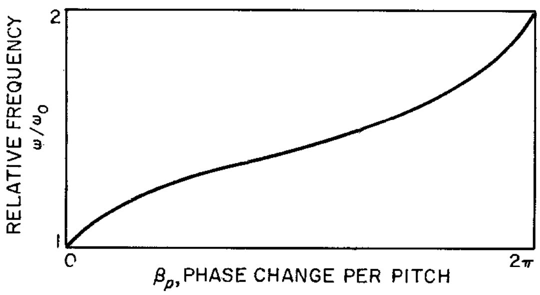

Figure 10—Dispersion curve of stub-supported meander line.

It therefore seemed desirable to devise an all-metal circuit in which all bars are directly connected to massive heat sinks and with no free ends. The circuit shown in Figure 9 was found to have many of the desirable properties. It was analyzed using the simplified field theory first suggested by Fletcher [6]. In this approach, the actual field is approximated by the superposition of a number of transverse electromagnetic waves travelling in the direction of the rungs, that is, at right angles to the direction of propagation of the slow wave. This analysis [18] led to dispersion curves such as that shown in Figure 10, which were in reasonable agreement with experiment except in the immediate vicinity of the cut-off frequencies. The discrepancies there are a result of the approximations in the theory.

The dispersion curve is seen to represent a forward fundamental mode, although here, as in the crossed-wire structure, a backward fundamental also exists. The most-important feature of this curve is that it extends without break over a complete octave. Naturally it is not possible to operate too near the cut-off frequencies, but nevertheless, in demountable experiments at X band, working on a backward space harmonic. an oscillation bandwidth of 1·7:1

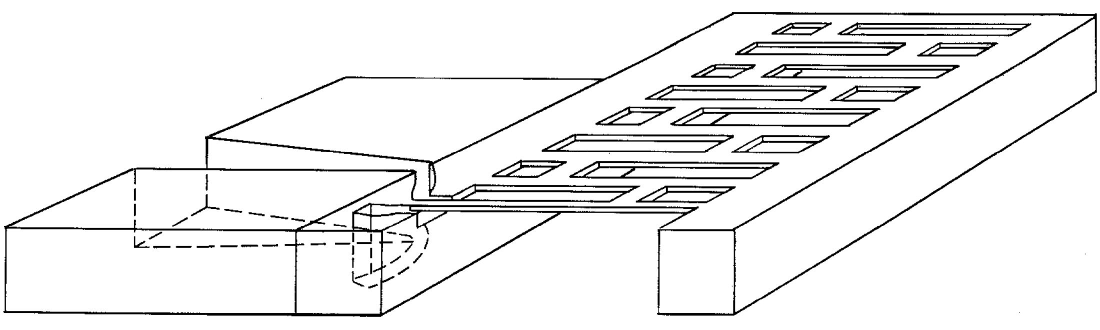

Figure 11—Stub-supported meander-line-to-waveguide transition.

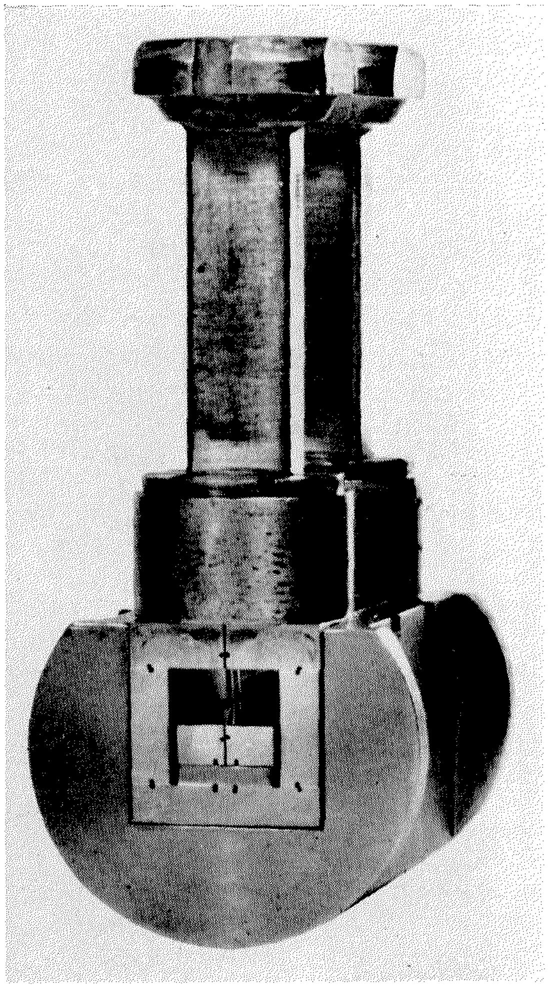

Figure 13—6-millimetre meander-line assembly with two waveguide transitions.

was measured. Here again the electron beam was very weak; in a suitably designed tube an even-wider bandwidth might be obtained.

The analysis enables one to predict how the impedance of this structure will vary with the thickness of the rungs of the ladder. To choose this dimension, it is now necessary to take account of how the losses, the importance of which has been stressed in Section 3, vary with thickness, and also to estimate the required thermal dissipation. Finally there is the question of whether for a particular design the required thickness can be realized in the construction. The thickness is severely limited with photoetching methods. However, the spark erosion technique permits the use of very-much-thicker ladders, and in most cases the optimum thickness for a particular design can in fact be adopted.

One of the main problems in attaining large bandwidths is the difficulty of matching the circuit to a waveguide. The essence of the method adopted is indicated in Figure 11 and the results obtained are shown in Figure 12. This very-broad-band match was achieved by utilizing the rapid variation in impedance of the output guide close to its cut-off frequency.

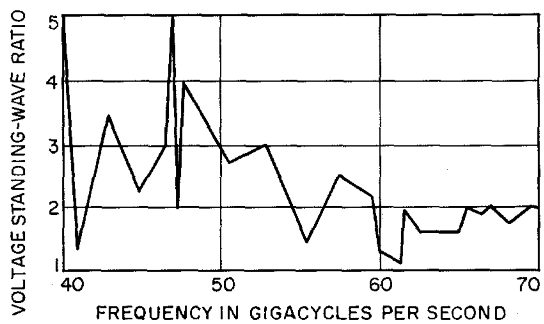

Figure 12—Typical measured performance of stub-supported meander-line structure.

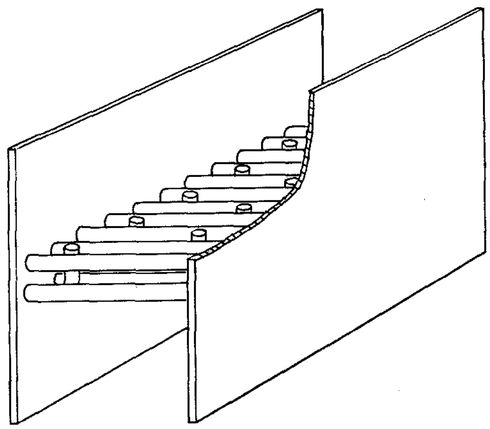

Figure 14—Double meander circuit showing stacked rod construction.

A circuit using this match has been incorporated in a backward-wave oscillator with a band centre at 6 millimetres. A photograph of parts of the assembly is shown in Figure 13.

The circuit of Figure 9 can be assembled into a multiple array in the manner indicated in Figure 3. There is, however, an alternative approach indicated in Figure 14 in which there is actual metallic contact between the various ladders. This will tend to increase the coupling, which is very desirable to ensure the phase coherence of the whole array. The circuit has a dispersion curve similar to that shown in Figure 10 but no hot experiments have so far been attempted.

6. Conclusions

The importance of attenuation as one characteristic that governs the choice of slow-wave circuits at millimetric wavelengths has been emphasized. Both the attenuation and the interaction impedance are inversely proportional to the group velocity. The choice of the group velocity is therefore a critical design decision; a method for choosing it so as to minimize the starting current, or alternatively so as to maximize the efficiency, is outlined.

The advantages of ladder structures for millimetric tubes are discussed, particularly with regard to their incorporation in a multiple array. Analysis has shown that a 4-ladder array should provide an output power at least an order of magnitude higher than that from a single ladder structure. The advantages of a number of specific ladder structures are compared. A particular variant, having an exceptionally wide pass band, has been studied in some detail, and a method of achieving a satisfactory match to an external waveguide is indicated.

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Eric A. Ash was born in Berlin, Germany, in 1928. He received from the Imperial College of Science, University of London, a B.Sc. degree in electrical engineering in 1948 and a Ph.D. degree in 1952 for work on electron interaction effects.

From 1952 to 1954, he was research assistant and later research associate at the Electronics Research Laboratory of Stanford University, in California. For one year he held a fellowship at the Nuclear Particle Laboratory, Queen Mary College, London University. In 1955, Dr. Ash joined Standard Telecommunication Laboratories, where he is now head of the high-frequency electron devices laboratory.

J. Froom was born in Rochdale, Lancashire, England, in 1920. He received B.Sc. degrees in engineering in 1942 and in physics in 1952 from the University of London.

From 1942 to 1946, he served with the Royal Air Force. He was with Mullard Research Laboratories from 1946 to 1957. He then joined Vickers Research Laboratory. Since 1960, he has done research on millimetre-wavelength travelling-wave devices at Standard Telecommunication Laboratories.

Mr. Froom is an Associate Member of the Institution of Electrical Engineers.

United States Patents Issued to International Telephone and Telegraph System; February–April 1962

Between February 1962 and April 1962, the United States Patent Office issued 54 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

B. Alexander, M. Press, and J. Murgio, ITT Laboratories, Collision Avoidance System, 3 025 514.

M. A. Argentieri and F. E. Lind, ITT Laboratories, Adjustable Delay Line, 3 020 497.

E. A. Ash and J. D. Pattenden, Standard Telecommunication Laboratories (London), Coupled Waveguides, 3 020 498.

R. W. Blanchard and G. M. Nonnemacher, ITT Laboratories, Automatic Visual Flight Information Display System, 3 029 304.

E. L. Bush, Standard Telecommunication Laboratories (London), Purification of Gases used in the Production of Silicon, 3 029 135.

K. W. Cattermole, Standard Telecommunication Laboratories (London), Electric Pulse Modulating and Demodulating Circuits, 3 020 349.

R. F. Chapman, ITT Laboratories, Automatic Gain Control System, 3 025 473.

P. Cheilik, Federal Telecommunication Laboratories, Transistor Multivibrator, 3 020 417.

W. Clement, Mix & Genest Werke (Stuttgart), Method of Sorting-Out Parts of Insulating Material, 3 020 409.

D. W. Davis, ITT Federal Laboratories, Information Storage Display Tube and Storage Screen Assembly Therefor, 3 031 597.

C. L. Day, Farnsworth Electronics Company, Method of Making Target Electrode for Barrier-Storage-Grid Tube, 3 020 622.

C. L. Day, ITT Laboratories, Method and Apparatus for Assembling Photo Tubes, 3 026 163.

K. De Brosse and E. Behun, ITT Laboratories, Cooling System, 3 025 680.

J. Donceel and M. Mus, Bell Telephone Manufacturing Company (Antwerp), Electrical Multiple Relay Unit Using Sealed Reed Contacts, 3 030 468.

J. J. Econom, L. F. Evans, and G. Reade, ITT Federal Laboratories, Feeding and Support Assembly, 3 028 943.

H. Endres, Mix & Genest Werke (Stuttgart), Automatic Character Recognition, 3 025 495.

R. C. Ferrar, Federal Telecommunication Laboratories, Signal-Level-Recording Receiver, 3 029 336.

A. N. Gulnick and R. K. Van Vechten, ITT Laboratories, Tape Transports, 3 029 006.

W. H. Heiser, Federal Telecommunication Laboratories, Frequency-Controlled Switch, 3 029 310.

R. A. Hill, Standard Telecommunication Laboratories (London), Electrolytic Capacitors, 3 029 370.

R. C. P. Hinton, Federal Telecommunication Laboratories, Party-Line Detector Connector, 3 029 314.

G. Hirschfeld, W. Hinz, and H. Fritzsche, Mix & Genest Werke (Stuttgart), Sorting Equipment, 3 029 944.

G. D. Hulst, Federal Telecommunication Laboratories, Reflected-Binary-Code Counter, 3 020 481.

S. M. Khanna and M. C. Vosburgh, ITT Laboratories, Radar Mapping Simulator, 3 028 684.

G. F. Klepp, Standard Telephones and Cables (London), Electric Discharge Tube, 3 029 364.

H. E. Krefft, Kuthe Laboratories, Cathode Structure, 3 025 428.

E. J. Leonard, ITT Kellogg, Multidigit Electrical Door Lock, 3 024 452.

M. Losher, Federal Telecommunication Laboratories, Radio Navigation System, 3 020 545.

L. F. Mayle, ITT Federal Laboratories, Dynamic Focusing, 3 021 073.

A. E. Nashman, ITT Laboratories, Vehicle Suspension and Stabilizing System, 3 029 089.

S. B. Ost and B. Dzula, Federal Telecommunication Laboratories, Party-Line Substation Identification System, 3 025 354.

M. Padalino, ITT Laboratories, Signal Identification System, 3 025 352.

W. H. P. Pouliart and G. Van Mechelen, Bell Telephone Manufacturing Company (Antwerp), Sorting Machine, 3 028 958.

W. H. P. Pouliart and G. Van Mechelen, Bell Telephone Manufacturing Company (Antwerp), Sorting Machine Using Markers, 3 028 961.

A. J. Radcliffe, Jr., M. Ribner, and W. V. Sayner, ITT Kellogg, Relayless Line Circuit, 3 029 315.

L. J. Regis and W. E. Richeson, Jr., Farnsworth Electronics Company, Voltage Comparator, 3 021 514.

A. G. Richardson, ITT Federal Laboratories, Magnetic Recording and Reproducing Apparatus, 3 020 358.

D. S. Ridler and A. D. Odell, Standard Telecommunication Laboratories (London), Intelligence Storage Equipment, 3 020 526.

W. L. Roberts and E. De Faymoreau, ITT Federal Laboratories, Strobing Circuit, 3 030 620.

M. Rogoff, Federal Telecommunication Laboratories, Phase-Measuring Device, 3 020 478.

H. W. G. Salinger, ITT Laboratories, Image Intensifier, 3 030 514.

P. C. Sandretto, Federal Telecommunication Laboratories, Loran Receiver, 3 025 518.

R. G. Schriefer, Capehart-Farnsworth, Automatic Tracking System, 3 020 537.

W. Sichak, ITT Federal Laboratories, Sideband Generator, 3 029 396.

W. Sichak, ITT Laboratories, Diversity Combining System, 3 029 338.

K. J. Staller, ITT Laboratories, High-Current Rectifier, 3 025 436.

F. Steiner, C. Lorenz, Doppler-Type Direction-Finder, 3 025 522.

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E. P. G. Wright and J. Rice, Standard Telecommunication Laboratories, Equipment for Performing a Complex Sequence of Operations, 3 025 351.

E. P. G. Wright and J. Rice, Standard Telecommunication Laboratories, Intelligence Storage Equipment, 3 024 993.

E. P. G. Wright and J. D. Reynolds, Standard Telecommunication Laboratories, Static Electric Switches, 3 024 448.

E. P. G. Wright, Standard Telecommunication Laboratories, Data-Processing System, 3 020 336.

E. P. G. Wright, D. A. Weir, R. C. Price, and B. Dzula, Standard Telecommunication Laboratories and Federal Telecommunication Laboratories, Data Processing Systems, 3 025 341.

J. Young, Bell Telephone Manufacturing Company (Antwerp), Sorting Machine, 3 019 896.

Data-Processing Systems

3 020 336

E. P. G. Wright

This patent concerns the receiving matrix for the Strad switching system. It provides for a signal store for each line, common central apparatus for all lines, and a plurality of central stores. Apparatus controlled by a signal on a line causes a scanning of the stores and sequential transfer of information from an incoming line to an outgoing line.

Data-Processing Systems

3 025 341

E. P. G. Wright, D. A. Weir, R. C. Price, and B. Dzula

For the Apogee switching system, this patent covers the main storage equipment, the transfer of messages to the main store in accordance with an established precedence of the messages and in the order of their arrival, and their transfer to the outgoing store. Means are provided with control to transmit the messages over their selected outgoing lines in accordance with their precedence and order of their storage in the incoming line stores.

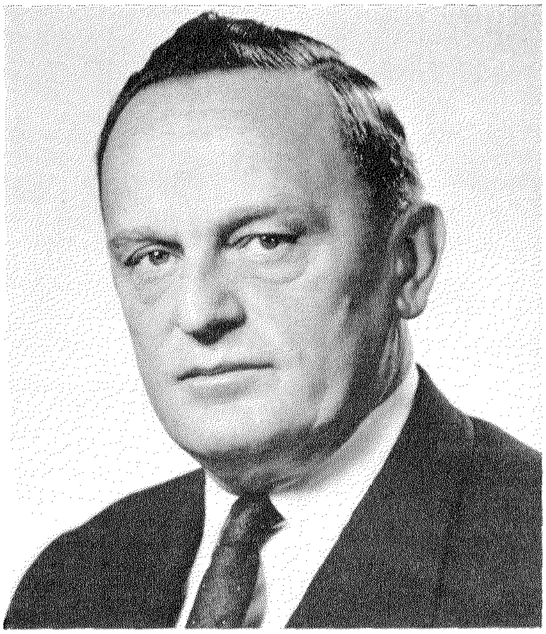
Sorting Machine

3 028 958

W. H. P. Pouliart and G. Van Mechelen

For collating documents, a sorting machine having only two sorting stages has been developed. The articles being sorted are compared and directed to one of two outputs in accordance with their rank. The outputs of each stage become the two separate inputs of the other stage. This enables the two stages to provide as many sorting passes as may be required.

In Memoriam



WILLI GRUBE

Willi Grube, member of the board of directors of Standard Elektrik Lorenz and general manager of the Mix & Genest Division, died unexpectedly on his 63rd birthday, 8 December 1962.

He was born in Bremen, Germany, received the Dr.-Ing. degree from the Berlin Institute of Technology, and then served at this Institute as an assistant for ten years, until 1934. In the years following, he was a member of the signal corps of the armed forces.

He joined Mix & Genest in 1947, during which year he became manager of the technical office in Hamburg and then manager of government sales. In 1950, he was promoted to director and two years later was elected to the board of directors of Mix & Genest and entrusted with the sales management of the company.

In 1954, he was appointed to the board of directors of Standard Elektrik Lorenz. In 1959, he became general manager of the Mix & Genest Division and manager of domestic sales of Standard Elektrik Lorenz. He contributed essentially to the rise of Standard Elektrik Lorenz to its present position in the telecommunications field.

His contributions were not limited to Standard Elektrik Lorenz. A large number of committees and organizations profited from his extensive experience and sound advice. He was for many years a member of the Board of Chairmen of the Association of Telecommunication Industries within the Central Federation of the Electrotechnical Industry (ZVEI), and was elected chairman at the last membership meeting.

Dr. Willi Grube will be remembered for his pre-eminent personality and his dedication to his work.

Principal ITT System Products

Telecommunication 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
Long-distance dialing and signaling equipment
Automatic message accounting and ticketing equipment
Switchboards: manual, central office, toll
Telephones: desk, wall, pay-station
Automatic answering and recording equipment
Microwave radio systems: line-of-sight, over-the-horizon
Radio multiplex equipment
Coaxial cable systems
Submarine cable systems, including repeaters
Data-transmission systems
Teleprinters and facsimile equipment

Military/Space Equipment and Systems

Aircraft weapon systems
Missile fuzing, launching, guidance, tracking, recording, and control systems
Missile-range control and instrumentation
Electronic countermeasures
Electronic navigation
Power systems: ground-support, aircraft, spacecraft, missile
Radar
Simulators: missile, aircraft, radar
Ground and environmental test equipment
Programmers, automatic
Infrared detection and guidance equipment
Global and space communication, control, and data systems
Nuclear instrumentation
Antisubmarine warfare systems
System management: worldwide, local

Industrial/Commercial Equipment and Systems

Distance-measuring and bearing systems: Tacan, DMET, Vortac, Loran
Instrument Landing Systems (ILS)
Air-traffic control systems
Direction finders: aircraft and marine
Ground and airborne communication
Data-link systems
Inverters: static, high-power
Power-supply systems
Altimeters
Flight systems
Railway and power control and signaling systems
Information-processing and document-handling systems
Analog-digital converters
Mail-handling systems
Pneumatic tube systems
Broadcast transmitters: AM, FM, TV
Studio equipment
Point-to-point radio communication
Marine radio
Mobile communication: air, ground, marine, portable
Closed-circuit television: industrial, aircraft, and nuclear radiation
Slow-scan television
Instruments: test, measuring
Oscilloscopes: large-screen, bar-graph
Vibration test equipment
Magnetic amplifiers and systems
Alarm and signaling systems
Telemetering
Intercommunication, paging, and public-address systems

Consumer Products

Television and radio receivers
High-fidelity phonographs and equipment
Tape recorders
Microphones and loudspeakers
Refrigerators, freezers
Air conditioners
Hearing aids
Incandescent lamps
Home intercommunication equipment
Electrical housewares

Cable and Wire Products

Multiconductor telephone cable
Telephone wire: bridle, distribution, drop
Switchboard and terminating cable
Telephone cords
Submarine cable
Coaxial cable, air and solid dielectric
Waveguides
Aircraft cable
Power cable
Domestic cord sets
Fuses and wiring devices
Wire, general-purpose

Components and Materials

Power rectifiers: selenium, silicon
Parametric amplifiers
Transistors
Diodes: tunnel, zener, parametric
Semiconductor materials: selenium, germanium, silicon
Capacitors: wet, dry, ceramic
Ferrites
Tubes: power, transmitting, traveling-wave, rectifier, receiving, thyratron
Picture tubes
Relays and switches: telephone, industrial
Magnetic counters
Resistors
Varistors
Fluorescent starters
Transformers
Quartz crystals
Crystal filters
Printed circuits
Hermetic seals
Magnetic cores

VOLUME 38 • NUMBER 2 • 1963