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This Issue in Brief

Paris Network and Numbering Plan—The Paris telephone network uses 7-digit dialing while the provinces use 6 digits. A single digit is added to Paris and 2 digits to provincial numbers to obtain national numbers, both then having 8 digits. A 2-digit code for access to the national network results in 10 digits for placing calls over that network.

There are 4 switching areas, urban, suburban, Regional 1, and Regional 2, extending progressively from the center of the city. Transit centers are provided to handle calls from one switching area to another, 4 serving the suburban and 2 the regional areas. Where traffic warrants, direct trunks are provided to reduce the load on the transit centers. A special outgoing center handles calls from the urban to Regional 2 areas.

By dialing *16*, access is had to a national register, with a second dial tone, for placement of national calls. Similarly, international calls require dialing *19* for access to an international register, also with a second dial tone.

Introduction of Pentaconta Switching in Paris—

The present automatic telephone network in Paris employs rotary switching, pulse dialing and pulse signaling between central offices, and a charging system in which a train of pulses related to the distance between stations is sent to the subscriber's meter every 3 minutes.

The inauguration in 1964 of 2 new central offices has started the conversion of the entire network to Pentaconta crossbar switching, multifrequency code signaling between offices, and charging in which an initial train of pulses will correspond to distance and following pulses will be at time intervals inversely related to distance. Pulse dialing will be retained.

The new Pentaconta switching offices are equipped with all necessary conversion units for interworking with existing rotary exchanges, transit centers, and other Pentaconta offices that will be placed in operation. No changes are required in the existing network. Circuits and

junction diagrams to provide for these interfaces are described.

Pentaconta System Remote Line Units—Remote line-selection units with a capacity of 1040 subscriber lines are connected to the parent exchange over only 113 pairs and allow for a total traffic of 0.066 erlang per subscriber line. Power for the talking circuits may be provided at the remote unit or from the parent exchange. There are 2 stages of switching in the remote units. Switching signals are transmitted over 5 wires in a 2-out-of-5 code. All facilities available at the parent exchange are also available at the remote units.

Pentomat T Private Automatic Branch Exchange

—This private automatic branch exchange is based on Pentaconta crossbar switches, sealed reed relays, and electronic components, such as code receivers and converters, that permit push-button as well as dial signaling. A medium-size exchange suitable for between 20 and 400 extensions is described. A traffic capacity of 10 erlangs is provided for each 50 lines.

Indirect control permits all but the equipment in the speech circuit to be released after a call is established. Any abnormal delay in dialing a busy or dead called number, improper class of service, or failure to return the handset to the cradle results in line lockout in which busy tone is supplied by the line circuit and the switching train is released.

Direct inward dialing, conference connections, break-in on a busy line by authorized lines and by the operator, automatic queueing to reach a busy line, paging a called subscriber who does not answer, direct operator call-back by pressing a button, holding and transfer of calls, and connection to a central dictation service are available.

Flexible Routing Plans—There is a demand for more-flexible routing facilities in national and international networks.

In national networks, inefficiency is often due to the slow switching and signalling systems that have been installed. In international networks, long east-west circuits have an unremunerative day/busy-hour ratio on account of time differences, and administrations are naturally anxious to find more-flexible routing plans that will ensure more revenue from very expensive circuits.

The preferred method of approach is to use a separate signalling channel to transmit supervisory signals, and such an arrangement offers the possibility of almost an unlimited number of signals.

The use of a separate signalling channel demands that the signals carry some form of identity number so that those relating to the same call may be associated together. Identity numbers can assist substantially in the provision of more-flexible routing because they can be used to control the extent of advisable overflow, and they can also be used for tracing the route used.

Sensitivity Coefficients as Criteria for Noise in Telecommunication Lines—As noise induced in telecommunication lines from power lines covers a wide frequency band, psophometric measurements are made to evaluate its disturbing effects.

Magnetic-field and electric-field coupling from power lines to transposed and nontransposed telecommunication lines that are either capacitance balanced or unbalanced to ground are considered. Equations are developed for coefficients of sensitivity to disturbance from each field.

Measurements were made on an open wire line 4.3 miles (7 kilometers) long. Disturbing signals were injected into the center of the line to simulate pickup from a parallel disturbing line.

For an electric field the transposed line is much less sensitive to disturbance than is a nontransposed line. Although sensitivity for a magnetic field is substantially less than for an

electric field, the nontransposed line is slightly less sensitive than the transposed line. For the same capacitance unbalance to earth, the electric field produces much more disturbance than does the magnetic field.

Measurement of Magnetic Properties of Thin Films—The properties of magnetic thin films with induced anisotropy have given rise to various phenomenological theories. The Kondorsky, the Stoner-Wohlfarth, and the Shtrikman-Treves theories are examined. These three models make it possible to define the static or quasi-static properties of the material in the form of a critical stability curve but do not take into account their dynamic behavior.

The astrometer is an apparatus that enables us to directly plot the critical curve of the material on the screen of a cathode-ray tube. The operation of this device is analyzed on the basis of the Stoner-Wohlfarth theory.

Magneto-Optic Astrometer for Measurement of Magnetic-Thin-Film Memories—This apparatus, based on the same principle as the standard astrometer, directly plots the critical switching curve of thin magnetic films. The detection device uses the Kerr magneto-optic effect, a theoretical review of which is given. The optical probe causes no disturbance and its small size permits a detailed analysis of the characteristics of the film for very-close points.

Expanding Global Submarine-Cable Network—The potential revenue from high-quality reliable telecommunications between two countries trading with each other will conservatively amount to 0.5 percent of their trade volume.

High-frequency radio systems are most economical for global communication but there are not enough usable channels to meet the needs. Repeated submarine cables have demonstrated their ability to provide high-quality reliable circuits over global routes, and present rates permit recovering capital investment within 5

years. Traffic is growing at about 20 percent per annum.

Submarine-cable development and future trends are outlined. A number of short-haul repeatered coaxial submarine cables were installed in the decade before the first transatlantic telephone cable was laid in 1956. Its original 36 channels have been increased through additional cables and Time Assignment Speech Interpolation to the present 528 channels across the Atlantic. The other oceans have also been spanned and Europe may now talk via North America with Japan, Singapore, Australia, and New Zealand.

Submerged Repeater for the Commonwealth 160-Circuit Cable—The capacity of the Australia to New Guinea to Guam sections of the British Commonwealth submarine-cable telephone system was doubled to 160 circuits of 3 kilohertz each over the 80 circuits provided in the Atlantic, Pacific, and Southeast Asia networks. The design of the required wider-band repeaters was based on those for the 80-circuit system.

As a limiting design for a hypothetical system of 3000 nautical miles (5600 kilometers), a frequency band from 60 to 1200 kilohertz,

repeater gain of 50 decibels, and using coaxial submarine cable 0.99 inch (25.15 millimeters) in diameter, an average repeater spacing of 16.2 nautical miles (30 kilometers) is required, calling for 185 repeaters and 18 equalizers. Psophometrically weighted noise must not exceed 1.85 picowatts per nautical mile (1 picowatt per kilometer) averaged over all circuits.

For the repeater design selected, the 6.25-kilovolt rating of the capacitors in the power-separating filters limits the maximum voltage across the system to 12.5 kilovolts, half of which is applied at each terminal. With 86 volts across each repeater and 21 volts for the interconnecting cable lengths, only 117 repeaters may be used. The frequency bands assigned for supervisory signals further limited the system to 110 repeaters and a total cable length of 1780 nautical miles (3300 kilometers).

For supervision a carrier generator at one terminal sweeps over a frequency band and a filter in each repeater selects only its frequency. Simultaneously a band of noise generated near 612 kilohertz or a test signal at 720 kilohertz modulates the carrier sent to each repeater. The required sideband is returned to the supervisory terminal via the supervisory return circuit for noise and loop gain measurements, respectively.

Paris Network and Numbering Plan

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Compagnie Générale de Constructions Téléphoniques; Paris, France

R. MUGNIER

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1. Introduction

At the present time, the Paris network is the world's largest telephone area using the rotary switching system. The network is now being further developed with the addition of the Pentaconta* crossbar system.

The problems posed by the introduction of a new system can be clearly understood only if one is familiar with the present routings. The aim of this paper is to explain briefly the composition of the Paris area and its operation.

2. Paris Network As a 7-Digit Area

For a clear understanding of the routings handled in this network, it is helpful to have some familiarity with the methods of numbering used in France.

2.1 LOCAL NUMBER

All subscribers of the French network connected to an automatic exchange have local numbers with letters and numerals arranged as follows: 6 digits, *LLNNNN*, in the provinces, and 7 digits, *LLLNNNN*, in the Paris area.†

2.2 NATIONAL NUMBER

All subscribers connected to the automatic interurban network have national numbers composed of their local number preceded by an interurban code as follows: 2 digits, *LL*, in the provinces, or 1 digit (numeral 1) in the Paris network.

Thus, the national number of a subscriber always has 8 digits, either *LLLLNNNN* or *1LLLNNNN*. All subscribers having a national number with the same interurban code constitute a dialing area within which they can

call each other by setting up the 6- or 7-digit local number. The Paris area forms a 7-digit dialing area.

When two subscribers belong to two distinct dialing areas, they use the national number for calling each other and dial 10 digits, that is, the 2-digit access code to the national network, *16*, followed by a second dial tone, and then the 8 digits of the national number.

3. Territorial Organization

The Paris network is divided into 4 areas:

(A) Urban area, which corresponds to the city of Paris.

(B) Suburban area, which includes the nearby suburbs.

(C) Regional Area 1, which extends beyond the suburban area out to approximately 6 miles.

(D) Regional Area 2, which includes the balance of the 7-digit dialing area.

The urban Paris area, which is 100-percent automatic, comprises about 620 000 lines; the suburban area, also 100-percent automatic, about 235 000 lines (as of the middle of 1964); and Regional Area 1, which is 75-percent automatic, includes 135 000 lines (See Figures 1 and 2).

Regional Area 2, although considered from the viewpoint of dialing to be an integral part of the Paris network, is quite independent because of its remoteness. It must be reached through particular transit centers by means of the automatic interurban code. The signaling used for sending digits in this case is the French single-frequency system.

4. Routing of Calls (See Figures 2 and 3)

4.1 BETWEEN URBAN EXCHANGES

Direct lines are used for interconnecting two urban exchanges without using transit centers.

* Registered trademark of the International Telephone and Telegraph Corporation.

† *L* = the digits 2 through 9; *N* = the digits 0 through 9.

Paris Network and Numbering Plan

4.2 BETWEEN URBAN AND SUBURBAN EXCHANGES

The exchanges of the suburban area are connected to 1 of 4 transit centers: Carnot (1), Diderot (2), Nord (3) or Vaugirard (4).

In theory, calls between urban and suburban

exchanges are routed via the transit center to which the suburban center belongs. However, because of the increase in traffic between urban and suburban centers, many direct connections have been made between these two types of offices to reduce the load on the transit centers.



Figure 1—Paris urban and suburban telephone areas.

4.3 BETWEEN 2 SUBURBAN EXCHANGES

Theoretically, the routing of a call between 2 suburban exchanges makes use of the transit centers to which these offices are connected. This may involve 2 transit centers or a common transit center if they are tied to the same one. In practice, however, suburban offices have direct connections to all 4 transit centers to simplify this type of operation.

4.4 BETWEEN URBAN OR SUBURBAN EXCHANGES AND AUTOMATIC REGIONAL 1 EXCHANGES

Using tandem operation, the 5th transit center shown in Figure 2 handles the routing of calls from urban and suburban exchanges toward Regional Area 1, while another, the 6th, which is an exact replica of the 5th, handles calls from Regional Area 1 to urban and suburban areas.

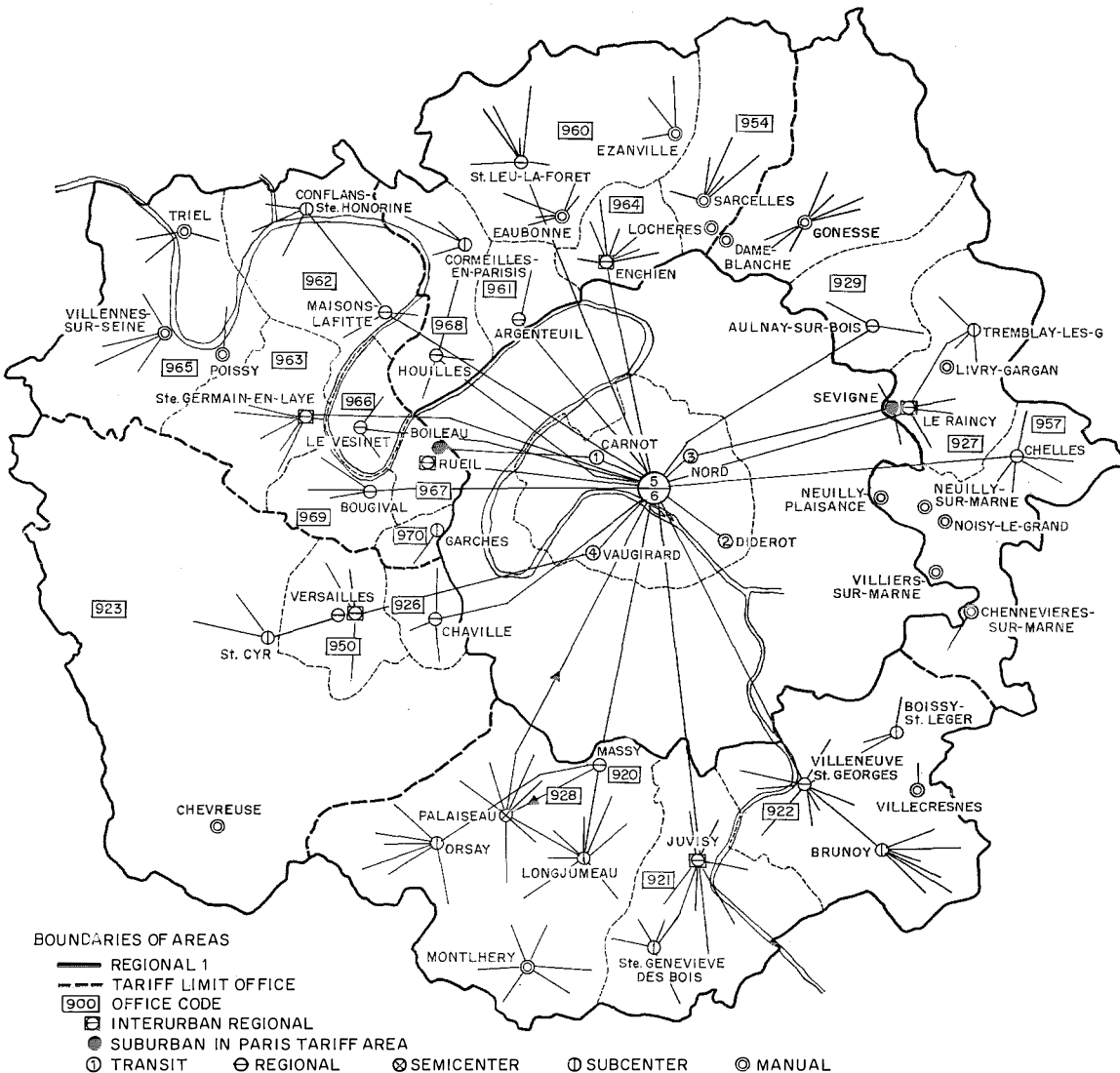


Figure 2—Paris Regional Area 1.

Paris Network and Numbering Plan

An evolution, similar to that which took place in the suburban area centers, is now affecting the Regional Area 1 centers between urban or suburban offices and regional centers, in that direct connections are being used when traffic justifies it.

4.5 BETWEEN REGIONAL 1 EXCHANGES

Normal routing between Regional Area 1 offices is through transit center 5 but direct connections are used between adjacent offices.

4.6 BETWEEN URBAN OR SUBURBAN EXCHANGES AND AUTOMATIC REGIONAL 2 EXCHANGES

Calls from Paris to Regional Area 2 are routed through a special outgoing center called "2FR." The national interautomatic code (French single-frequency system) is used between 2FR and Regional Area 2 exchanges.

4.7 BETWEEN REGIONAL 1 AND AUTOMATIC REGIONAL 2 EXCHANGES

Calls between Regional Areas 1 and 2 normally pass through two transit exchanges, the 6th transit center, and then the 2FR.

4.8 BETWEEN AUTOMATIC REGIONAL 2 EXCHANGES AND URBAN OR SUBURBAN EXCHANGES

Like interurban calls, those between Regional Area 2 and urban or suburban exchanges arrive at the incoming tandem exchanges (Dabout, Vaugirard, Bonne Nouvelle) in the automatic interurban code and are then routed to the proper urban and suburban exchanges either directly or through 1 of the 4 urban transit centers.

4.9 BETWEEN AUTOMATIC REGIONAL 2 EXCHANGES AND AUTOMATIC REGIONAL 1 EXCHANGES

Calls between automatic Regional Area 2 and Regional Area 1 exchanges also arrive at the

incoming tandem exchanges mentioned in Section 4.8 and, by means of the 5th transit center, are routed to Regional Area 1.

4.10 MANUAL EXCHANGES

To use a manual exchange in the Paris Regional Areas (1 or 2), the subscribers of the urban and suburban Paris areas dial 11. These calls are handled by an operator of the manual regional office Poissonniere that routes the call. Subscribers of the manual regional centers obtain their outgoing or incoming calls through the regional interurban centers.

4.11 NATIONAL AND INTERNATIONAL CALLS (SEE FIGURE 3)

4.11.1 Automatic Outgoing

A national interurban center, the CIAD (automatic interurban outgoing center) handles all outgoing nationwide calls of the Paris network; these calls involve a second dial tone. By dialing 16, the subscriber's call is routed to the CIAD, where a national register sends the subscriber the dial tone requesting the national number, then the CIAD controls the establishment of the call.

Since November 1964 the CADET exchange (automatic outgoing center to foreign countries), a Pentaconta installation, has handled outgoing automatic international traffic by means of a special access code, 19, followed by a second dial tone. Its operation is similar to that of CIAD.

4.11.2 Manual Outgoing

Three interurban centers, Archives, Poissonniere, and Bonne Nouvelle, each handling an area of France, route calls of Paris network subscribers. (Archives also handles manual international calls.)

The subscriber reaches the interurban center by dialing 10 (prefix of the manual exchange)

followed, after a second dial tone, by an *LL* prefix indicating the desired province. In the urban offices and the suburban transit offices a special link, with a regional recorder, routes the call toward the manual interurban operators who handle the called area.

4.11.3 *Automatic Incoming*

There are four automatic tandem exchanges for incoming calls: Dabout, Vaugirard, Bonne Nouvelle, and the CINAT (international and

national transit and incoming center, a Pentaconta installation). These centers route calls toward subscribers of the Paris network through special interurban links.

4.11.4 *Manual Incoming*

Manual incoming traffic is handled by the incoming manual tandem centers, Archives and Poissonniere. The operators call the Paris network subscribers through a direct selection circuit and interurban inward connections.

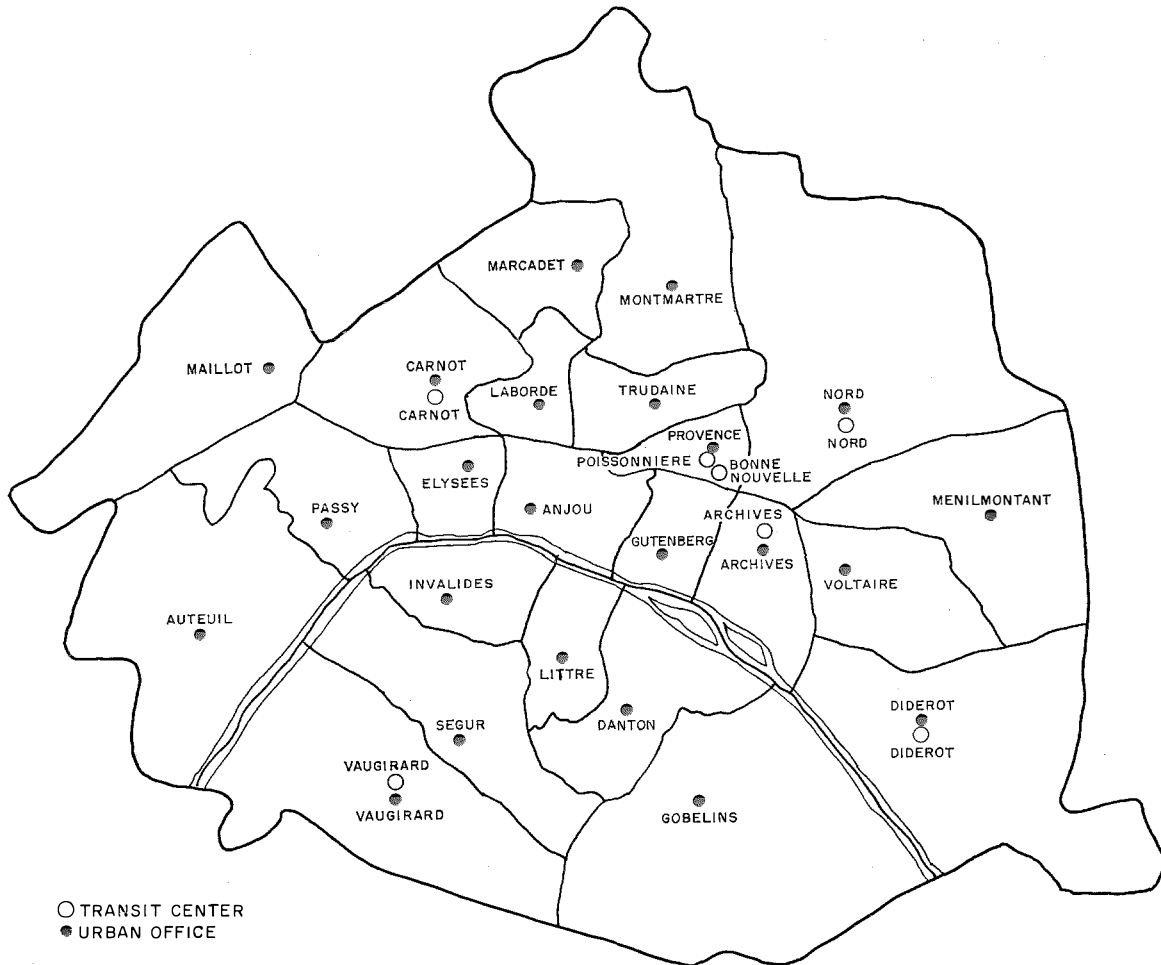


Figure 3—Transit centers of the Paris network.

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5. Future Development

The development of the Paris network is characterized on the one hand by the adoption of the crossbar system as a new component of its exchanges, and on the other hand by the installation of new transit centers to provide for increasing automation of national and international traffic.

5.1 URBAN TRAFFIC

A new urban transit center will be installed to the southwest of Paris in a new building located in the Gobelins exchange area (see Figure 3). Its functions will be similar to those of the 4 existing offices but it will be specially designed to deal with the interconnection of

Pentaconta-to-Pentaconta systems, rotary-to-Pentaconta systems, and vice versa.

5.2 REGIONAL TRAFFIC

The routing center for outgoing calls toward Regional Area 2 will be duplicated by a second center designed to work with the rotary and Pentaconta systems. It has been designated as CESAR (CEntre Sortant Automatique Régional).

5.3 NATIONAL OUTGOING TRAFFIC

A second extension automatic urban center, called Diane, will duplicate the present CIAD. National outgoing traffic will be divided between these two exchanges.

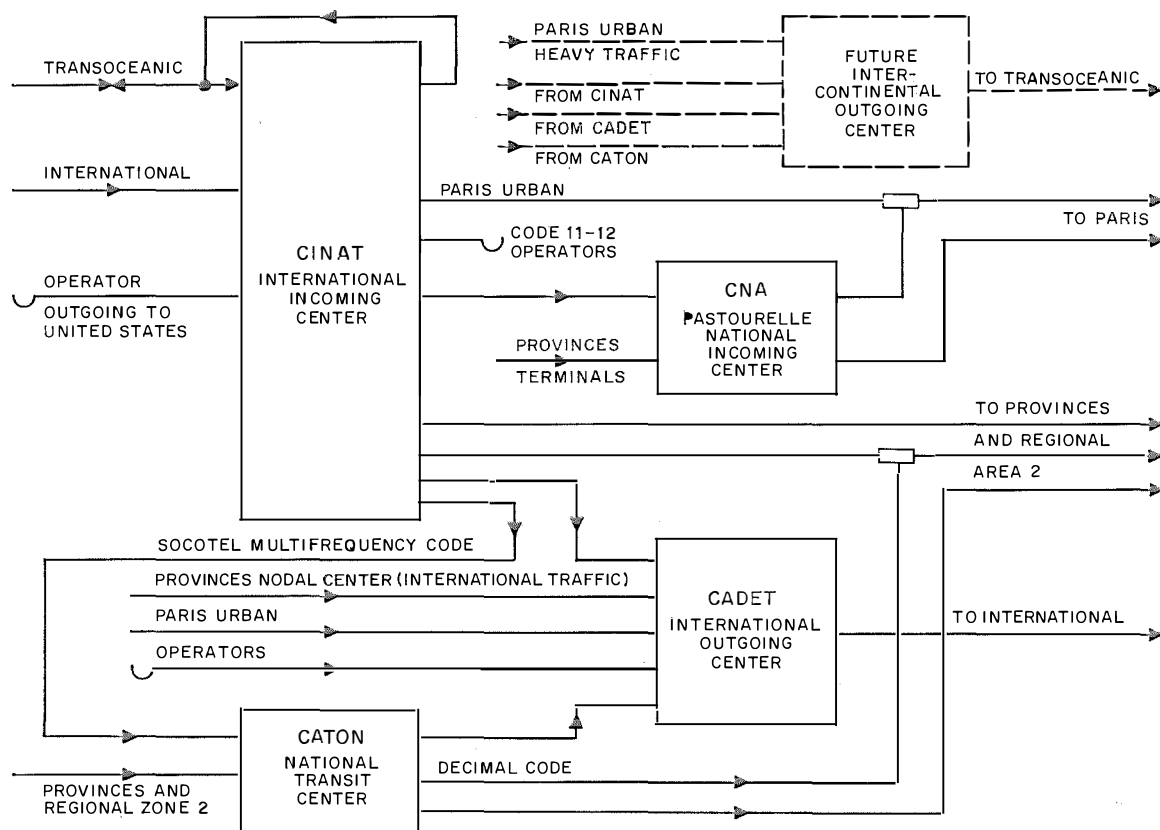


Figure 4—General diagram of interurban transit network.

5.4 NATIONAL AND REGIONAL INCOMING TRAFFIC

The incoming centers Dabout and Vaugirard being at the limit of their capacities, an incoming center with 6000 incoming circuits will handle calls to the urban area by means of 6000 auxiliary lines.

5.5 NATIONAL TRANSIT TRAFFIC AND INTERNATIONAL TRAFFIC

Because of the steady increase in international traffic, the CINAT will specialize in international transit calls and the incoming Paris area traffic. To handle its present national transit function a new center, called CATON, will be put into service. This will result in a rearrangement of the CADET office.

In addition, the installation of a special center for intercontinental traffic is being considered. Figure 4 shows the interconnection of these various exchanges, all installed in the Pastourelle building, and indicates the routings that are handled there. All of the above new transit centers are now being studied and they will be placed in service, by successive stages, before 1970. The Pentaconta system, adapted to interurban traffic, is the common basis for all of these new automatic exchanges.

Jacques P. Basset was born in Lyons, France, on 16 October 1925. He received an engineering degree from the Institut Électrotechnique de Grenoble.

In 1954, he joined the Compagnie Générale de Constructions Téléphoniques to develop circuits for the Pentaconta system. Since 1964, he has been in charge of the switching development department for the Pentaconta system.

6. Conclusion

This brief account gives some idea of the complexity of the routings for a network as dense as that of Paris. As the introduction of new developments progresses, the concept of such a network becomes increasingly complicated. When it was decided to introduce the Pentaconta system into the Paris area, the first step was a complete review of the situation as outlined above. Only after this analysis was made could the execution be started, including diagrams of the new exchanges, development of means of signaling between old and new systems, and so on. These studies have resulted in complete compatibility between two different equipments working together in the same telephone area.

7. References

1. M. Lacout and M. Mauge, "Système Pentaconta, Signalisation (CINAT)," *Commutation et Électronique*, number 6, pages 116-141; April 1964.
2. M. J. Jacquet, A. J. Henquet, and H. van Deth, "Système Pentaconta, Le Centre International et National d'arrivée et de transit (CINAT)," *Commutation et Électronique*, number 7, pages 80-108; October 1964.

Roger Mugnier was born in Chalon-sur-Saône, France, on 4 November 1934. In 1958 he received a degree from École Supérieure des Télécommunications of Paris.

In 1958 he joined Le Matériel Téléphonique and worked on the application of Pentaconta crossbar switching to the modernization of the Paris telephone network. Since 1963 he has been in charge of the switching department.

Mr. Mugnier is a member of the Société Française des Électroniciens et Radioélectriciens.

Introduction of Pentaconta Switching in Paris

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1. Introduction

The first 2 Pentaconta* telephone exchanges introduced into the Paris network: Chenier, installed by Compagnie Générale de Constructions Téléphoniques, and Gounod, installed by Le Matériel Téléphonique, were cut over on 21 January 1964. These exchanges, located in the suburban areas of Paris, were followed on 20 May 1964 by the cutover of another at Aulnay-sous-Bois, in Regional Area 1.

The implementation of these exchanges marks the beginning of the modernization of the Paris network, which involves the adoption of new switching and interoffice signaling systems, Pentaconta crossbar [1] and Socotel † multi-frequency code [2]. This paper explains how the old [3] and new systems were interconnected and describes the means developed for bridging this interface.

* Registered trademark of International Telephone and Telegraph Corporation.

† Socotel indicates an association of French telecommunication manufacturers and the Post and Telecommunications Administration called Société Mixte d'Étude de Commutation Téléphonique.

2. Rotary Office Interconnection

2.1 ROUTING A CALL

Let us take, for example, a call that originates at a rotary exchange and is directed to another rotary exchange through a suburban transit center. (See Figure 1.)

When the calling subscriber lifts his handset, he initiates a 2-stage conditional search (primary and secondary finders) that results in connection to a register. The latter receives and stores the number of the called subscriber. This register first controls a primary selector (and, in some instances, a secondary selector), the control of which follows code translation by the outgoing office. The call is then directed to a junction toward that suburban transit center serving the desired office. The register sends, in addition, selection digits, also translated at the transit center, to ensure that the call will reach a junction connected to the desired office. At the incoming office the register successively controls the 3rd and 4th groups and final selector to obtain the called subscriber.

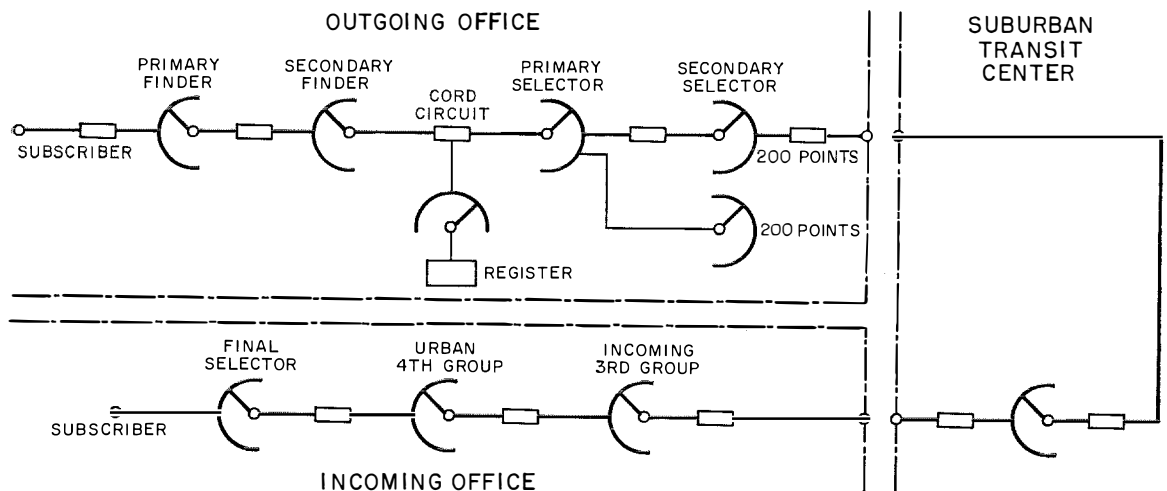


Figure 1—Call between 2 rotary offices through a transit center.

2.2 REGISTER CONTROL

The selection process first guides the selector to a level corresponding to a group of junctions connected to the distant exchange or to the desired subscriber and then searches for and finds a free line in this group.

In the following paragraphs we shall take up these two types of selection in detail. Figure 2 shows the final selector of the rotary system. Selectors for the 1st, 2nd, 3rd, and 4th groups are identical to the final selector except that they lack the commutator *INT1*.

2.2.1 Level Selection

Level selection under control of the register of the outgoing exchange is made over the speech wires using a circuit called the "basis for selection" circuit. (See Figure 3).

Control of level selection by the outgoing register uses the principle of reverive pulsing, which means that the distant selector at each change of level sends a backward pulse to the outgoing register.

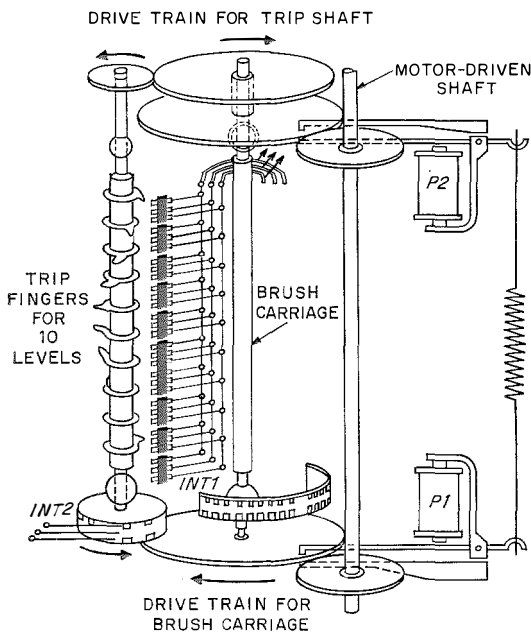


Figure 2—Rotary final selector.

To begin a selection, the register connects its *a1* and *b1* wires together at the originating end. The ground on wire *a* of the selector is thus extended to wire *b*, and relay *Glr* is energized in series with the sensitive relay *Osr* of the register. When relay *Glr* is energized it in turn energizes the drive magnet *P2*, which causes the 10-position shaft that mounts the commutator *INT2* of Figure 2 to be rotated. At each change of level *INT2* grounds wire *b*, and relay *Osr* is then released by the resulting short circuit.

Since relay *Osr* is pulsed reverively by *INT2*, the register has constant information on the position of the shaft on which *INT2* and the 10 trip fingers are mounted. When the *INT2* shaft is in the correct position to have a trip finger release the 3 rotating contacts on the desired level, the register by opening the loop *a1-b1* causes *Glr* to release and the shaft stops at that level.

2.2.2 Hunt for Free Outlet

Once the trip-finger shaft is in position, a free line at that designated level toward the next selection stage must be found. To do this, the register in Figure 4 closes the loop of wires *a1-b1* again, *Glr* is again energized in series with *Osr* of the register and closes the circuit of the magnet *P1*. This engages its drive train and the brush carriage turns. The brush carriage carries 30 wipers, 3 for each of 10 switching levels. On passing the trip-finger shaft, the

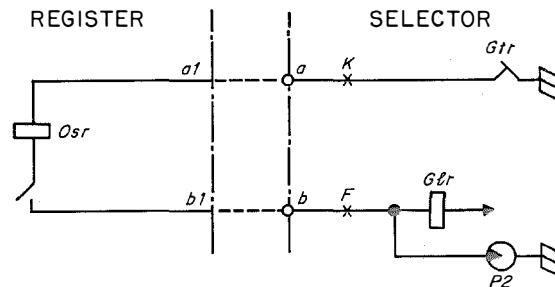


Figure 3—Fundamental circuit for numerical selection in the rotary system.

Introduction of Pentaconta Switching in Paris

single trip finger that has previously been rotated to its operating position, trips the 3 wipers on its level to make contact with a bank of contacts over which it sweeps. When the extended brush-carriage contacts arrive at a free line, as indicated by a battery potential on wire *c*, relay *Gtr* is energized, removing the ground connection from wire *a*. This causes *Osr* to release, indicating to the register that the search is over and, by releasing *Glr*, stops the brush carriage. Wires *a* and *b* are then shifted to the following selector and the register begins the next numerical selection.

2.3 LINE SUPERVISION

When the selections are complete, cord circuit relays *SB* and *SY* in Figure 5 operate in series with relay *As2r* of the third group. On closing, *As2r* checks the presence of the calling subscriber as well as the closing of relays *SB* and *SY*, thereby indicating completion of the selection.

When the called subscriber answers, the loop is opened for an instant and relays *SB* and *SY* are pulsed in reply. The second loop is reclosed, indicating that the called subscriber is on the line; its subsequent reopening indicates that he has hung up.

Summing up the foregoing process, selections are performed under the guidance of the register of the outgoing office by numerical selection

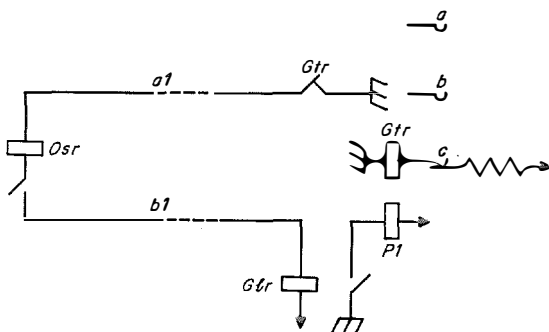


Figure 4—Fundamental circuit for automatic selection in the rotary system.

of direction and automatic selection of a free line; supervisory signals are retransmitted back to the outgoing line.

3. Criteria for New Network

3.1 CHOICE OF PENTACONTA SYSTEM

The Paris network uses many direct lines for interconnection between exchanges. This saves space at the transit centers and gives shorter selection time, better transmission quality between exchanges, and easier handling of traffic. The urban area, using rotary equipment, has about 620 000 lines spread among 23 buildings.

The first requirement for the new system was, therefore, large-capacity exchanges. This capacity had to at least equal that of the rotary system and be capable of providing units of 20 000 lines through the process called "pairing" of exchanges.

The Pentaconta system was chosen for modernization of the Paris network for the following reasons.

- (A) Its 1040-outlet units met the need for large-capacity offices.
- (B) It could be interconnected to the rotary system by its auxiliary control circuits.
- (C) Through the use of its local translator, it could handle the heavy-traffic lines common to this area.

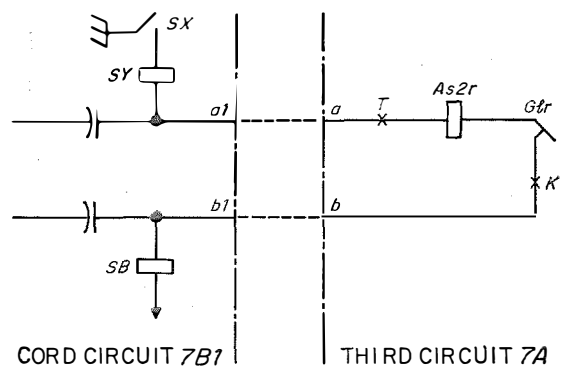


Figure 5—Line supervision between rotary offices.

(D) The equivalent of urban service could be provided to small-capacity residential zones through the use of its remote line units.

(E) Difficult problems of special services and special operations could be handled through its subscriber classes.

(F) Its numerous alternative-routing facilities would ensure a high grade of service.

(G) Rotary and Pentaconta junctions could be effectively combined in the same building.

and code conversion between the two systems. The junction between the transit center and a rotary office would operate in the rotary code, while the junction between the transit center and the Pentaconta exchange would use the Socotel multifrequency code, which has been chosen as the connection code between French crossbar offices.

The first method, which offered more flexibility in choosing routes, was initially adopted. However, the second method may be adopted as soon as the first urban Pentaconta transit center is put in service.

3.2 PENTACONTA-ROTARY INTERCONNECTION

3.2.1 Principles

Two methods were initially considered to interconnect rotary and Pentaconta switching systems in the Paris network without adding equipment in the existing rotary exchanges.

The first method requires equipping the Pentaconta exchanges with adapters (rotary senders and receivers) to enable them to work with any existing rotary office.

The second method requires building tandem transit centers to provide the interconnection

3.2.2 Operation

3.2.2.1 Pentaconta System Toward Rotary

An outgoing call from a rotary office is handled by the outgoing register. For a Pentaconta office the situation is similar except that the outgoing Pentaconta register calls an auxiliary rotary sender that supervises the selectors of the distant rotary exchange. Thus: (A) the primary and secondary selections are replaced, in the Pentaconta system, by the outgoing group

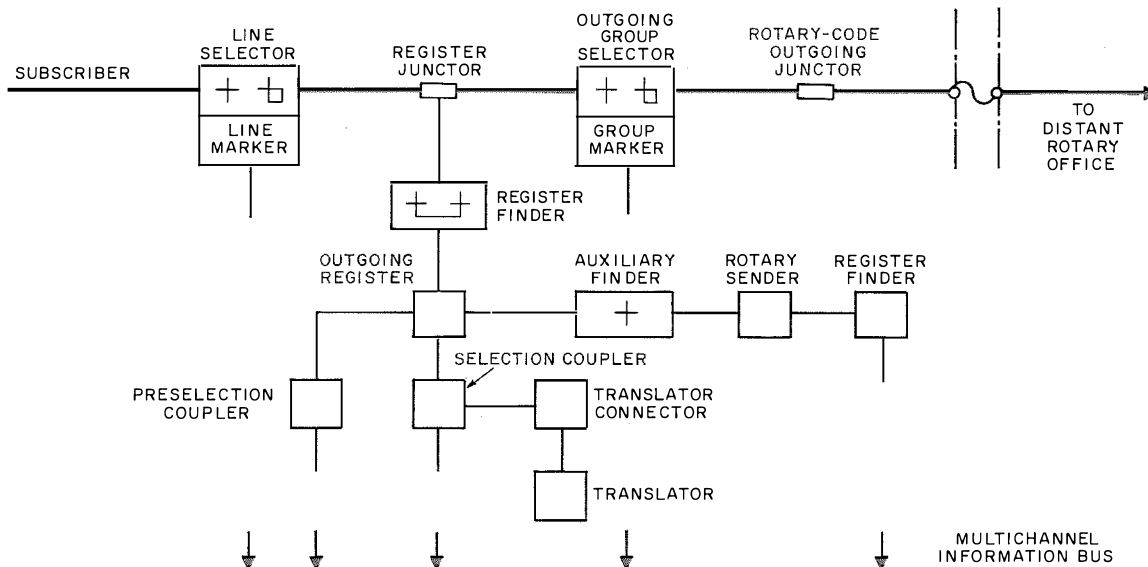


Figure 6—Pentaconta exchange interconnecting toward a rotary exchange.

Introduction of Pentaconta Switching in Paris

selection, (B) the selections translated at the transit office, and the 3rd, 4th, and final selections at the inward office, are checked by the rotary sender, and (C) line supervision is handled in the rotary system by the cord circuit. In the Pentaconta system, proper functioning is monitored by the outgoing junctor, operating in rotary code. Thus, two interconnection units are employed: the rotary sender, and the outgoing rotary code junctor. (See Figure 6.)

3.2.2.2 Rotary Toward Pentaconta System

For interconnection from rotary toward a Pentaconta exchange, there are also two interconnection units. The incoming rotary register simulates the 3rd, 4th, and final selections, preceded if necessary (in the case of 20 000 lines) by a translated selection. The incoming rotary feed junctor, which is of the urban or inter-urban type depending on the origin of the call, transmits the supervision signals to the distant rotary office.

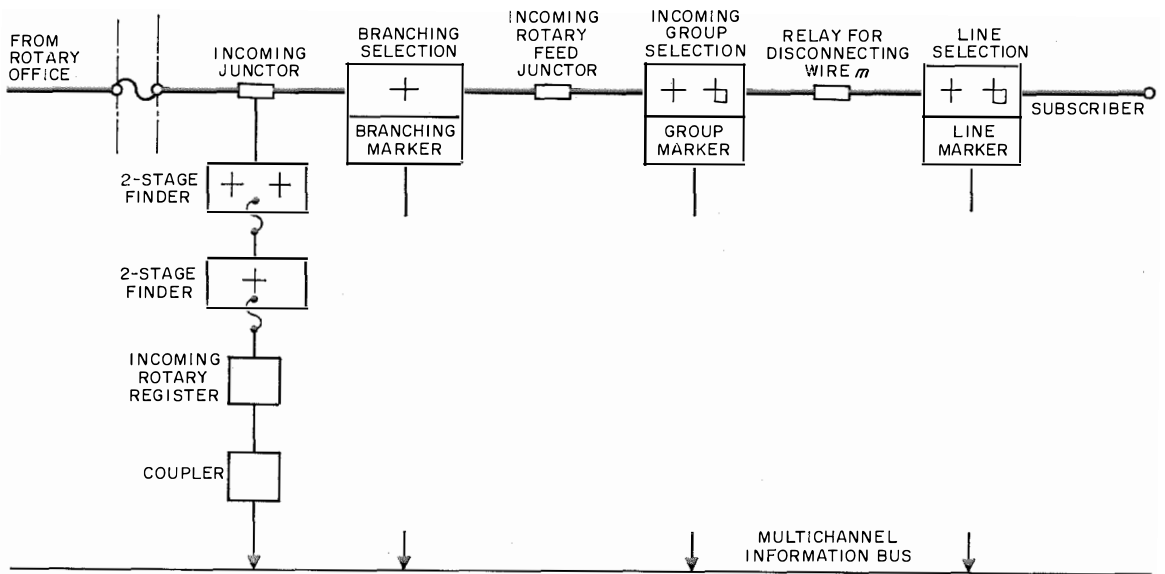


Figure 7—Rotary interconnection to a Pentaconta incoming chain.

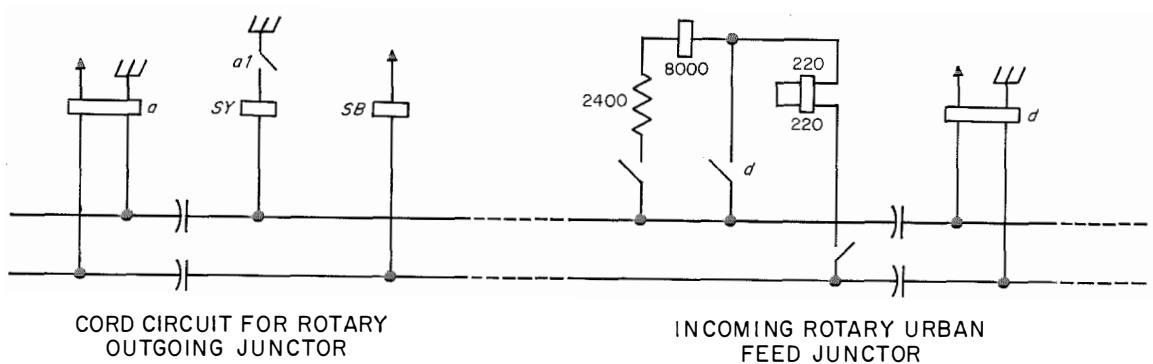


Figure 8—Rotary urban supervision.

3.2.2.2.1 Incoming Rotary Register

The incoming rotary register is composed of (A) a receiving section that simulates the rotary selections (numerical and automatic) and stores the information in its memory after having translated it, and (B) a section that controls the Pentaconta system selections. The latter is a purely Pentaconta unit.

3.2.2.2.2 Incoming Rotary Feed Junctors

The incoming rotary feed junctors (A) provide the "end of selection" or the busy signal and (B) retransmit a signal indicating the presence of the called subscriber. (See Figures 7, 8, and 9.)

3.3 SOCOTEL MULTIFREQUENCY CODE AND MULTIFREQUENCY INTERCONNECTION

To ensure interconnection between the crossbar exchanges of the French network, and between urban and interurban exchanges as well, the French Post and Telecommunications Administration has standardized on the Socotel multifrequency code.

3.3.1 Frequencies and Combinations

In all, 7 frequencies are used. Combinations of 2-out-of-6 of these frequencies provide for 15 digits, the 7th frequency being used as a check to guarantee reliable signaling. The 6 frequencies in hertz are

$$\begin{array}{lll} f_0 = 700 & f_2 = 1100 & f_7 = 1500 \\ f_1 = 900 & f_4 = 1300 & f_{11} = 1700 \end{array}$$

The resulting codes: 0, 1, 2, 4, 7, and 11, when added in pairs, provide for the conventional digits as follows.

$$\begin{array}{lll} 0 + 1 = 1 & 2 + 4 = 6 & 0 + 11 = 11 \\ 0 + 2 = 2 & 0 + 7 = 7 & 1 + 11 = 12 \\ 1 + 2 = 3 & 1 + 7 = 8 & 2 + 11 = 13 \\ 0 + 4 = 4 & 2 + 7 = 9 & 4 + 11 = 14 \\ 1 + 4 = 5 & 4 + 7 = 0 & 7 + 11 = 15 \end{array}$$

The check frequency is $f_0 = 1900$ hertz. Frequency f_{11} is used only for international calls.

3.3.2 Signaling Process

In signaling, tones are transmitted in both directions. Each transmission of a digit, consisting of 2-out-of-6 frequencies, is replied to by transmitting the check frequency f_0 back to the source, thus reducing to a minimum the signaling energy and time required. Each party, calling or called, transmits in turn according to the program in force in the network. This exchange of information is divided into 3 groups (see Tables 1 and 2).

Group A: Routing of the call.

Group B: Data concerning conditions applying to the selection and the class of service of the called subscriber.

Group C: Identification of the calling party.

Since the same frequencies and therefore the same signals are used in both directions, it is possible for each transmitting unit to check its own transmissions. This also results in total suppression of echoes when transmission stops.

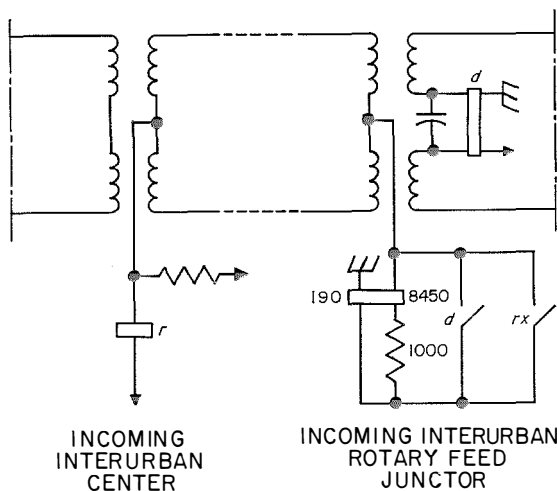


Figure 9—Rotary interurban supervision. If the subscriber's line is free, the 8450-ohm winding is short-circuited for 200 milliseconds; if the subscriber is busy the short-circuit continues.

Introduction of Pentaconta Switching in Paris

TABLE 1
REGISTER SIGNAL CODES—FORWARD SIGNALS

Access Code (Preliminary Information)	Numerical Code (Numerical Information)	Calling Subscriber Class Code
<i>a1</i> Regional call	<i>b1</i> Digit 1	<i>c1</i> Dial subscriber
<i>a2</i> Regional call after alternative routing	<i>b2</i> Digit 2	<i>c2</i> Dial subscriber with invoice justification*
<i>a3</i> National call	<i>b3</i> Digit 3	<i>c3</i> Calling absent subscriber†
<i>a4</i> National call after alternative routing	<i>b4</i> Digit 4	<i>c4</i>
<i>a5</i> 2-digit call	<i>b5</i> Digit 5	<i>c5</i>
<i>a6</i>	<i>b6</i> Digit 6	<i>c6</i> Keyset subscriber
<i>a7</i>	<i>b7</i> Digit 7	<i>c7</i> Keyset subscriber with invoice justification*
<i>a8</i>	<i>b8</i> Digit 8	<i>c8</i> Routing in extra class code
<i>a9</i> International semiautomatic	<i>b9</i> Digit 9	<i>c9</i> Night service
<i>a0</i> International automatic	<i>b0</i> Digit 0	<i>c0</i> Operator

* Subscriber who wishes to receive itemized account of all calls.
† Absent subscriber, on return home, asking that service be resumed.

TABLE 2
REGISTER SIGNAL CODES—RETURN SIGNALS

Code <i>A</i> (Selection)	Code <i>B</i> (State of Called Subscriber)	Code <i>C</i> (Calling-Subscriber Identity)
<i>A1</i> Send the access code and the first 2 or 4 digits	<i>B1</i> Called subscriber free, with charging	<i>C1</i> Send the calling-subscriber's class and the first 4 digits of his national number (<i>LLLL</i>)
<i>A2</i> Send the last digits	<i>B2</i> Called subscriber free, without charging	<i>C2</i> Send the last 4 digits of the calling-subscriber's number (<i>NNNN</i>)
<i>A3</i> Shift to code <i>B</i>	<i>B3</i> Called subscriber busy	<i>C3</i> Shift to code <i>B</i>
<i>A4</i> Shift to code <i>C</i>	<i>B4</i>	<i>C4</i> Shift to code <i>A</i>
<i>A5</i> Send calling-subscriber class	<i>B5</i>	<i>C5</i>
<i>A6</i> Normal transit	<i>B6</i>	<i>C6</i>
<i>A7</i> With alternative routing	<i>B7</i>	<i>C7</i>
<i>A8</i>	<i>B8</i> Shift to extra code	<i>C8</i>
<i>A9</i> Congestion	<i>B9</i>	<i>C9</i>
<i>A0</i>	<i>B0</i> Absentee subscriber	<i>C0</i>

TABLE 3
REGISTER SIGNALS FOR A CALL TOWARD
A 7-DIGIT DIALING AREA

Phase	Outgoing Office	Incoming Office
1		← <i>A1</i>
2	Access code and first 4 digits →	
3		← <i>A2</i>
4	Last 3 digits →	
5		← <i>A3</i>
6		← <i>B1, B2, B3, B8, or B0</i>

Figure 10 illustrates how this self-checking is accomplished.

A unique feature of the Socotel multifrequency code is the systematic transmission, prior to any office code (*LLLL, 1LLL, LLL, or LL*), of an access code indicating the nature of the traffic involved. This permits taking into account previous alternative routings used in the network when a traffic center is crossed. The signals *A6* for normal routing and *A7* for alternative routing permit modification of the access code at the outward office to answer a possible *A1* signal arriving later, and to interpret the *A2* signal asking for the last digits (2, 3, or 4).

Table 3 shows an example of the exchange of information for a traffic terminal in a 7-digit area, when several offices are grouped in one building and controlled by the same control unit.

3.3.3 Multifrequency Interconnection

A multifrequency interconnection is easily accomplished as follows: The originating register calls on an auxiliary multifrequency control circuit and sends the required digits as the

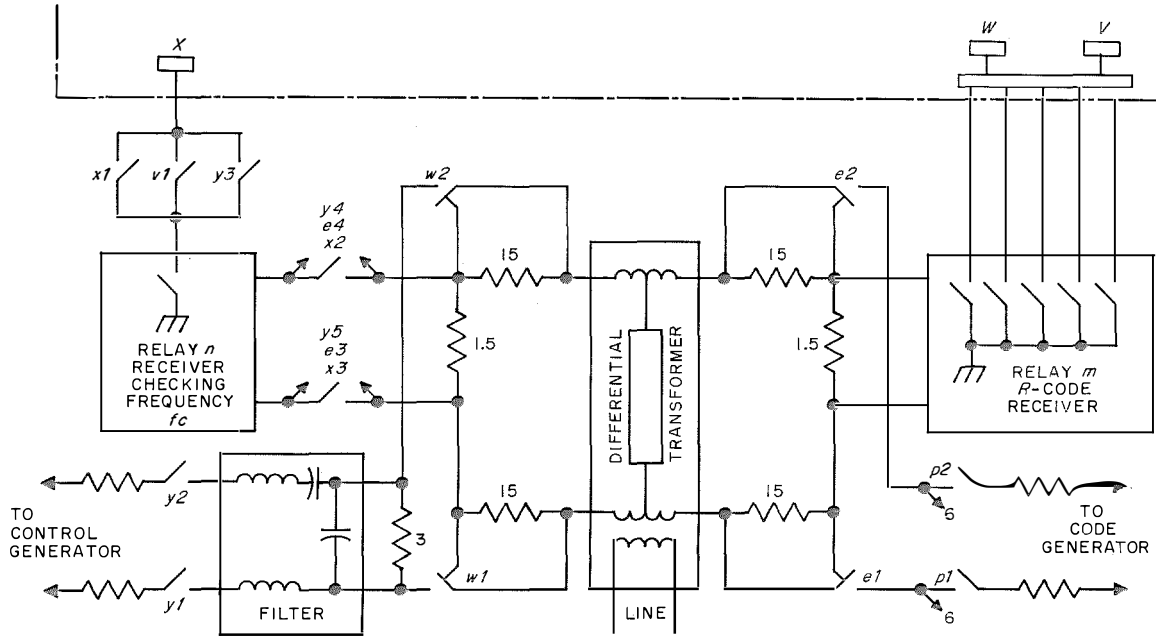


Figure 10—Self-checking of signaling frequencies in the multifrequency code. Resistance values shown are in kilohms.

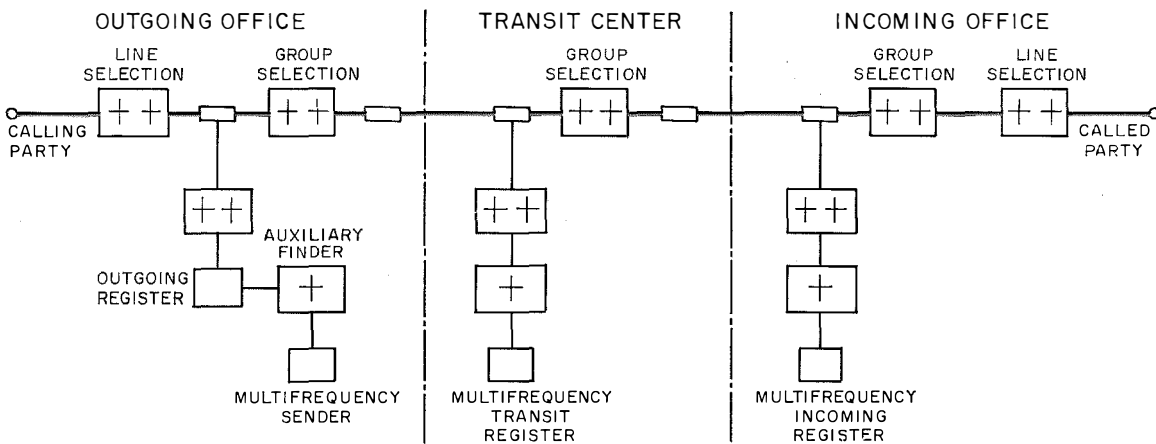


Figure 11—Multifrequency interconnection using a transit center.

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requests come in from the originating office. Each register encountered carries out the necessary transit selection until the terminal office is reached, where the last register takes charge of the called-line selection and transmits the information of group *B* to the outgoing register. Figure 11 illustrates this routing.

3.4 REMOTE LINE UNIT

To provide the equivalent of urban service in the suburban residential areas, it has been decided to employ one of the features of the Pentaconta system—the ability to locate the line-selection unit in an area that is remote from the parent exchange [4].

The use of these remote line units (concentrators) permits a reduction in the number of junctors arriving at a main exchange, with a resulting saving in cabling and a reduction in size of the incoming distributors.

3.5 URBAN TRANSIT AND TANDEM CENTERS

In Figure 12, let us assume that 2 exchanges, *A* and *B*, are connected via 2 transit centers, *T1* and *T2*. Each transit center contains a register that receives a certain number of digits to permit the crossing of that center. In this equipment, two kinds of operation are possible.

3.5.1 Pure Transit Operation

When the signaling (rotary code or multifrequency code) is homogeneous throughout, it is sufficient to send to the transit centers a limited

number of digits to obtain the necessary connections within the crossed office. After this the two registers of the outgoing and incoming offices exchange the balance of the necessary information. In addition to the requirement for homogeneous types of signaling, it is necessary that the characteristics of the traversed junctions be such as to ensure the transfer of the dialing signals from one end of the circuit to the other. In some cases the pulses must be regenerated in one of the transit centers crossed. This is true in rotary signaling when two transit centers are crossed.

3.5.2 Tandem Operation

If the signaling is not homogeneous, as in the case of a call from rotary equipment passing through a transit center where it is translated into a multifrequency call, or vice versa, it is necessary that one of the traversed registers completely decode and re-encode the transmitted data. In Figure 12, if exchange *A* is a rotary office and *B* is a Pentaconta system office, one of the two transit centers, *T1* or *T2*, must transform the codes by using appropriate auxiliary devices.

3.5.3. Effect on Paris Network

To accomplish the foregoing, the new transit centers introduced into the Paris network must ensure

- (A) pure rotary transit
- (B) pure multifrequency transit
- (C) rotary tandem operation

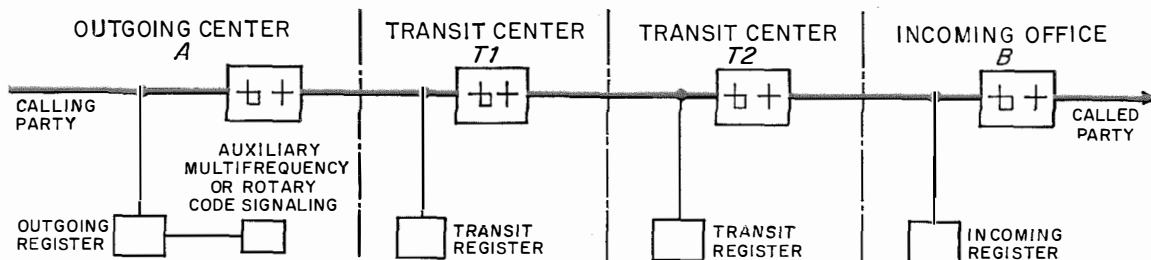


Figure 12—General diagram for call passing through 2 transit centers.

(D) rotary-rotary tandem operation

(E) multifrequency-multifrequency tandem operation (if needed).

Two types of registers are provided, one assigned to incoming rotary code junctions and the other to incoming multifrequency code junctions. Each has access to rotary or multifrequency auxiliary control circuits to permit transformation of codes. (See Figure 13.)

Note that the rotary code information consists of translated digits. By pairing of hundreds groups it permits preliminary selection from 20 000 numbers. Consequently, translation into multifrequency code requires another translator that decodes selections and digits already translated into regular numbers.

3.6 ACCESS TO NATIONAL AND INTERNATIONAL NETWORKS

3.6.1 Outgoing Calls

Access to the national network is obtained by

dialing 16; to the international network, by dialing 19. In both cases, a distant register is connected and furnishes a second dial tone. In other words, when the subscriber dials 16 or 19, the outgoing Pentaconta register performs a selection over a level that goes to CIAD for national traffic or to CADET for international traffic. The outgoing junctor initiates the hunting of a national register at CIAD or an international register at CADET, and the outgoing register of the Pentaconta exchange is released. The national or international register then sends a second dial tone and the subscriber can go on dialing.

The outgoing registers are capable of storing the 8 digits of the national number. They could then select a specific outgoing center and send the number to that center. This mode of operation (not being used at present) has been provided for cases where several national outgoing centers each have access to a part of the French territory.

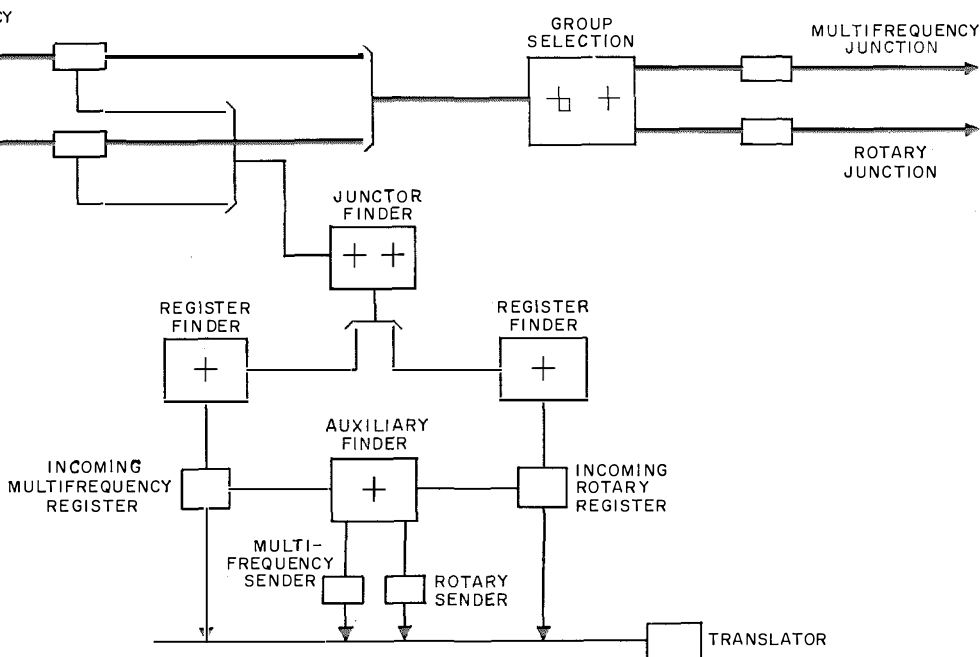


Figure 13—Diagram for an urban transit.

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This possibility has not been contemplated in the case of international traffic since storing the international number would involve complications and, in addition, since the dialing systems of some countries are "non-closed," the resulting complications would require their reception in special registers.

In both cases, the loop dialing of the calling subscriber is transmitted to the parent exchange over a simplex circuit to permit increasing the length of the junction between the outgoing exchange and the national or international outgoing centers. (See Figure 14.)

3.6.2 Incoming Calls

At present all inward centers operate in tandem, single-frequency and multifrequency, using the interautomatic code for incoming national traffic, the codes for international traffic through CINAT, and the rotary interurban code for outgoing calls to the Paris network.

A new tandem center, Pastourelle, comprising 6000 incoming circuits and 6000 outgoing junctions, is under consideration. When this transit center is in operation, the multifrequency code will be used between it and the urban Pentaconta exchanges to which it will be directly connected. If the multifrequency code is used for terminating calls, a pure transit will occur in which the transit center receives sufficient digits to permit selection; the final digits will

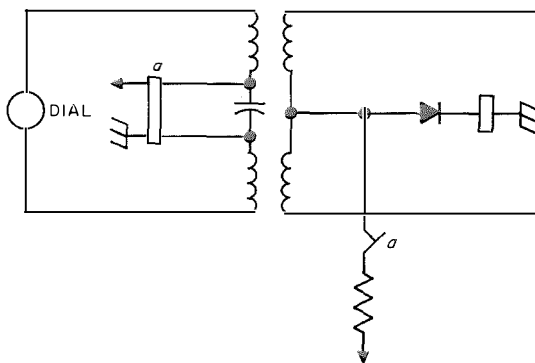


Figure 14—Retransmission of pulses to the national and international outgoing centers.

be sent directly from the originating office to the terminal exchange, the transit center then being essentially a metallic connection. If the interautomatic decimal code is used, a tandem operation that requires code conversion after all digits are received will be necessary.

3.7 CHARGES FOR CALLS

3.7.1 Rules for Paris Area

Calls between two subscribers in the urban and suburban areas of the Paris network are charged without regard to their duration. Calls for the regional and interurban areas are charged according to the distance and the duration of the call.

There are two tariff systems now in use.

(A) The 3 + 3 rate, in which a train of pulses is sent to the subscriber's meter every 3 minutes, the number of pulses of a train being a function of the distance. This rate, formerly in general use, is now reserved for manual calls.

(B) The charge for automatic calls is controlled by periodic pulses. In this method, following a train of pulses that corresponds to the distance for the call, a periodic pulse is sent to the subscriber's meter, the length of the time interval between pulses being inversely proportional to the distance [5].

3.7.2 Charging Equipment

In the rotary system the cord circuit transmits the charge for each call (the urban fee). In case of multiple fees, meters or multiple counting junctions are associated with the outgoing junctors.

In the Pentaconta system the charging equipment is incorporated in the outgoing junctors that require it.

3.7.3 Indication of Fee Level

3.7.3.1 Rotary System

In urban and interurban areas, the charge is sent from battery as a pulse train over wire *A*

for regional traffic, and as a pulse train over wire *C* for national traffic, from the appropriate transit center (regional or national).

In the regional areas the translator indicates directly to the multiple counting circuit the base rate to be applied. For national traffic the process is the same as that used for the urban or suburban areas.

3.7.3.2 Pentaconta System

When the outgoing charge junctor is connected to a rotary exchange, the process is the same as that described above.

When the charging junctor uses the multifrequency code, the translator indicates the distance fee to the junctor over a multichannel information bus. (See Figure 15.)

3.7.4 Pentaconta Meters

Once the level of fee is furnished, a central electronic timer provides the necessary pulses to all circuits requiring them over a distribution network.

3.7.5 International Charging

Three-wire junctions link the urban, suburban, and regional exchanges to the originating international transit center. The counting pulses are sent directly over the third wire from the international center to avoid the need to install special electronic timers in the exchanges.

4. Paris Network Pentaconta Office

4.1 ROUTING OF CALLS

The diagram of Figure 16 shows the connections of the Pentaconta automatic switching exchange introduced into the Paris network (urban, suburban, Regional Area 1, and Regional Area 2). This installation has a total capacity of 30 000 lines.

4.1.1 Switching Network

4.1.1.1 Line Selection

A Pentaconta line-selection unit handles the originating and terminating traffic of 1040 subscriber lines, of which 40 are unnumbered.

The subscriber lines are connected to the outlets (or levels) of the secondary (or terminal) sections, in the proportion of 52 lines per secondary section (there are 20 secondary sections per line selector).

The primary sections are made up of call finders that handle the outgoing traffic, 50's selectors that handle the incoming traffic, and entraide selectors [6] that by means of entraide paths handle the portion of outgoing and incoming traffic that is routed toward the entraide group of lines (between primary sections).

The line selector can be a remote line unit (refer to Section 3.4).

4.1.1.2 Group Selection

The group-selection units may be originating or incoming. The number of incoming calls to be connected determines the minimum number of group-selection units required.

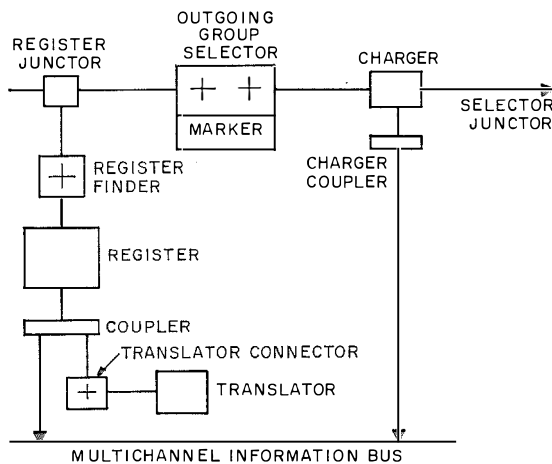


Figure 15—Method of transmitting charges in the Pentaconta system.

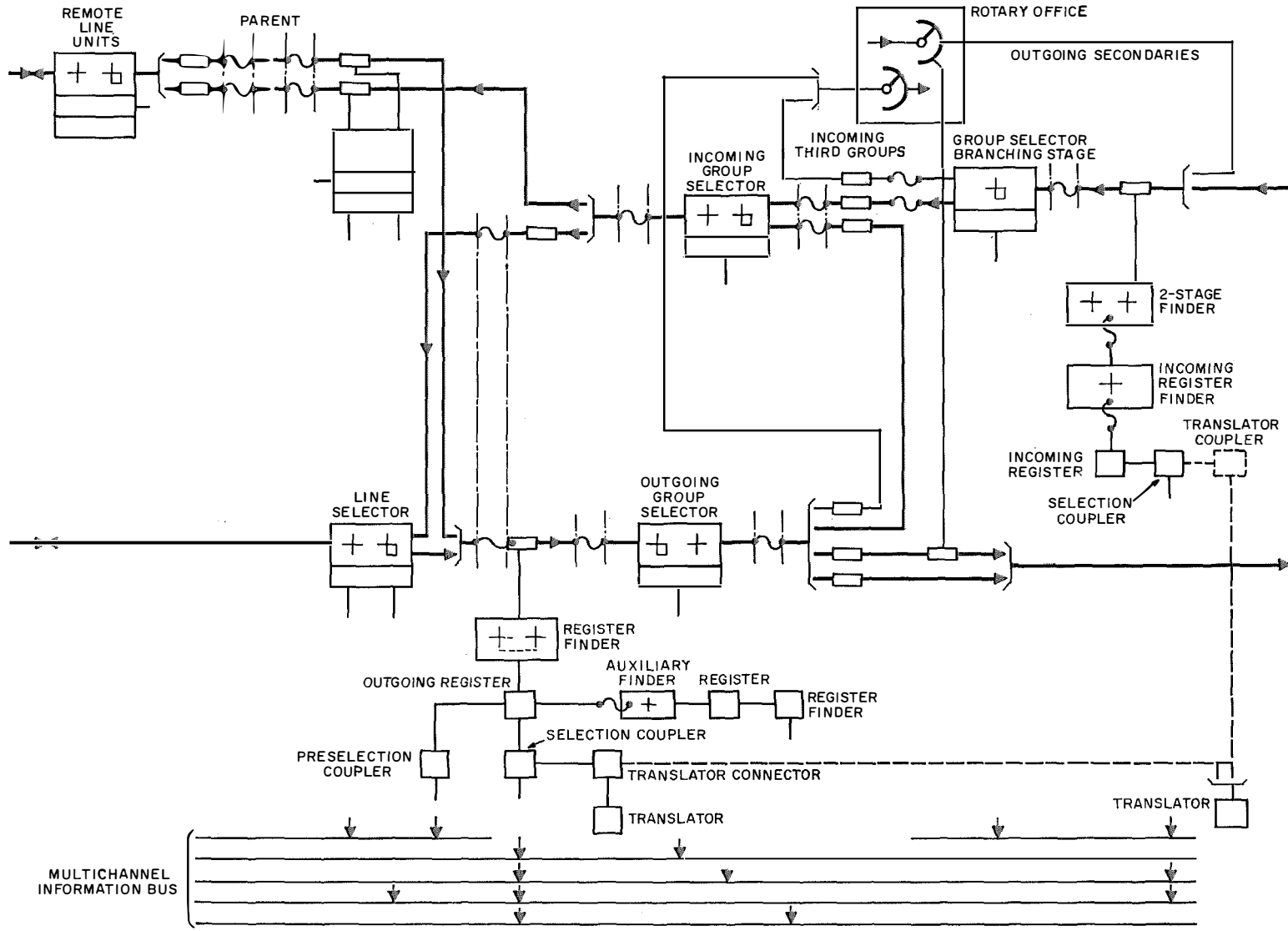


Figure 16—Pentaconta exchange in the Paris rotary network. It has a capacity of 30 000 Pentaconta and 20 000 rotary lines.

The composition of a 2-stage group-selection unit is similar to that of a line-selection element, having 1040 outlets divided into 20 secondary sections (52 levels and 14 secondary selectors per section) connected to the primary section by double link connections providing 40 levels per primary section, the remaining 12 being used by the entraide. Each primary section can have 22 to 66 selectors (primary and entraide).

The marking relays are capable of simultaneous marking of all the levels assigned to the same outgoing group of lines.

For 30 000 lines, the group-selection units are multiplied by pairing their outgoing lines. These are then connected to a distributing frame and the uniform grading obtained permits handling all of the junctors and feeders accessible through this stage. This process permits handling more than 1040 junctions, meanwhile maintaining excellent accessibility.

The outgoing group selectors route traffic coming from the normal or remote line-selection units.

The incoming group selectors handle the local traffic from the outgoing group selectors, incoming traffic from other urban, suburban, and regional centers, and interurban traffic from the manual and automatic interurban centers.

4.1.2 Feeders and Junctors

Feeding of the subscriber lines (called or calling), supervision and charging of calls, and connection between the chains of the urban, suburban, and regional networks, or of the automatic interurban networks, are carried out by special units (feed junctors and metering junctors).

The local feed junctor is used for calls between two subscribers of the Pentaconta system exchange.

Incoming feed junctors are used for routing terminating calls. They are specially designed to work with the particular type of incoming

circuit: urban rotary, interurban rotary, or Socoltel multifrequency.

The outgoing and incoming junctors play a part in the exchange of signals between offices, respectively supervising the calling subscriber (origination of call) and the called subscriber (termination of call). In addition, the outgoing junctors handle charges (including multiple-fee tariffs) to the calling subscriber. They are specially designed to work in specific types of outgoing circuits.

4.1.3 Common Controls

The common controls consist of the complete assembly of devices that control the selectors, feed junctors, and junctors used in routing a call. These units are the registers, receivers, senders, and translators that are connected to each other by auxiliary control-circuit finders, by couplers (selection and preselection), and by translator connectors.

Selectors gain access to registers by register finders and the multichannel information bus.

4.1.3.1 Registers

To accomplish certain functions, the registers call on special auxiliary control-circuit receivers, senders, and translators. The outgoing registers route calls from subscribers connected to the exchange or its satellites. The incoming registers handle calls from other urban centers or from transit and interurban centers. They are of two types, one for handling rotary code and one for the multifrequency code.

4.1.3.2 Auxiliaries

The auxiliary control circuits enable the registers to work with the various types of signaling employed, such as subscriber dialing, rotary code, and multifrequency code.

4.1.3.3 Translators

The code translator determines the information necessary to permit the first selection to be

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made, retransmits a translated code for selection of an outgoing route toward a distant exchange, and gives the tariff to the metering junctors.

The local translator determines the required code for the last selections in routing a call to a subscriber in the exchange. It is installed only if operational requirements justify its use (group of subscribers after the incoming group selector).

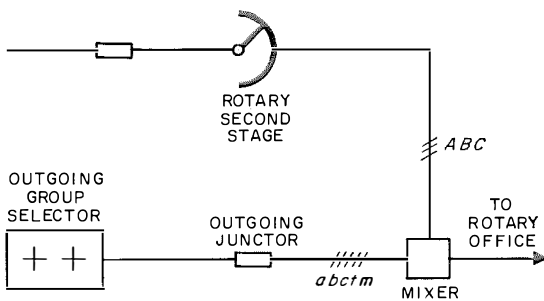


Figure 17—Paralleling of outgoing junctions toward the rotary exchange from the Pentaconta and rotary offices.

4.1.3.4 Couplers

The couplers provide connections between the registers and the multichannel information bus.

4.1.3.5 Multichannel Information Bus

Multichannel information buses provide a temporary connection between the registers and translators, and between the markers of the selection devices.

4.2 COMBINED PENTACONTA AND ROTARY OFFICES

It is important that buildings originally equipped for the rotary system can be extended by the installation of Pentaconta equipment.

Actually these two types of exchanges can be housed in the same building and need not be entirely independent of each other. To provide maximum flexibility and efficiency in the combined groups of lines, it was decided to parallel the outgoing junctions of the Pentaconta and rotary exchanges in the same building.

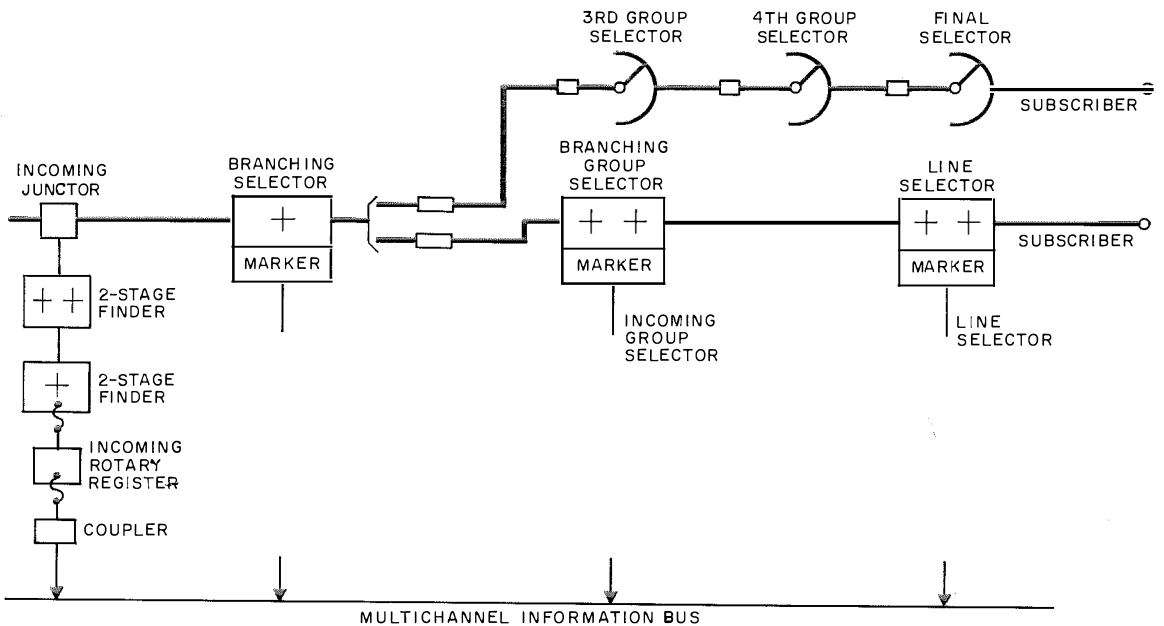


Figure 18—Principle of the branching stage.

Also, in some cases it was decided to parallel the incoming junctions and, by means of a routing stage using a translated selection, share the traffic between the Pentaconta and rotary equipment or, in case the rotary equipment is of small capacity, make the incoming group selector play the part of a router.

The traffic between rotary and Pentaconta exchanges located in the same building is handled the same as traffic between 2 separate exchanges. (Actually the building traffic in Paris is only a small portion of the total traffic.)

4.2.1 Paralleling Outgoing Junctions

The method of paralleling the outgoing junctions from the combined Pentaconta and rotary offices to the rotary switching system is shown in Figure 17.

Testing is performed differently in the rotary and Pentaconta systems (500-ohm test over wire *c* with testing of all outgoing junctions in rotary; 330-ohm test over wire *t* with random search of all free junctions in Pentaconta). For

this reason it was necessary to develop a unit known as a mixer, which makes a level unavailable to rotary when the Pentaconta system is testing, and vice versa.

4.2.2 Paralleling Incoming Junctions

If the rotary equipment in the building is of substantial magnitude, the incoming groups of lines of the rotary exchange are separated from those of the Pentaconta equipment.

However, in some cases of unbalance, for example when it has been decided not to complete certain 20 000-line rotary exchanges but to begin immediately to introduce the Pentaconta system into the building, separate groups of lines for the rotary equipment are no longer justified. In such cases, one of two methods has been adopted: either installing at the entrance a branching stage (see Figure 18) for distributing the calls to the rotary or the Pentaconta system or, in the case of 2000 rotary lines, for example, placing the 4th groups directly behind the incoming group selection as in Figure 19.

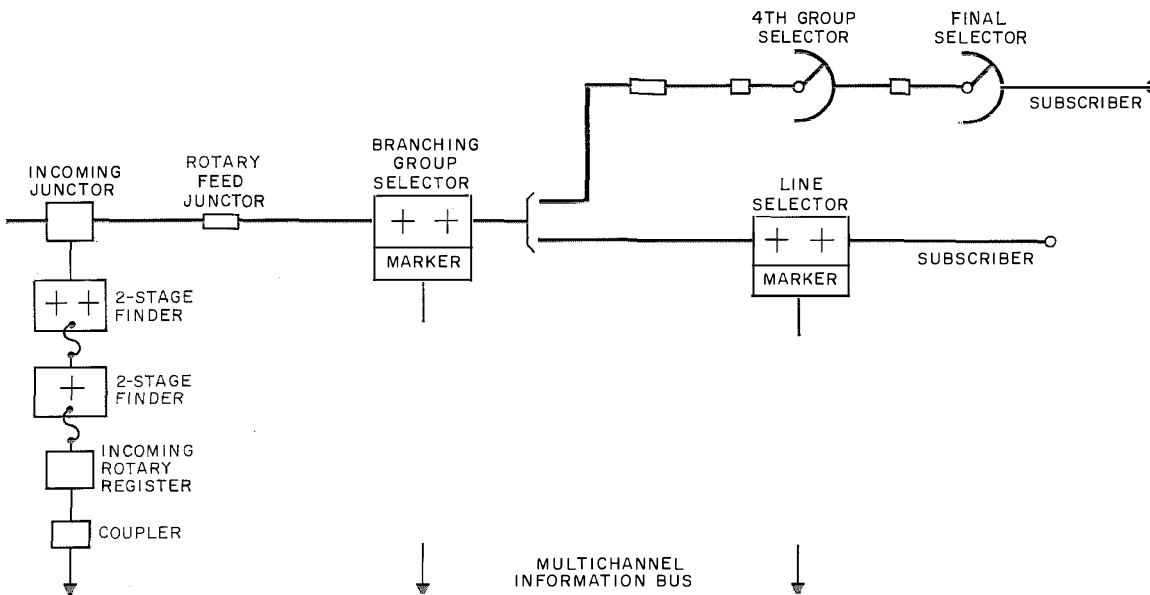


Figure 19—Pentaconta incoming group selector as a branching stage.

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5. Maintenance

The regular maintenance principles of the Pentaconta system have been retained for the Pentaconta exchanges of the Paris network. They include the test chain, the surveillance robot with recording of incidents on punched cards, identification devices for false calls, and various supervision devices as well as standard observation of traffic.

In addition, each of the offices called Socotel has an automatic sender for 10 simultaneous calls permitting, by simulated traffic, detection of local faults in the exchange.

Direct interconnection of the Pentaconta system offices with rotary offices has made it necessary to retain some of the features of the

older network, particularly automatic testing of the outgoing junctions.

Finally, simulators for testing the incoming rotary senders and registers have been designed to permit checking for satisfactory operation of these units.

6. Conclusion

The confidence placed by the French Post and Telecommunications Administration in the Pentaconta system installation in the Paris network has proved to be fully justified. The preceding description has given only a glimpse of the problems involved and the scope of the required studies. Only a general outline of this development could be sketched in this short paper.

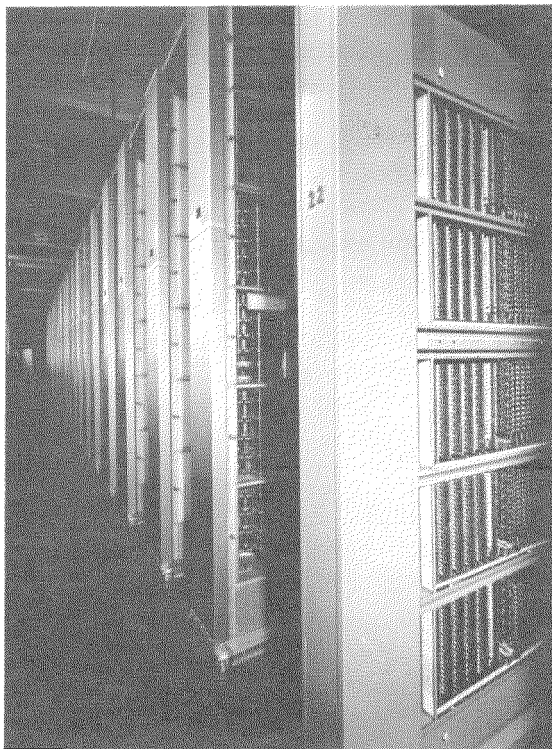


Figure 20—Gounod exchange in Paris. This is the interface between the existing Val d'Or exchange, which is equipped with two 7B1 rotary systems, and the new Gounod Pentaconta office.

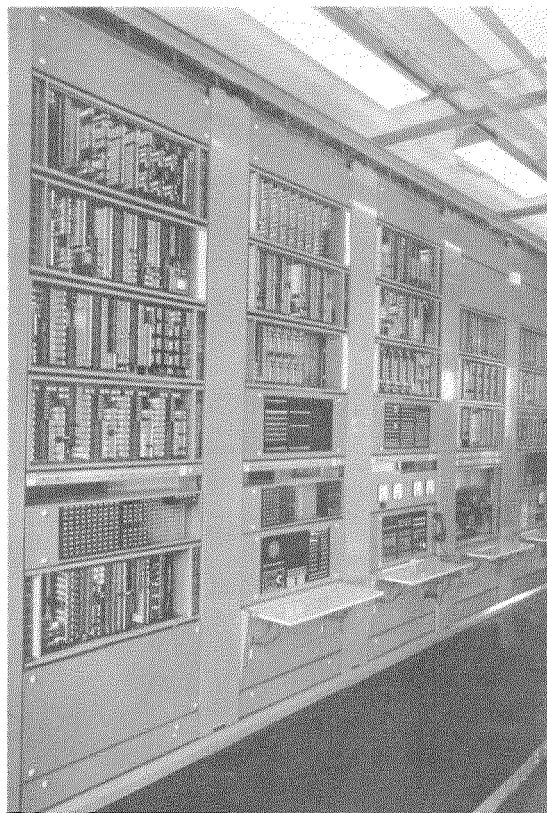


Figure 21—Supervisory equipment in the Chenier Pentaconta exchange in Paris.

The service given by the Gounod and Chenier exchanges, views of which may be seen in Figures 20 and 21, respectively, has very satisfactorily demonstrated the success of the enterprise.

Establishment of the Carnot Pentaconta exchange, replacing the first automatic Carnot 7A exchange, which was built in 1928, marks the beginning of the transformation of the Paris network.

7. References

1. F. Gohorel, "Pentaconta Dial Telephone Switching System," *Electrical Communication*, volume 31, number 2, pages 75–106; June 1954.
2. A. Gazanion and R. Lagare, "Système de signalisation multifréquence SOCOTEL,"

Commutation et Électronique, number 4, pages 32–43; April 1963.

3. J. P. Basset and R. Mugnier, "Paris Network and Numbering Plan," *Electrical Communication*, volume 41, number 1, pages 5–11; 1966.

4. J. P. Basset and R. Mugnier, "Pentaconta System Remote Line Units," *Electrical Communication*, volume 41, number 1, pages 30–34; 1966.

5. A. Delbouys, "L'introduction du régime de taxation par impulsion périodique dans le réseau téléphonique français," *Commutation et Électronique*, number 6, pages 69–83; April 1964.

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

J. P. Basset and R. Mugnier. Biographies appear on page 11.

Pentaconta System Remote Line Units

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1. Introduction

Telephone density in suburban residential sections is normally less than that found in urban areas. To utilize exchanges of rather-large capacity in suburban areas, it has been necessary to accommodate subscribers distributed over a relatively large geographical area, resulting in an excessive average length of subscribers' lines.

To cope with this difficulty, large-capacity remote line units (concentrators) have been considered for incorporation in Pentaconta switching systems. These units, with a capacity of 1040 subscriber lines, permit remote line selection, hence they are called E.L.E. (éléments de sélection de lignes éclatés) or remote line-selection units.

A remote line-selection unit permits concentrating the traffic of 1040 subscribers' lines within a switching point located in the area of those subscribers, resulting in economical handling of this traffic by means of a reduced number of wires connecting this switching point to the parent exchange.

Depending on the remoteness of the parent exchange, two types of remote line-selection units can be used. One is called the E.L.E.N.A. (éléments de sélection de lignes éclatés non alimentants) or non-feeding remote line-selection unit for which the talking battery for the subscriber's station is supplied from the parent exchange, the subscriber dialing directly toward the parent exchange register. The other is the E.L.E.A. (éléments de sélection de lignes éclatés alimentants) or feeding remote line-selection unit for which the talking battery for the subscriber's station is provided by the remote line-selection unit itself, with the subscriber's dialing pulses regenerated in that unit.

2. General Description

A remote line-selection unit as shown in Figure 1 is composed of two principal parts: the

remote part, to which the subscribers' lines are connected, and the local part, the so-called "pseudo element" providing connection between the automatic exchange and the remote line-selection unit.

2.1 SPEECH NETWORK

The remote part of a local line-selection unit also contains its two stages of switching (the terminal selector frames are standard). The call finders are connected to the register junctions through (*A*) a calling line junctor in the remote part that permits going from 4 to 2 wires, and (*B*) an incoming junctor in the parent exchange that permits return from 2 to 4 wires.

In the same manner, the outgoing levels of the group-selection unit assigned to remote selection are connected to the 50's selectors by means of an outgoing junctor in the remote line unit. This connection is also 2-wire.

2.2 COMMON UNITS

Units common to the remote and local portions are duplicated. The pseudo markers, pseudo primary sections, and relays common to the parent exchange correspond to the markers, the remote common relays, and the concentrator primary sections. The markers and pseudo markers are each associated with a transmitter for signaling between them.

3. Exchange of Information Between Remote Line Unit and Parent Exchange

3.1 BETWEEN JUNCTORS

The exchange of information between junctors involves such items as holding of the connection and call charging. The holding is done locally on receipt of a connection signal (-48 volts over 1 wire); release is accomplished by a release signal (+48 volts over the other wire).

Both signals are sent with "acknowledgment receipt." In the event of a fault, a delayed alarm is transmitted to the exchange. The charge is sent by means of 50-hertz alternating current in simplex over the line wires.

3.2 BETWEEN PRIMARY SECTIONS AND PRIMARY PSEUDO SECTIONS

Information is exchanged between primary and primary pseudo sections over the junctors.

3.3 BETWEEN MARKERS AND PSEUDO MARKERS

Three wires are used between markers and pseudo markers as shown in Figure 2 for switching information. Five wires serve for the fast transmission of coded information such as the number of the called subscriber, class of the calling or called subscriber, coordinates of the called line, code for registration of faults, and identification code of the calling subscriber. To effect this, a transmitter is associated with each of the 2 units. By means of a sequential

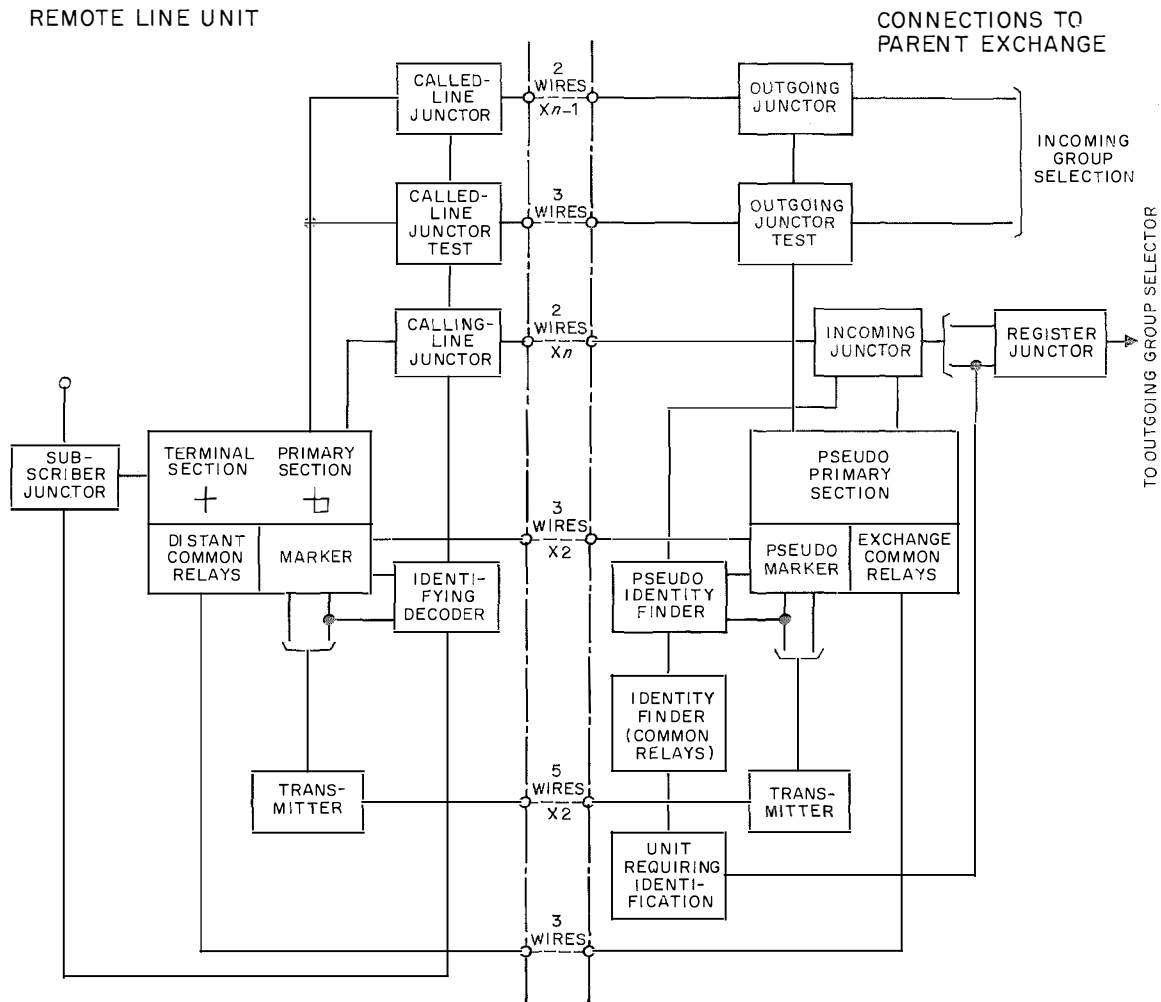
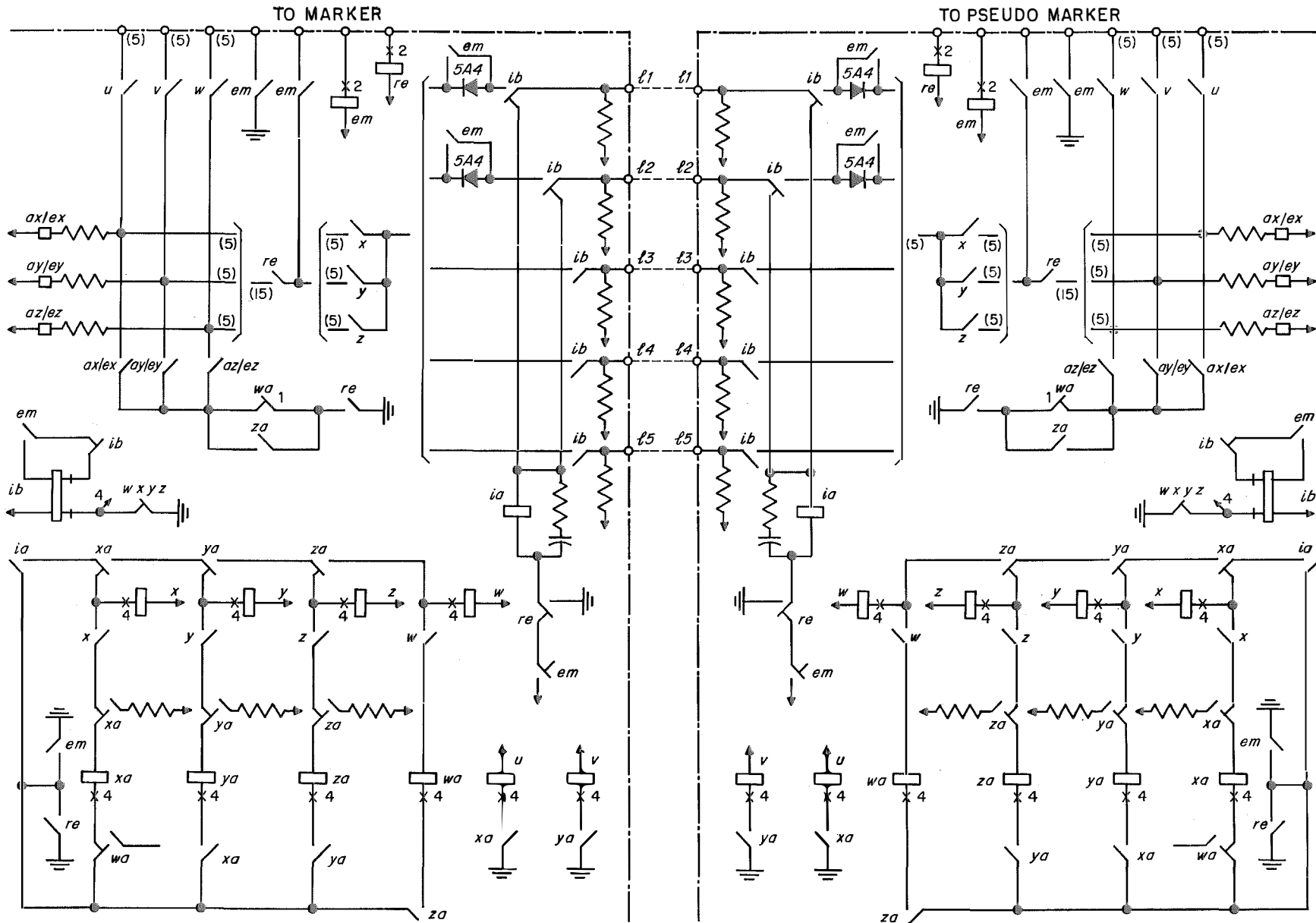


Figure 1—Remote line-selection unit and the pseudo elements at the parent exchange. For the connecting lines, n = the number of junctions in each direction.



switching circuit, 1 of the 2 transmitters is set in the sending position, the other in the receiving position, and the codes are transmitted in a 2-out-of-5 code. The number of the called subscriber would be transmitted, for example, as 3 transmissions of signals on 2 of the 5 wires.

3.4 BETWEEN REMOTE COMMON RELAYS AND EXCHANGE COMMON RELAYS

Three wires carry calls between the remote common relays and the exchange common relays.

4. Principles and Operational Features

The operational principles and the services available to the subscriber are identical to those of a subscriber connected directly to the exchange.

4.1 CALL CHARGING

Each subscriber has an individual meter (message register) in the remote unit, with the charging pulses being transmitted from the parent exchange in 50-hertz alternating current over the line wires. In addition, this current is capable of operating a meter on the subscriber's premises if desired.

4.2 TESTS

By means of a 3-wire called-line connection, which also serves for normal traffic, there are provisions for testing subscribers' lines from the test chain of the parent exchange.

4.3 ABSENT, CANCELLED, TRANSFERRED, OR SUSPENDED SUBSCRIBERS

The various classes of cancelled, transferred, and contract-bound absent subscribers are handled, as in local operation, by transfer to the

distributing frame on a special pair for re-transfer toward the center for temporarily absent subscribers. In addition, a control pair is provided for actuating the relays that place the absent subscribers in absentee condition.

4.4 REGISTRATION OF FAULTS

Faults that occur in the remote unit are reported on punched cards in a fault-registration device at the parent exchange, as they are for a local line-selection unit. This information is transmitted between the common relay group of the remote unit and the corresponding group of the parent exchange.

4.5 IDENTIFICATION OF CALLING SUBSCRIBER

A recent development has made it possible to identify the calling subscriber in the remote line-selection unit. This information is forwarded to the parent exchange by the transmitters and serves to identify false calls (permanent signals), to provide central charging on tickets or tape (automatic message recording), and to transmit fault indications.

4.6 ALARMS

Two classes of alarms, urgent (major) or not urgent (minor), are retransmitted to the parent exchange over a special pair.

5. Economy in Cable Requirements

Under ordinary circumstances the direct connection of 1040 subscribers to the parent exchange would require 1040 pairs of wires. When a remote line-selection unit is installed near these subscribers, the pair requirements for a total traffic per line of 0.066 erlang is reduced to

- 50 pairs of junctions in each direction
- 8 pairs between markers and pseudo markers
- 1.5 pairs between common relays
- 2 pairs for absent subscribers
- 0.5 pair for 3rd-wire test junction
- 1 pair for alarm

Figure 2—Principles for transmission of information by the transmitters associated with the markers and pseudo markers.

for a total of 113 pairs, resulting in a saving of nearly 90 percent.

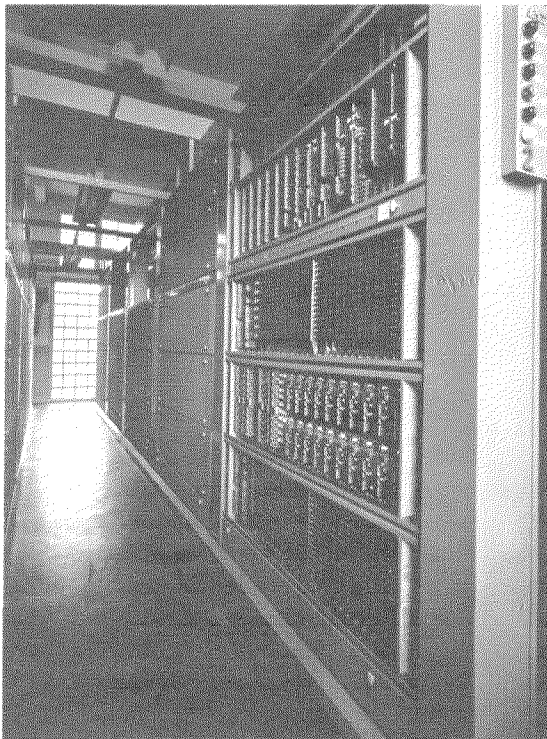


Figure 3—Remote line-selection unit at Saint Cloud, which is connected to Gounod, its parent exchange.

6. Connection to Various Types of Exchanges

A remote line-selection unit for 1000 subscribers can be connected to various other types of exchanges. For instance, numerous applications have been made involving rotary 7A and 7B1 in the Paris and Marseilles areas. Connections have also been made to Strowger, R6, and AGF500 equipments. A few extra connections are necessary at the parent exchange for code conversion, but this is easily accomplished.

7. Conclusion

The development of remote line-selection units (Figure 3) in lower-density telephone areas and, especially, in the suburban areas of large towns or cities, has permitted the installation of standard exchanges of the same size as those of the urban areas, thereby providing these subscribers with all the conveniences of urban service. In addition, this development has expedited the furnishing of telephone service to a large number of additional subscribers.

J. P. Basset and R. Mugnier. Biographies appear on page 11.

Pentomat T Private Automatic Branch Exchange

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Pentomat* T private automatic branch exchanges may be of medium size (20 to 400 lines) or large size (up to 10 000 lines). Although the two sizes use different equipment practice, both provide the same features and facilities. This paper describes only the medium-size exchange.

1. Main Features

The medium-size private automatic branch exchange uses as its basic element a Pentaconta† crossbar switch having 14 horizontal bars, one of which is used as a changeover bar, to provide for switching 52 outlets [1, 2].

Electronic components and sealed reed relays are used in the code receiver, code converter, and all other circuits that handle code signals initiated from push-button subscriber sets. This quasi-electronic approach is justified by operational and cost considerations [3, 4].

Direct-current push-button signaling is well fitted to the high operating speed of the exchange [5, 6]. It is possible to use both push-button and dial subscriber sets in the same exchange.

Numerous optional services may be provided to meet national requirements. A high traffic capacity of 10 erlangs is available for each 50 lines.

A feature known as "line lockout" causes circuits to be released if no digit is sent, if too long an interval elapses between digits, if a dead or a busy number is called, if a call is not permitted by the subscriber's class of service, or if the calling party fails to replace his handset. The subscriber in the line-lockout condition receives busy tone for a short time from his own line circuit. Thus switching circuits are not tied up unnecessarily.

The trunk circuits to the central office are arranged to permit direct inward dialing.

A register and marker system provides flexibility in traffic direction and for economical identification of a subscriber as needed for outgoing city traffic, transfer of a city call, class of service, and metering of toll calls.

Tone and ringing generators use transistors. Their on and off periods are controlled by standard relays instead of by thermal units or motor-driven cams.

Arcs across contacts are quenched by varistors or resistance-capacitance units, the latter being used for contacts operating at specified frequencies under control of pulse signals. Circuits are individually fused except for line circuits and terminal selectors, which are fused in groups of 8 and 5, respectively, because of their low current. Circuits can be disconnected manually by individual switches.

The alarm system is divided into urgent, routine, and delayed categories; the latter is used for the line-lockout condition and operates only if the handset is off the hook too long. Lamps and ringers on the operator's desk and on cabinets signal the alarms.

Terminals are provided for connecting routine test equipment and traffic recorders. A test set is also available to check the operating conditions of extension lines and subscriber sets.

Wrapped connections are used. Plug-in circuit units and multiswitches provide for variations in traffic, rearrangement of equipment, maintenance, and expansion. Front-access cabinets may be mounted back-to-back or against the wall.

2. Junction Diagram and Traffic Capacity

Figure 1 is a junction diagram. As in all indirect-control systems, once a connection has been established, only those units in the speech path remain engaged [7].

* Trademark of Bell Telephone Manufacturing Company; Antwerp, Belgium.

† Registered trademark of International Telephone and Telegraph Corporation.

Pentomat T Private Automatic Branch Exchange

2.1 SWITCHING SCHEME

Switching is based on groups of 50 subscriber lines. As the selector has 52 available outlets, the extra 2 are generally used for automatic call-back.

For more than 50 lines, overflow connections (not shown in Figure 1) on the preselection side are fitted between the groups of 50 and increase the traffic capacity to accommodate peak traffic. Above 200 lines, as grading is introduced, overflow connections are also used on the selection side [8, 9].

The auxiliary finder (Figure 1) proves useful, especially in low-capacity exchanges. It allows unrestricted subscribers to obtain a free path to a city trunk even if all local links are occupied.

A separate city chain is provided for up to 50 subscribers; for higher capacities, local terminal traffic and 2-way city traffic concentrate on the terminal selector.

For push-button calling, a code receiver and

code converter are necessary. The code receiver reads and sends codes for a local selection to the local register, while codes sent for a city selection are transmitted to the code converter for translation into direct-current or voice-frequency pulses.

2.2 TRAFFIC CAPACITY

Each group of 50 lines has a capacity of 10 erlangs, with a 1-percent loss probability. Local originated traffic and local terminal traffic each have 2.50 erlangs, and 2-way city traffic has 5.00 erlangs.

For fewer than 50 subscriber lines, with from 4 to 6 local links (excluding auxiliary circuit) and from 5 to 9 city trunks, traffic capacity is as follows.

Local originated	0.87 to 1.93 erlangs
Local terminal traffic	0.87 to 1.93 erlangs
2-way city traffic	1.36 to 3.80 erlangs

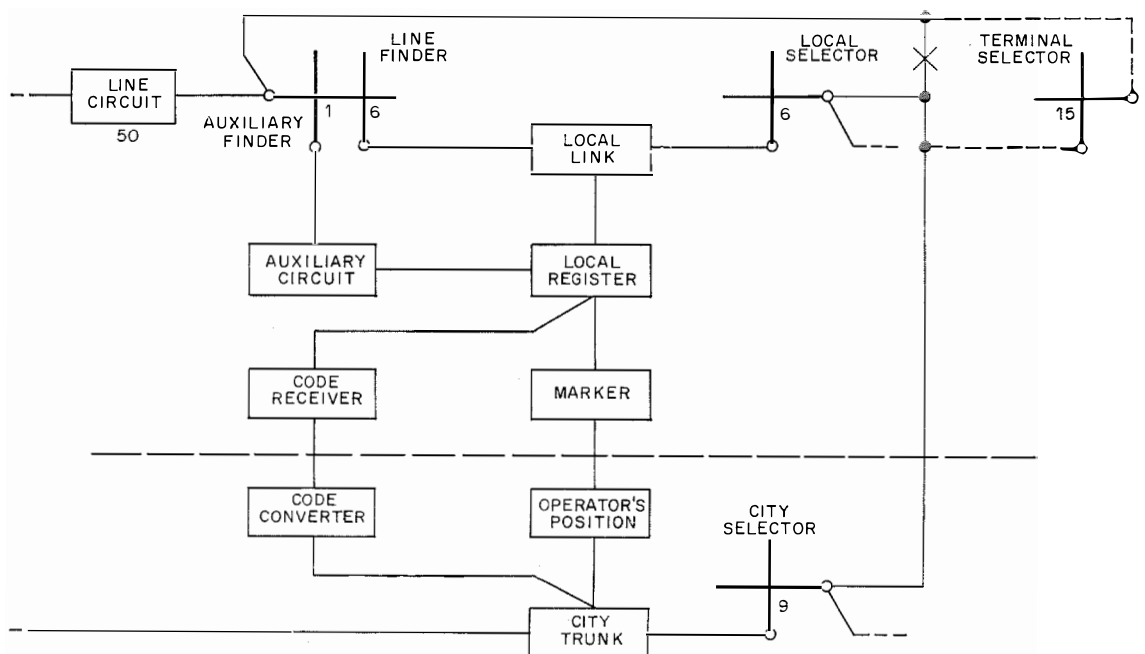


Figure 1—Junction diagram. For over 50 extensions the broken-line equipment is connected and the then shunting line is opened at X.

Switching accounts for only 250 milliseconds of the waiting time for dial tone and ringing tone.

3. Circuit Characteristics

Circuits are simple, as the city switching chain is separate from the local one. Indirect control permits many services to be provided economically.

3.1 TECHNICAL DATA

The maximum allowable resistance of subscriber line and set is 1000 ohms. Minimum permissible leakage is 20 000 ohms either between line wires or between these and ground.

Dialing is at 8 to 12 pulses per second with pulses of 50 to 70 percent duration. At least 400 milliseconds must be allowed between two digits. For push-button calling the maximum speed is 15 digits per second, with both digits and intervals between digits persisting for at least 30 milliseconds.

Operation is from a 48-volt supply with limits between 44 and 56 volts. Batteries or battery substitutes may be used. Temperature may vary between 0 and 45 degrees Celsius with a maximum relative humidity of 96 percent. Exchange operations are protected against voltages induced on extension lines [10].

3.2 NUMBERING

Numbers may consist of 2 or 3 digits. In making internal calls, the 2- or 3-digit extension number begins with 1...4, 1...6, 1...7, or 1...8. For special services, prefixes 5...0, 7...0, 8...0, or 9...0 are used.

Normally, 9 and 0 are used, respectively, for calls to operator and to the city network; however, the use of prefixes is flexible. Subscribers may be given access to only those services defined by certain prefixes. Since each subscriber can have his own party line, local numbering may be extensive.

3.3 CLASSES OF SUBSCRIBERS

Allotment of the 8 classes of subscribers is flexible, for both local and city traffic. Table 1 is given as an example.

At peak traffic times the operator can transfer certain subscribers from class 5 to class 7.

All subscribers can call over a third group of city trunks by dialing the prefix 8. Unrestricted subscribers can call over a second group of city trunks by dialing the prefix 7. These additional groups of trunk circuits are necessary in the following cases.

(A) The private automatic branch exchange is connected to several urban exchanges.

TABLE 1
ALLOTMENT OF SERVICES FOR CITY TRAFFIC

Services	Subscriber Classes							
	Unrestricted					Semirestricted		Fully Restricted
	1	2	3	4	5	6	7	8
Privileged service	x							
International calls	x	x						
Long-distance calls	x	x	x					
Suburban calls	x	x	x	x				
City calls	x	x	x	x	x			
Incoming city calls (1st group)	x	x	x	x	x	x		
Incoming city calls (2nd group)	x	x	x	x	x	x	x	
Local calls	x	x	x	x	x	x	x	x

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(B) The private automatic branch exchange is connected to the customary exchange, but toll service is separate from the local city service.

(C) Semiautomatic calls to local-battery and manual central-battery equipments, or to other private automatic branch exchanges, are requested.

City numbering control can be applied to two groups of city trunks to verify whether a subscriber is authorized to call into the city central office.

3.4 TRANSMISSION

Table 2 describes the transmission characteristics. The psophometric noise voltage on main-distribution-frame terminals of a line is 0.30 millivolt maximum. Wetting of non-fed contacts is provided.

3.5 SIGNALING

Transistor generators supply current at 25 and 450 hertz for ringing current and signaling

tones, which comply with the recommendations of the Comité Consultatif International Télégraphique et Téléphonique. Rapid ringing, to distinguish between city and local calls, is available also.

Continuous dial tone is used as it allows faster selection. In addition, a distinctive busy tone is sent to callers authorized to enter a busy connection.

To queue an unlimited number of calls for the same busy subscriber, a test distributor is provided; it prevents double connections and operates only toward the cabinets where calls are queued to accelerate connection when the subscriber becomes free.

4. Local Calls

When a subscriber initiates a call, the line connects to a direct local link via a line finder. Should all local links be busy, the line connects to an overflow local link to receive dial tone from a free register. If the overflow link is also busy, the line waits until a link circuit is released, or engages the auxiliary circuit if provided.

When digits enter the register, the marker selects the called party in a single operation even if there are two selecting stages. As soon as the called subscriber is reached through the local and terminal selectors, ringing current and ringing tone are sent immediately and the register and marker are released. If the called subscriber is busy, the entire switching chain is released and the caller receives busy tone from his own line circuit.

If push buttons are used, the code receiver is engaged for each digit by the register, where codes are stored. Should the caller delay selection for more than 10 seconds, either before sending digits or between digits, the register releases and the subscriber is placed in line-lockout condition.

Description	Frequency in Hertz		
	300	800	3400
Maximum insertion loss in nepers (decibels) for local and trunk calls	0.2 (1.74)	0.1 (0.87)	0.1 (0.87)
Minimum crosstalk attenuation in nepers (decibels) for local and trunk calls	8.5 (73.6)	8.5 (73.6)	8.5 (73.6)
Minimum unbalanced attenuation in nepers (decibels)	5 (43.4)	5.5 (47.8)	5.5 (47.8)
Minimum crosstalk attenuation in nepers (decibels) through common tone circuit	6.5 (56.5)	6.5 (56.5)	6.5 (56.5)
Minimum crosstalk attenuation in nepers (decibels) in line-lockout condition	5 (43.4)	5 (43.4)	5 (43.4)

4.1 BREAK-IN (PREFERENCE SERVICE)

Break-in service permits an authorized subscriber to break in on a conversation if the line is busy. Instead of being placed in line-lockout condition, the calling line is kept in the link circuit and receives a distinctive busy tone. If the caller now sends the digit 1, he can speak to the subscribers who are already talking; his joining the conversation is signaled by a warning tone. As soon as the wanted subscriber becomes free, ringing current and ringing tone are sent automatically.

4.2 AUTOMATIC QUEUEING

If an authorized subscriber calls a busy number, he receives a distinctive busy tone. The subscriber then presses the ground button and hangs up. The called number is supervised by the link circuit and when free, ringing current is sent to the caller. On answering, the caller receives ringing tone and the called party receives ringing current. Such queueing is cancelled if an incoming city call intervenes, the caller makes other calls, the caller delays replying for more than 15 seconds after the called subscriber becomes free, or the called subscriber does not finish his conversation within 3 minutes.

4.3 THROUGH DIALING

Through dialing over tie-lines and for paging and central dictation automatically inserts repeaters to compensate for attenuation of the speech level.

4.4 PARTY LINE

The capacity of the exchange can be increased through party-line connections. Ringing current is then applied in a discriminating manner between the two subscriber sets on the single line. The conversation also can be made private.

4.5 HUNTING GROUP

Provision is made to hunt for a free line within a group. This can be applied to 6 predetermined numbered lines in each group of 50 lines. Hunting groups are selected either by the subscriber number or by a 1-digit prefix.

4.6 PAGING

Paging [11] transfers the call to a number of signaling devices to find a subscriber who is not at his subscriber set. Optical, acoustic, or other types of signals may be used for paging. It can be initiated by sending a suffix during ringing of the called number or by sending a prefix and then the desired number. The called subscriber sends a prefix from the nearest subscriber set and the conversation is established on a single link circuit.

4.7 CALLS PLACED THROUGH OPERATOR

Conventional operator service may be used. However, a privileged subscriber, 5 of whom can be accommodated in each group of 50 lines, may call the operator by pressing a button without lifting the handset. The operator answers by pressing a marking button. The caller may wait for the operator to establish the desired connection or may hang up and be called by the operator. To facilitate service to such subscribers, the operator can break in on a busy line to announce the waiting call. Moreover, for urgent needs any subscriber can select a special operator's line and ask the operator to be connected to the wanted subscriber.

5. City Calls

City calls pass through the city trunk, city selector, and terminal selector (Figure 1). This service can be made fully automatic by means of equipment that allows direct dialing from the outside subscriber to the inside subscriber.

City trunks form an ideal group and depend on the grading in the city exchanges to provide for maximum traffic.

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5.1 OUTGOING CITY CALLS

An unrestricted subscriber can make outgoing city calls automatically or through the operator, while a semirestricted subscriber can make them only through the operator. The former sends the city prefix, which is generally 0, into a local register. Should all link circuits be busy, he reaches the register through the auxiliary link. He can then dial the city call. Fully restricted subscribers are connected into line lock-out, while semirestricted ones are connected to the operator. In push-button calling, the marker connects the code converter to the city trunk circuit.

If the subscriber is not entitled to receive a service offered by the city exchange, the marker connects blocking equipment to the calling city trunk, identifying the subscriber's class.

The subscriber can obtain dialed or undialed city connections from the operator by booking them through the operator's line. The operator connects the city trunk to the subscriber by operating as for incoming calls. However, for the undialed city connections the operator, by pressing a push button, can connect the city trunk directly without the subscriber hanging up.

5.1.1 *Selection Toward a City Exchange*

For conventional dialing the digits pass directly toward the city exchange. For push-button operation the signals are detected by the code receiver and sent to the code converter, which arranges for immediate translation into direct-current or voice-frequency pulses.

If a subscriber tries to make unauthorized use of city service or if a push-button subscriber delays more than 10 seconds before sending digits, the switching chain is released and the subscriber line put into line lockout.

5.1.2 *Call-Back (Inquiry) Call*

Local subscribers during a city conversation have the possibility to call other local subscrib-

ers, the operator, or the city exchange, through a second city trunk without releasing the first connection. This is made possible by pressing the ground button of the subset and, on receipt of the dial tone, by sending the respective number. During call-back all subscribers can maintain the same class as for normal calls.

In case of call-back toward a second city trunk, the speech wires of the first city trunk are metallicly extended to keep insertion loss low.

By pressing the button again the caller releases the call-back chain and returns to the previous connection.

5.1.3 *Broker's Call*

A subscriber may act as an intermediary between a called local subscriber and a called city subscriber by reaching the local subscriber through a call-back connection. Each time he sends the digit 1 he passes from call-back connection to city connection and vice versa without releasing the call-back chain.

5.1.4 *Automatic Transfer to Other Subscribers*

Following a call-back conversation a call may be transferred from one subscriber to another, if the calling subscriber hangs up. The trunk is returned to the operator for transfer either to a city subscriber or to a fully restricted internal subscriber.

5.1.5 *Call-Back and Transfer to Operator*

For call-back calls to the operator the 2-way city trunks release the engaged call-back chain and connect directly to the operator, while the outgoing city trunks connect through the operator's line as these circuits are not represented on the operator's desk. Push-button subscriber sets, besides the ground button, have another supplementary button used for direct access to the operator without engaging the call-back chain. After the call-back the subscriber can

transfer the city connection to the operator by replacing the handset, or return to the city connection by pressing the ground button again.

5.1.6 *Transfer to Other Subscribers via Operator*

After having received a transfer, the operator can forward the city connection to another subscriber by operating as for incoming city calls. For making a transfer of an outgoing city trunk the operator acts through the operator's line as a normal station. If the operator's line enjoys break-in and broker's-call services, the operator may either break in on a busy subscriber or speak privately with the inside subscriber and with the outside subscriber. Thus 1-way city trunks offer the same advantage as 2-way trunks.

5.1.7 *Return to Operator*

The subscriber can transfer a trunk to the operator by pressing his ground button and replacing the handset without waiting for a reply. For 2-way trunks the return signal appears individually on the operator's desk, while a common signal appears with outgoing trunks. The operator connects to the outgoing trunk through the operator's line by sending the reduced-service prefix (Section 5.3.2).

The trunks signal the operator in the same way if a subscriber executes a wrong operation, thus guaranteeing that a city call is not lost.

5.1.8 *Metering of Toll Calls*

A resettable meter per trunk, equipped on the operator's desk, and/or an individual meter per extension, are available. The extension meter may be associated with the trunk meter to give combined totals. The number of trunks provided with meters may be reduced if all taxed calls are handled by the operator.

Metering pulses are transmitted by the city exchange at 50 hertz on speech wires against

earth or at a frequency above audibility (16 kilohertz) on speech wires alone.

If counting is by meter per trunk, the subscriber's number appears optically at the operator's desk. At the same time a lamp connected to the meter flashes, indicating that pulses have been recorded. At the end of each call the operator copies the meter reading and subscriber number, then resets the meter to zero. The trunk circuit, optical display, and lamp associated with the meter thereupon release, while the city line and inside subscriber are released as soon as the call ends.

If the trunk is 2-way, a new incoming call that arrives before the meter has been reset is indicated but cannot be answered by the operator until the meter is reset.

5.1.9 *Controlled Availability*

Some city exchanges connect large groups of city trunks to a more-efficient city switching chain. Generally speaking, such groups comprise at least 15 trunks. They establish a call to the private automatic branch exchange by means of a 3- or 4-digit number.

In these cases, the current in the city line is removed if failures occur. Taking advantage of this arrangement, the trunk circuit makes outgoing connections subject to the presence of current in the city-exchange line circuit.

5.1.10 *Adaptation to Local Battery*

A subscriber or operator can call a local-battery subscriber set or exchange. Ringing current can be sent to the subscriber set; at the end of the call the end-of-conversation pulse is not sent but the trunk circuit is released immediately. Both ringing and end-of-conversation pulses are sent to the local-battery exchange and the trunk circuit is released 15 seconds after the subscriber hangs up. This delayed release, which is used also for incoming calls,

Pentomat T Private Automatic Branch Exchange

enables the operator of the local-battery exchange to end the connection before another subscriber engages it.

5.1.11 *Delayed or Controlled Release*

As in local-battery exchanges, release is delayed by 15 seconds in manual central-battery exchanges. Unfortunately, controlled release is seldom applicable, and therefore incoming calls from automatic city exchanges may also need delayed release. In this case the delay is only 7.5 seconds.

5.2 INCOMING CITY CALLS

The advantages of cordless manual boards are well known [12]. Trunk circuits appear individually (spring-loaded button and 2 lamps) on the operator's desk; a pilot lamp and ringer are provided, too, and the latter can be disconnected.

If trunks are multiplied, the operator who first replies to a call causes busy signals to appear on the other operators' desks for the trunk circuit involved. At 25 seconds after the first calling signal appears, the lamp flashes more frequently, calling attention to the delay. The calling condition is supervised by ringing current sent from the city exchange; should this current cease before the operator answers, the connection is released.

5.2.1 *Holding*

After answering, the operator can place the trunk in a holding condition in which the outside subscriber waits for the operator to re-establish voice communication. A lamp indicates this condition to the operator by flashing more frequently.

5.2.2 *Selection of Inside Subscriber*

Selection may involve normal, party, or hunting-group lines. The operator always uses his keyboard for this selection and may absorb the extra parts of the called number.

The keyboard becomes available for other calls as soon as the switching chain has been completed; this occurs 250 milliseconds after the last digit has been sent. The subscriber is supervised from the operator's desk, including restricted, free, busy, and reply conditions. A different busy signal is provided for local and city calls.

5.2.3 *Extension of Calls by Operator*

Incoming city calls can be extended either automatically or with assistance. In the first case busy and ringing tones can be sent to the outside subscriber, while in the second case completion of the extension is indicated on the operator's desk.

Although the operator can communicate with a fully restricted subscriber, he cannot place such subscriber in communication with the calling city subscriber, as the connection would return to the operator's desk. During automatic extension, if the busy or free conditions last more than 25 seconds, the lamp flashes more quickly and the operator may enter the trunk circuit and inform the outside subscriber of the progress of his call.

The operator may assist the call by remaining connected on the trunk circuit or by re-entering it before the called party replies.

The operator can extend a call a second way. During automatic extension, he presses a common button that permits him to be called back when the called subscriber replies. This call-back is signaled by both lamp and ringer.

5.2.4 *Splitting*

Before the inside subscriber replies, the operator can talk with the outside subscriber. After the called subscriber replies to an operator-assisted call, the operator can speak privately with either subscriber.

5.2.5 *Offer*

The operator may offer the call to a busy sub-

scriber. By pressing a common button, he cuts in on the conversation in progress after sending the warning tone. Ringing current is sent automatically as soon as the called subscriber hangs up.

5.2.6 Chain Call

If the outside subscriber wishes to communicate with several inside subscribers, the operator arranges for the chain call by pressing a common button. When the call is ended, the trunk is presented in a particular call-back condition to the same operator who put through the call. Thus further extensions of the trunk call can be made, until the chain call is cancelled by the operator.

5.3 NIGHT SERVICE AND REDUCED SERVICE

Night service and reduced service are provided by actuating the respective push buttons on the operator's desk to permit intermediate service between the city exchange and inside subscribers when the operator is absent. The following conditions apply.

(A) Wrong manipulations by subscribers during a city call return the call to either the night service or the reduced service.

(B) Individual meters per trunk record the total number of fee metering pulses during such service.

(C) Temporarily unrestricted subscribers cannot be transferred to a lower class of service.

(D) Semirestricted subscribers who dial the city prefix are placed in line lockout.

5.3.1 Night Service

The operator presses the night-service button. Thus incoming calls automatically go to a predetermined subscriber. If several subscribers require night service, they are connected in a hunting group.

Should the night subscriber's line be busy, incoming calls are accompanied by a warning tone that invites him to hang up. The night subscriber may be automatically transferred from a lower class of service to a higher one, to provide the most-effective temporary service.

5.3.2 Reduced Service

The operator presses the reduced-service button. Incoming calls set off telephone ringers in strategic locations. Any subscriber who is not fully restricted and dials the prefix for reduced service is connected to the city caller. He can therefore call back and transfer the call to another local subscriber.

5.4 HANDLING OF CALLS BY OPERATOR

The operator's routine could differ between dial and push-button equipment if no code converter is provided for dial equipment. Code converters are regular equipment in exchanges using push-button signaling, so that the use of the keyboard is standard. Table 3 shows the options available to the operator.

Option	City Call		Internal Call Via Operator's Line or Tie-Line
	Incoming	Outgoing	
Push button		x	
Keyboard	x	x	x
Dial		x	x

By pressing a push button the operator can establish 10 separate outgoing city calls to numbers composed of a maximum of 10 digits each. For this service the private automatic branch exchange is fitted with a repertory key-sender so that each push button of the keyboard represents a complete number. The repertory key-sender is an integral unit of the code converter. Push-button subscribers can also use it by engaging the trunk circuit with a special prefix.

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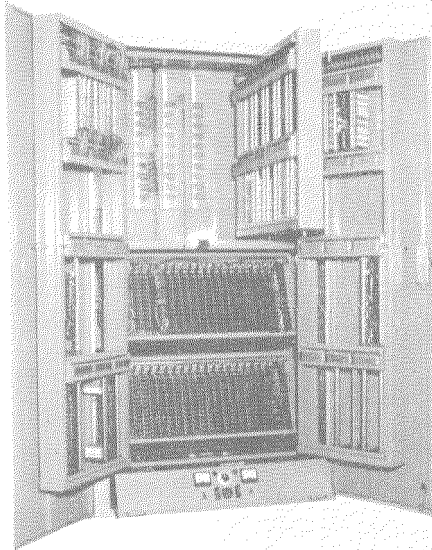


Figure 2—400T cabinet with multiswitch frames swung out.

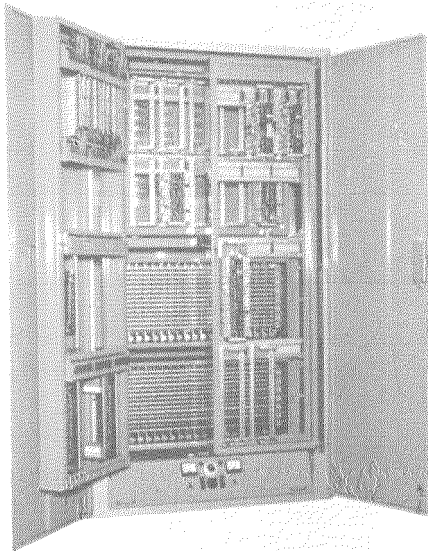


Figure 3—400T cabinet with equipment partly retracted.

5.5 DISTRIBUTION OF TRUNKS AT OPERATORS' DESKS

Each trunk is multiplied on 2 desks with full operation possible from either. If the number of trunks requires, they may be divided between the 2 desks.

5.6 EMERGENCY

Emergency service automatically connects city lines to predetermined subscribers on failure of a trunk-circuit fuse or the loss of supply current.

5.7 PRIORITY

Subsets can be connected directly to city lines with exclusion of the related city trunk if they are provided with an appropriate push button combined with a lamp. The lamp indicates at any moment the free or busy condition of the line in order to avoid breakdown of calls in progress.

6. Direct Inward Dialing

Both incoming and 2-way city trunk circuits are used for direct dialing to an inside subscriber by a city subscriber. Repeaters can be added to the trunk circuits in question, in accordance with local regulations. For direct inward dialing, all or part of the following criteria and signals may be used.

- (A) Controlled availability and engagement.
- (B) Readiness to receive dialing with or without initial dial tone.
- (C) End of selection, ringing, or busy tone.
- (D) Answer, end of conversation, and release.
- (E) Offer and re-call from interurban manual positions.

The outside subscriber may obtain operator assistance by dialing a prefix, generally digit 1.

7. Tie-Lines, Central Dictation, and Watchman Control

The link circuit is arranged for through dialing and for identification of the calling sub-

scriber. Therefore, authorized subscribers may call (by conventional dialing or by push button) tie-lines connected in a hunting group, the device for central dictation, and the watchman.

8. Rapid Call and Conference Call

By associating the subset with a keyboard, the subscriber may be able, by using up to 15 individual push buttons, either to call other subscribers or to place himself in conference with other subscribers, with the possibility of varying the number of subscribers connected in conference. Supplementary circuits providing the above facilities are prearranged for break-in service.

9. Equipment Characteristics

The 40T exchange accommodates 20 to 40 extension lines, and the 400T serves from below 50 to 400 extension lines. Two sizes of cabinets, 3 of operators' desks of the table type with capacities of 6, 12, and 24 trunks, and 2 plug-in units have been designed for these exchanges. Printed-circuit boards are used for quasi-electronic units. The designs permit production using common tooling.

Figure 2 shows the 400T cabinet with multi-switch frames swung out to give access to front and back. The open drawer at the bottom houses the power supply and emergency battery. Figure 3 shows the same cabinet with equipment retracted. Table 4 gives data for both types of cabinet.

Figure 4 shows a plug-in unit for mounting 24 double relays. A smaller version accommodates 16 double relays. Figure 5 shows the code-receiver unit. Figure 6 shows the 12-trunk table-type operator's desk. Space has been provided for 12 resettable meters and for display of the subscriber's number.

Table 5 shows the equipment required for various capacities of the exchange.

	Type 400T	Type 40T
Dimensions in millimeters (inches)	2000 × 1040 × 530 (79 × 41 × 21)	1600 × 1040 × 420 (63 × 41 × 17)
Main distributing frame	120 lines	56 lines
Stabilized power supply	7 to 8.5 amperes	5 to 6 amperes
Emergency battery	6 ampere-hours	6 ampere-hours

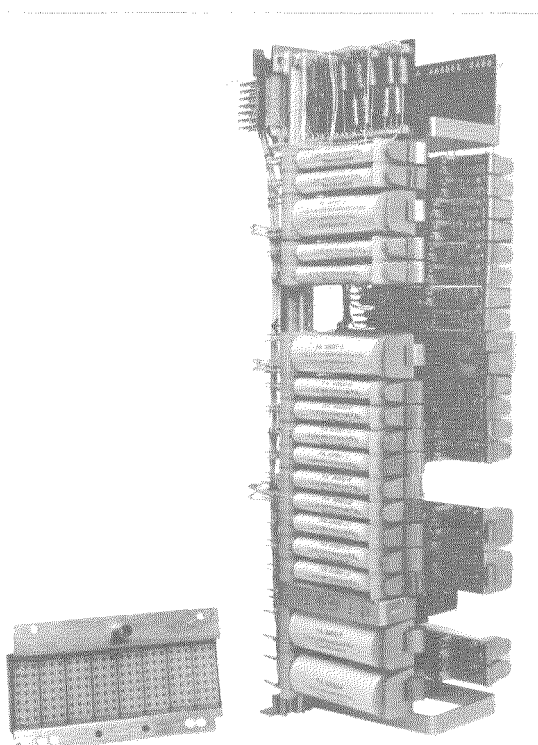


Figure 4--Plug-in relay unit.

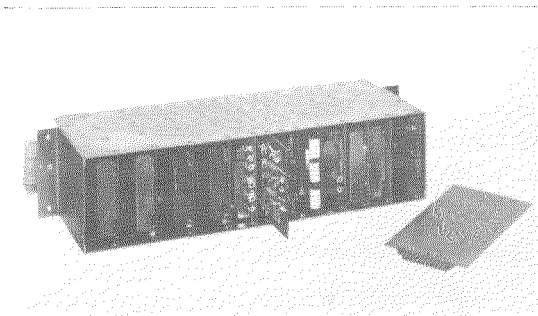
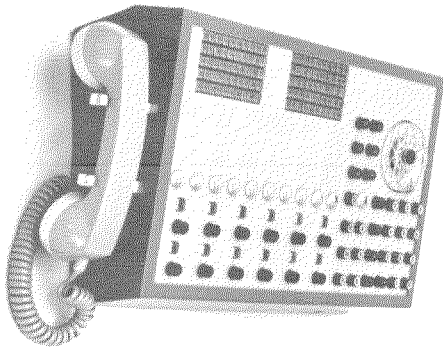


Figure 5—Code-receiver unit.

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Figure 6—Table-type 12-trunk operator's desk.



Capacities			Cabinets
City Trunks	Extension Lines	Local Links	
3 to 5	20 to 40	3 to 4	1 (small)
6	50	6	1
8	50	6	1
9 to 52	50 to 400	6 to 48	1 to 8

10. Cabling

Wrapped connections are used. The internal wiring for relays and multiswitches uses polyvinylchloride-covered yellow wires 0.5 millimeter thick (24 American Wire Gage). Power supply wires are blue for negative and red for positive polarity. Spiral cable forms leave the multiswitches at their rotation points. These cable forms terminate in female connectors on blocks that correspond to the male terminal blocks associated with each selector. It is thus easy to change a circuit configuration by shifting a female plug-in block from one male terminal block to another.

11. Acknowledgments

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12. References

1. F. Gohorel, "Pentaconta Dial Telephone Switching System," *Electrical Communication*, volume 31, number 2, pages 75–106; June 1954.
2. J. P. Basset and P. Camus, "1000B Pentaconta Crossbar Switching System," *Electrical Communication*, volume 38, number 2, pages 196–212; 1963.
3. H. Oden, "Aktuelle Probleme der Vermittlungstechnik," *SEL-Nachrichten*, volume 10, number 3, pages 125–138; 1962.
4. H. Schönemeyer, "Quasi-Electronic Telephone Switching System HE-60," *Electrical Communication*, volume 39, number 2, pages 244–259; 1964.
5. H. Oden, "Zur Einführung der Tastwahl in der Nebenstellentechnik," *SEL-Nachrichten*, volume 11, number 4, pages 174–177; 1963.
6. W. Klein, "Die Tastwahl in der Citomaten-Technik," *SEL-Nachrichten*, volume 11, number 4, pages 177–183; 1963.
7. A. Eilertsen and S. Kilander, "Crossbar P.A.B.X. ARD 561," *Ericsson Review*, volume 39, number 3, pages 72–79; 1962.
8. M. Gandais and A. Sanneris, STET—TORINO, "Principi di traffico telefonico," volume 1, appendix 1; 1956. Also volume 2, appendix 2; 1960.
9. M. Chastang, "Système Pentaconta—Calcul d'organes—Notions de Probabilités et de trafic," Compagnie Générale de Constructions Téléphoniques, Paris, France; 1961.

Pentomat T Private Automatic Branch Exchange

10. A. Bianchi, "Sul coefficiente di mutua induzione tra linee elettriche e di telecomunicazione," *Poste e Telecomunicazioni*, number 7-8, pages 41-47; 1962.
11. M. Göller and K. Richter, "Neue Ergänzungseinrichtungen für Nebenstellenanlagen," *SEL-Nachrichten*, volume 7, number 1, pages 46-51; 1959.
12. P. A. Marchant, "An Introduction to Large Cordless P.A.B.X.s," *Post Office Electrical Engineers' Journal*, volume 53, Part 4, pages 231-235; January 1961.

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Flexible Routing Plans

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1. Foreword

The International Telegraph and Telephone Consultative Committee is pressing forward with a new signalling technique that should be suitable for both intercontinental and intra-continental circuits. The new system should be faster and provide potential for the future as regards greater flexibility in routing [1]. If success is achieved in obtaining these aims and in providing a capacity for more signals, the question must arise as to the application of the new technique to part of the national networks.

This paper outlines some of the existing routing restrictions and ways in which a new signalling system may enable greater flexibility to be obtained.

2. Need for More-Flexible Routing

The growth in demand for telephone service has shown that both multi-exchange and international networks need greater routing flexibility.

Many administrations are finding that the growth of large multi-exchange areas is attributable not only to new subscribers but also to the need to extend the size of the area. Neither a star- nor a mesh-type network offers an attractive plan for the future; and even the more-efficient networks incorporating code translation, transit centres, and planned alternative routing are also facing increasing difficulties as the junction routes continue to increase in both length and number [2]. The restrictions and limitations that exist were unavoidable at the time of planning, but more-advanced techniques are now introducing new possibilities.

Many of the present networks impose routing restrictions to limit the number of junctions that may be used in series, and no doubt such limitations are necessary with slow signalling, slow switching, unamplified speech channels, and to a lesser extent amplified speech channels using frequency division. With the advent of data transmission, data processing, and digital speech-modulation systems, there is the need

for faster signalling and switching, but many of the routing limitations no longer apply. Evolution necessitates change, and well-tried devices such as the dial must inevitably follow the sun-dial and be replaced by new concepts more fitted to the needs of the future. There remains, however, the problem of organizing some competent interworking between the past and the future; it is impracticable to assume that the present plant can be scrapped, although a plan could be envisaged in which the existing plant continues while all new equipments are associated with a new network rather than the old one. There would need to be interfaces—unfortunately it is often difficult to introduce any improvements without these wasteful necessities.

Quicker operation and low-loss speech channels provide the possibility for better utilization of plant, but the technical ability to use any possible path between two centres only provides an economic or service advantage when there is adequate control or direction to ensure that calls do not meander round a network seeking a free route. In a national network it is reasonable to contemplate a single control centre that is adequately supplied with programmes and traffic reports to decide the correct action for each eventuality. For obvious reasons a central control for an international network is less attractive, and there are other aspects of international operation that are substantially different. Very long circuits are unavoidably expensive, and their efficient employment dictates the use of terminal equipment that cannot be justified for shorter national toll circuits.

Another consideration that applies most strikingly in the case of long east-west international circuits is the short effective working day caused by time differences. With flexible routing the use of a very indirect route may be justified to employ facilities that are lightly loaded at the time. It is relatively simple to decide to what extent a detour may be accepted in a national network, but the decision is more difficult if the detour involves a second administration. Another example that is likely to

arise in the future is the case in which the distance is substantially the same whether an eastward or westward approach is used; in such a case it would be advantageous to use the "dark" and therefore less busy route; such a decision might still be advisable if the dark route is rather longer than the other. What does seem pertinent is the fact that one route should be preferred at some hours of the day, whereas the reverse holds true for other hours. The same type of reversal of the preferred route may well apply to satellite communications, in which the distances to different ground stations are irrelevant compared with the better utilization of other links in the connection.

One reason for providing greater routing flexibility is to enable the order in which possible routes are searched to conform with existing traffic conditions that may vary systematically or statistically. Another and more important reason is to make available all the suitable routes rather than to have to depend on the rigid rules that must be followed with a hierarchical arrangement. A third reason is the need to provide proper relief in the case of a group of circuits being temporarily out of service; in such conditions other routes that are more indirect may also be made available, together with more channels in the existing indirect routes. However, the extent to which further overflow is advisable must depend on the state of congestion in the routes to which it is wished to direct more traffic. Despite the desirable principle that in normal conditions every customer should have an equal chance of success in obtaining a connection, it is unreasonable to set up a call through an emergency route if this action is likely to deny service to several other customers. In the case of a more general traffic overload affecting a number of circuit groups, the service requirements may be more demanding. It is certainly true that the largest number of calls can be satisfied by giving preference to those that can be completed with a single long-distance link. However, this procedure would result in discontinuing the service between all centres not

connected by direct links. It would be more reasonable to seek to reduce the grade of service* uniformly so that available facilities maintained some service for all potential users. It seems, therefore, that there would be merit in a routing-control process that could handle overload conditions by imposing a reduced grade of service; to achieve such results some advantage might be taken of the characteristic difference between satellite and cable circuits. A flexible routing plan needs to be able to determine the traffic situation before deciding if, and how, a call should be extended. The control processing needs to operate rapidly, and it is unreasonable to expect operators to establish the state of affairs sufficiently quickly to exercise adequate control.

In October 1963, representatives of a number of administrations discussed in Melbourne the needs for more flexible routing for international connections, and attention was drawn to the inherent difficulties of stage-by-stage selection of the route. When a state of congestion is encountered, there may be other routes over which the connection could be established, but the transit centre where congestion is met has insufficient information on which to make a decision. Another objection to re-routing being undertaken from such a transit centre was that the best route to use might not pass through this centre. Similarly, objections were raised to making a second attempt from the outgoing international centre, as it was difficult to provide each register with sufficient information and also difficult to ensure that the selection would follow any preselected route, especially if several transit centres were involved. It was

* The expression "grade of service" covers all causes which impair a customer's service owing to plant insufficiency. This could include measuring traffic outside the busy period, inaccuracy due to sample size or measurement process, growth estimation, and other reasons resulting in the number of working circuits in situ being inadequate. In the past, the expression has sometimes been loosely used to express the conversion process from a stated traffic to a number of circuits to be provided and has led to much confusion at international meetings.

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noted that the International Telegraph and Telephone Consultative Committee Number 6 Signalling System was expected to incorporate new signalling concepts that would provide extended facilities for routing control.

Hierarchical routing is often based on an “exploded” form of star-type network. In the world network there are a number of such areas, each including several important national centres. An adequate grade of service is ensured by the stipulation that each centre can reach any other centre by one or more final groups. The hierarchy is achieved by assigning a status to each centre, with the following obligations:—

(A) Each area must contain at least one *CT1*, with a direct final group to each of the other *CT1*'s.

(B) Each area may contain any number of *CT2*'s, each of which must have a direct final group to the *CT1* of its area.

(C) Each area may contain any number of *CT3*'s, each of which must have a direct final group to one *CT2*.

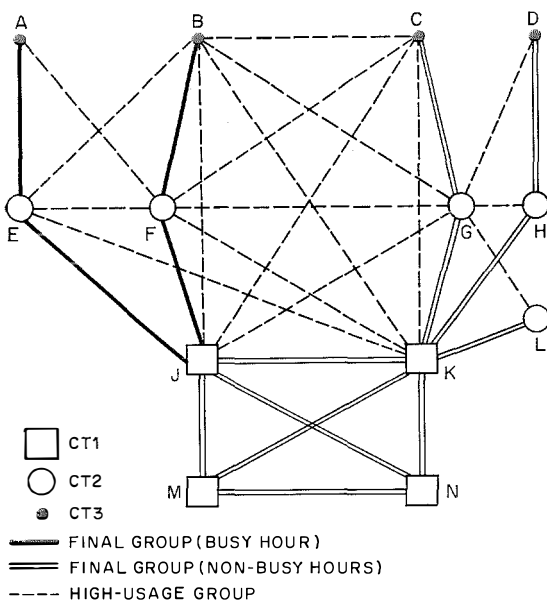


Figure 1—Hierarchical routing network.

It can be seen from Figure 1 that the maximum number of final groups between any pair of centres is 5; with certain safeguards a transit centre may be introduced between two *CT1*'s, thereby increasing this total to 6. In the majority of international connections the total number of links is limited to 12 by restricting the national networks associated with *CT1*'s, *CT2*'s, and *CT3*'s to 5, 4, and 3 national links respectively.

Superimposed on this backbone network there are high-usage circuit groups arranged to bypass two or more adjacent links of a final route. Such a plan has the merit that stage-by-stage selection may be made without regard to the source of the connection, but there is the disadvantage that no high-usage group may be used if the final route by which it is supported would involve too many centres for transmission. The first column of Table 1, which should be read in association with Figure 1, lists several possible routes connecting centres E and C, although only the bold lettered routes may be used with the hierarchical plan. Route EBC, for example, is not admissible because congestion at B would lead to the route EBFJKGC, which contains too many links. It is not suggested that the unrestricted use of all the indirect routes satisfying the maximum number-of-links requirement is necessarily beneficial. Some interesting studies on the use of simple, symmetrical, and hierarchical routing plans have been presented to the 3rd and 4th Teletraffic Congresses [3, 4].

3. New Tools and Concepts

It is interesting to speculate on the prospect of the Number 6 Signalling System providing more facilities for routing than have been available with earlier systems. In March 1963, the Chile Telephone Company proposed to the International Telegraph and Telephone Consultative Committee that the basic philosophy of the Number 6 Signalling System should include the use of a data stream transmitted over a separate signalling channel [5]. This recom-

mendation was made for the following reasons:—

(A) The signalling channel would be independent of transmission complications introduced by speech imitation of signals, by echo suppressors, by companders, by Time Assignment Speech Interpolation, and by future transmission developments that might make an in-band signalling system obsolete.

(B) A data stream using recognized data-transmission techniques could transmit many more signals than would be transmitted by conventional systems over speech channels. (For example, 500 speech channels might need 100 000 signals per hour, whereas a data channel should be capable of transmitting two or three times this amount.)

(C) In the future a faster signalling system will be required for data messages, and the larger signal-code capacity will be needed for satellite transmission systems.

A natural consequence of the use of a separate signalling channel is that each signal must include a label, or identity number, so that signals related to the same call may be associated together at the receiving end. This identity-number technique provides a convenient way of sending many different types of service message. Traffic-management signals or messages can be transmitted over common channels so long as they are provided with an identity number as if they had a message channel. These signals could be generated by traffic-measurement machines and be used to up-date stores that could be consulted when a choice of route had to be determined. One thousand signals per hour would enable the state of a circuit group to be reported every few seconds; it is unlikely, however, that such frequent reporting would be needed, as it is probable that only significant changes of state require to be reported. A routing monitoring signal could be used to trace the origin and the speech channels of a connection; such a signal sent with the identity number of the connection concerned could cause the various centres to transmit the identity numbers in

turn, so that details of the international route would be presented without reference to registers or speech-channel equipment. Messages for maintenance use could be transmitted as telegrams, using code words or code numbers to

TABLE 1
ROUTES, IDENTITY NUMBERS, AND SPEECH CHANNELS AVAILABLE BETWEEN TWO CENTRES

Route (1)	Quantity of Identity Numbers Normally Assigned			Speech Channels (5)
	Before Busy Hour (2)	Busy Hour (3)	After Busy Hour (4)	
EBC	8	10	8	10/10
EFC	8	10	5	15/10
EKC	5	10	8	10/15
EJC	8	10	5	50/10
EFBC	5	5	0	15/30/10
EBGC	5	5	5	10/10/30
EBFC	5	5	0	10/30/10
EAFB	5	5	0	20/10/10
EKGC	0	5	5	10/50/30
EKBC	0	5	5	10/10/10
EKFC	5	5	5	10/15/10
EKJC	5	5	5	10/80/10
EJGC	8	10	8	50/15/30
EJFC	3	5	5	50/50/10
EJBC	3	5	5	50/15/10
EJKC	8	10	10	50/80/15
EJKGC	10	15	10	50/80/50/30
	<u>91</u>	<u>125</u>	<u>89</u>	
	Quantity of Additional Numbers Made Available in Case of Emergency			
EBKGC	} 3 numbers per route = 57			
EBJKC				
EBJGC				
EFBGC				
EFBKC				
EJFBC				
EJFGC				
EJFKC				
EKJFC				
EKJGC				
EKHGC				
EKLGC				
EAFGC				
EAFKC				
EAFBC				
EAFJC				
EFGC				
EFJC				
EFKC				

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avoid language difficulties; no message channel is needed for these messages as they can use the signal channel, although an identity number is required to associate the characters of each message.

An advantage of the use of a data stream is the potential for fast signalling and, consequently, the possibility of making a second attempt sufficiently quickly so that the caller is not inconvenienced. In the past the post-dialling delay difficulty has involved some compromise between obtaining plant economy, by awaiting all address information before proceeding with the connection, and the alternative of commencing sooner although this has meant a less efficient use of the line.

A separate signalling channel can make a useful contribution to the reduction of post-dialling delay because at the outgoing centre it is possible to select an appropriate signal channel and identity number on receipt of the country code. The subsequent transmission of a Seizing Signal accompanied by the selected identity number will result in the link associations to the wanted centre being prepared in readiness for the transmission of the national number. By using a data stream it should be possible to establish such a signal path in less than half the time taken by conventional systems. The selection of the speech channels to be used can be delayed until after this signal-path association is established, and it is not therefore necessary to waste time on long circuits while waiting for the completion of the called subscriber's number.

It is thus seen that some identity numbers may serve to associate the signals of a particular call, while others may be used for a management message. In the latter case the identity number, besides being used for association, also provides the address to which the message should be delivered. A somewhat similar function is achieved if the identity number establishes a series of link associations to provide the means for sending further signals to some predetermined destination. There are other uses for identity signals that are described later.

The potentialities of faster signalling systems have not yet been sufficiently studied to decide which of the different arrangements best suits the various requirements of the future. Some appreciation of the possibilities can be obtained from an outline of a typical arrangement.

In addition to the number, variety, and speed of the signals available in a new system, there are new concepts that show some promise of providing the type of control needed for a flexible routing plan. As already mentioned, the use of a separate signalling channel demands some means of associating all the signals relating to the same call. The method used for this association is not necessarily important. It is more significant that these channel associations be recorded in such a way that signals may be passed along a succession of links. Such an arrangement provides a very natural source from which the routing of any connection may be ascertained. Identity numbers have another valuable application because they offer a means by which the control of route preselection may be exercised.

A separate-channel signalling system can be designed to provide the stage-by-stage routing, used in existing systems, by first engaging a speech channel and then transmitting a Seizing Signal that includes the identity of this speech channel. There are, however, more interesting ways of setting up a connection. Assume, for example, that each of a group of identity numbers signifies a circuit group forming a direct route from an outgoing centre to an incoming centre. The assignment and transmission of a free identity number in this group would enable the digits forming the national number to be associated at the receiving centre and thus allow the connection to be completed. The speech channel should be seized before the connection is estimated, but not necessarily before starting to send the national number. As with cross-office link-type systems, it is necessary to find a channel that has the appropriate access at both terminals. Naturally it will sometimes be found that no direct speech channels are available, and as a consequence an attempt must be

made to find a free identity number in an indirect route. At a suitable time the search for the speech channels would again be initiated. Route identity numbers provide a convenient means by which administrations may record the traffic per route. These procedures depend on quick signalling and the ability to send sufficient signals to control the speech-channel selection. A group of "route" identity numbers need not necessarily preselect the route completely and could perfectly well be used to extend the connection to some distant *CT1* where further routing could be preselected. The ability to use signals generously would enable the distant centre to be informed of the permissible number of transit points that might be added [6].

As an example, the preselection of the route as a whole would provide several useful facilities. Referring again to Table 1, it is shown that centre E has 17 possible normal routes by which it can reach centre C, and that during the busy hour for this relation there are 125 selectable identity numbers listed in column (3). At any time many of these identity numbers may already be engaged, but reference to traffic-congestion reports concerning the speech channels shown in column (5) could enable the load to be suitably spread. The selection of an identity number would not necessarily guarantee the availability of the required speech channel(s); rapid signalling would, however, enable a second attempt to be made by preselecting another route if the first was unavailable.

Columns (2) and (4) of the table indicate how the dispersal of the traffic might be varied both before and after the busy hour. As the busy hour moves from east to west, it is advisable to direct the traffic away from the more congested routes. It is also interesting that an administration may choose to use any combination of the available routes by agreement with the other administrations concerned.

In the lower part of column (1) a further 19 routes are listed as normally unavailable but capable of being employed in the case of emergency. Attention is drawn to the wide dispersal

of traffic that is possible and to the fact that the temporary breakdown of a group of circuits does not result in a serious increase in traffic to any other group.

The classification of centres as *CT1*, *CT2*, or *CT3* could remain to ensure the presence of a final route between any pair of centres. Some advantage may be gained by employing two *CT1*'s in each area to provide two final routes between any two centres in the area. The ability to select routes according to traffic-load patterns instead of hierarchy is likely to become increasingly useful with the introduction of satellite forms of transmission.

4. Conclusions

Flexible routing, as described, offers the following features:—

- (A) A flexible routing plan can, if desired, provide arrangements similar to those existing.
- (B) A flexible plan can also be arranged to preselect the route.
- (C) A flexible plan will usually offer a larger number of potential routes for normal conditions. This greater potential is possible because hierarchical restrictions do not apply.
- (D) Auxiliary channels or routes may be made available at times when such routes are not fully loaded owing to non-coincidence of busy hours.
- (E) Appropriate limitation of identity numbers can restrict the number of channels in any route that may be used for overflow by other relations.
- (F) In emergency conditions, such as the breakdown of a high-usage route, the permitted overflow via other routes may be increased temporarily, but only to some predetermined extent.
- (G) Introduction of emergency operation can be made dependent on bilateral or multilateral action.

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(H) Rather than follow an invariable rule, the sequence of channel selection can be varied to suit traffic and time factors.

(I) Choice of selectable routes may be made dependent on the number of carrier links in the national network.

(J) In the case of general congestion, access to certain multilink routes can be denied.

(K) Signals for establishing a connection can be transmitted over the signal channels before the speech channels are selected.

(L) Link-selection processes can be used for the selection of links within and between centres.

(M) Traffic per route can be conveniently recorded for accounting purposes.

The potential for more-flexible routing, which may become available with the Number 6 Signalling System, has been described with reference to the international service, which is by no means identical to the national service. However, there is ample scope in national networks for any flexibility that will allow more-efficient use of the plant in normal conditions and provide reasonable safeguards in emergency condi-

tions; a larger signal code and quicker operation are also likely to be valuable.

5. References

1. International Telegraph and Telephone Consultative Committee, Study Group XI, number 1; 1964–1968.
2. E. P. G. Wright, "Alternative Trunking for Telephone Traffic in a Multi-Office Area," *Electrical Communication*, volume 10, number 2, pages 86–88; 1931.
3. J. H. Weber, "Some Traffic Characteristics of Communications Networks with Automatic Alternate Routing," Third International Teletraffic Congress; 1961.
4. J. H. Weber, "Some Aspects of Routing and Control in Communications Systems," Fourth International Teletraffic Congress; 1964.
5. International Telegraph and Telephone Consultative Committee, Study Group XI, number III; 1961–1964. (Chile Telephone Company)
6. M. Segal, "Traffic Engineering of Communication Networks with a General Class of Routing Schemes," Fourth International Teletraffic Congress; 1964.

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For many years Mr. Wright has been a delegate to Study Groups of the International Telegraph and Telephone Consultative Committee dealing with signalling routing and data transmission. He is Chairman of a working party of that organization concerned with traffic engineering questions and is also a member of the Council of the International Teletraffic Congress.

Sensitivity Coefficients as Criteria for Noise in Telecommunication Lines *

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1. Introduction

Interference conveyed to telecommunication lines from power lines is not necessarily limited to the fundamental frequency of the power system but may include additional frequencies produced by generators, rectifiers, and transformers. The interference may thus consist of mixtures of frequencies.

The degree of such disturbance to the users of a telecommunication line varies with the frequency of the interference. Therefore a network weighting the interference as a function of frequency is used to evaluate the amount of disturbance. For broadcasting, only the properties of the human ear need be considered, while for commercial telephony, the electroacoustic properties of the telephone receiver are also of importance.

Figure 1 shows the well-known psophometric curves defining the amplitude-frequency characteristic of a weighting network that discriminates against the frequencies that have less disturbing effect than the 800-hertz reference frequency for telephony and 1000 hertz for broadcasting. When measuring voltages induced in telecommunication channels, a distinction must be made between weighted and nonweighted values.

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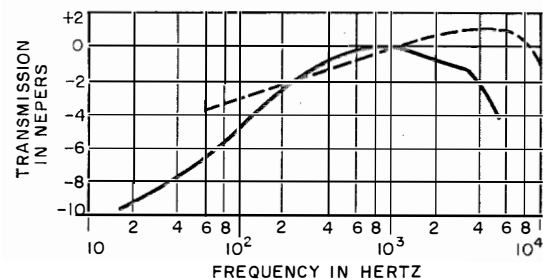


Figure 1—Psophometric frequency-weighting curves. The solid line is for a commercial telephone circuit, and the broken line is for a standard broadcast circuit up to 10 000 hertz.

2. Types of Interference

There are four principal causes of interference: magnetic-field coupling, electric-field coupling, and the effects of line capacitance unbalances to earth for each field. They are discussed below for the case where the power line consists of the single conductor with earth return, as for example, in a single-phase electric railway.

Figure 2 shows the case of the magnetic-field effect on a 2-wire telecommunication open line by a power line designated as O . The magnetic lines of force produced by the disturbing current I_{st} of the power line envelop both telephone conductors. The longitudinal voltage E_a induced in conductor a (nearer to the power line) is greater than E_b induced in conductor b . As a result there appears at the matched terminal impedance Z a transverse voltage U_o , which when weighted produces a noise voltage. This voltage depends on the

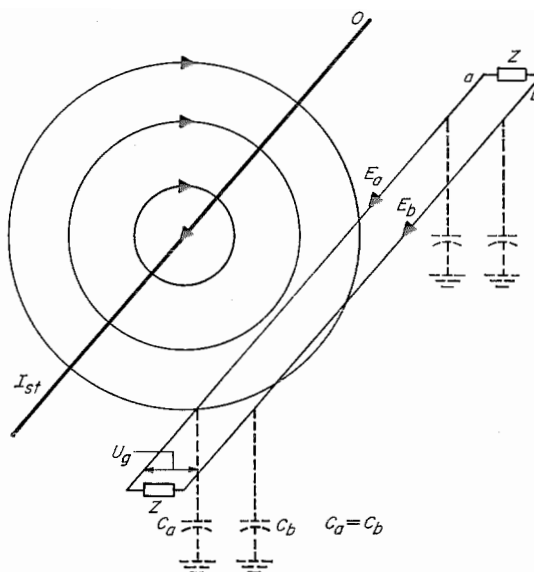


Figure 2—Magnetic-field effect on a 2-wire telecommunication line. I_{st} = disturbing current of the power line O ; E_a and E_b = longitudinal voltages induced in conductors a and b ; and U_o = transverse voltage appearing at matched terminal impedance Z .

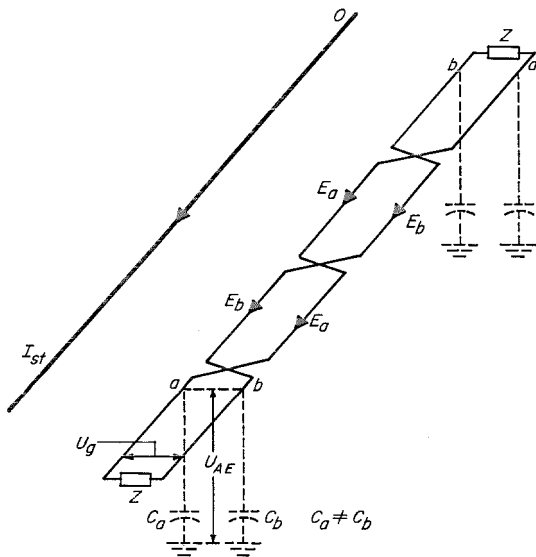


Figure 3—Magnetic-field effect combined with capacitance unbalances to earth. U_{AE} = voltages between conductors a and b and earth; C_a and C_b = capacitances between conductors a and b and earth; E_{gO} = longitudinal voltages; $\Sigma E_a = \Sigma E_b = E_{gO}$; $\lambda_t = (2U_g/E_{gO}) \times (600\Omega/Z)^{1/2}$.

geometric positions of conductors a and b ; if the capacitances to earth of the 2 conductors are assumed to be approximately equal, they will have no significant effect on the noise voltage.

Figure 3 is similar to Figure 2, but the 2 conductors of the open wire line are transposed at regular intervals so that their average distances from the power line are equal. Thus the longitudinal voltages induced in the 2 conductors are equal ($E_a = E_b$) and they produce no transverse voltage U_g . However, in the example shown the capacitances to earth are assumed to be different at the near end, and the voltages between the 2 wires and earth U_{AE} appearing as a result of the impressed longitudinal voltages E_{gO} are also different. Thus a transverse voltage U_g is produced indirectly by the magnetic field and unbalanced capacitance to earth.

If the noise voltage U_g is referred to 600 ohms and multiplied by 2, the noise electromotive force is obtained. If we divide this by the

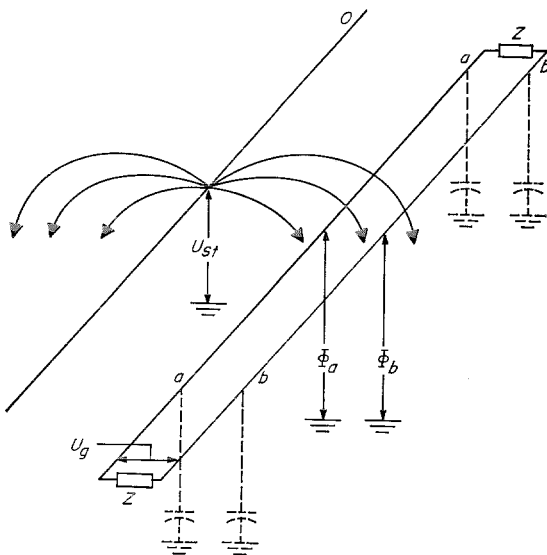


Figure 4—Electric-field effect on a 2-wire telecommunication line. Φ_a and Φ_b are the respective peak values of the potentials of conductors a and b .

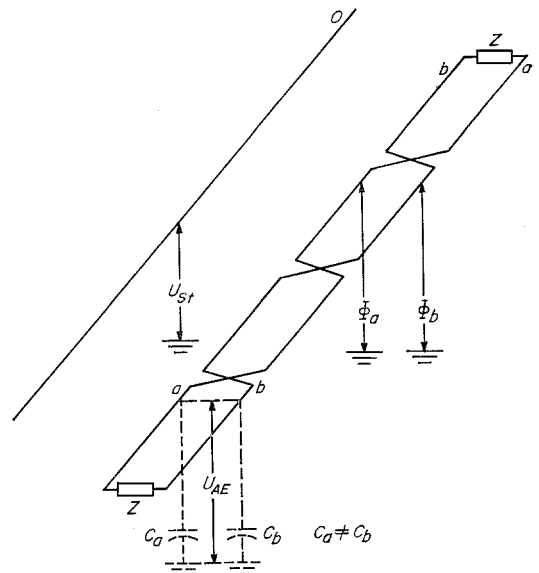


Figure 5—Electric-field effect combined with capacitance unbalances to earth. $\Sigma \Phi_a = \Sigma \Phi_b$; $(U_{AE})_w = U_{gO}$; $\lambda_t = (2U_g/U_{gO})(600\Omega/Z)^{1/2}$.

weighted impressed longitudinal voltages E_{g0} , we obtain the sensitivity coefficient for the case of magnetic interference λ_i , which is a criterion for the unbalance of a 2-wire line. The legend for Figure 3 gives the equation for this sensitivity coefficient, where Z is the characteristic impedance of the line. It is converted to 600 ohms. This type of interference also occurs in telecommunication cables.

Figure 4 shows an example of interference due to electric-field effects. It is of interest only for open wire lines. The electric lines of displacement due to the disturbing voltage U_{St} of the power line cause the potentials of the 2 conductors of the 2-wire line to rise to the values Φ_a and Φ_b , the potential Φ_a of conductor a (nearer the power line) being higher than that of conductor b . The difference between the potentials of the 2 conductors produces a noise voltage U_g at the terminal impedance Z (again resulting from the geometric positions of conductors a and b). The capacitances shown between the conductors and earth are equal and therefore participate only indirectly in producing the transverse voltage.

Figure 5 shows the case of the transposed line. The resultant potentials appearing on the 2 conductors are now equal and there would be

no transverse voltage at a matched terminal impedance Z , had it not been assumed in the present example that there was a capacitance unbalance to earth at the near end. The different voltages U_{AE} present between conductor and earth produce a noise voltage U_g , which results indirectly from the capacitance unbalance to earth. If we double the noise voltage and refer it to 600 ohms we obtain the noise electromotive force, which when divided by the weighted voltage to earth U_{g0} gives the sensitivity coefficient λ_e for the case of electric-field interference. This is also a criterion for the unbalance of a circuit. The legend for Figure 5 gives the equation for λ_e .

The various sensitivity coefficients assume different values if the circuit under investigation is one of a group of circuits. The neighboring lines then also have impressed on them longitudinal voltages and potentials, which may considerably change the noise voltage of the line under investigation.

This is shown in Figure 6 for the case of magnetic-field interference. The transverse capacitances, which are indicated only by C'_{45} and C''_{45} , would greatly influence the balance to earth of the 2 lines if, as a result of the longitudinal voltages impressed on all

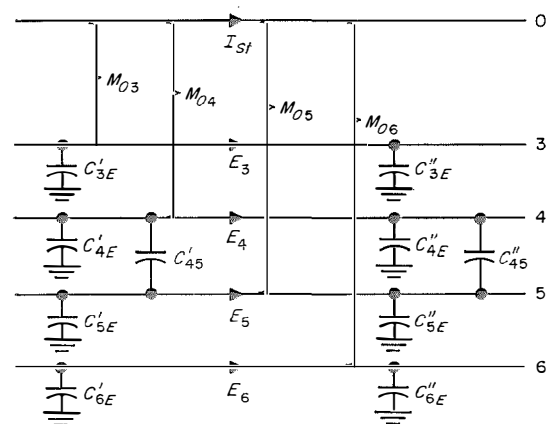


Figure 6—Effect of neighboring open wire lines in the case of magnetic-field interference.

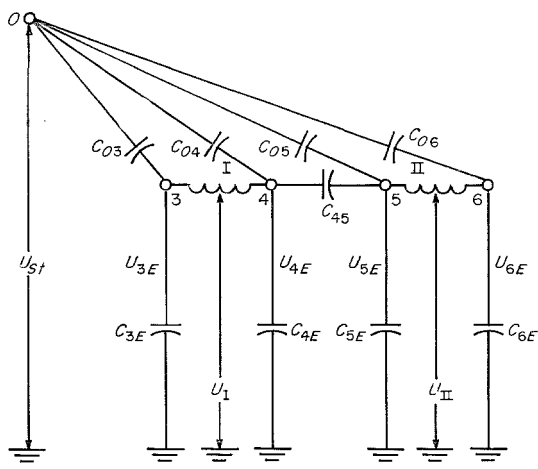


Figure 7—Effect of neighboring open wire lines in the case of electric-field interference.

the conductors, the voltage differences involved were not very small. Figure 7 shows a corresponding situation for the case of electric-field interference. The effect of the transverse capacitance C_{45} decreases as the difference decreases between the mean voltages U_I and U_{II} . In all investigations of the sensitivity coefficients, it is therefore important that account be taken of the operating conditions of the circuit. In the case of a group of open wire lines at a sufficient distance from the power line, it may be assumed that all conductors have about the same longitudinal voltage and the same potential impressed on them. The transverse capacitances are then of little importance. They are even less important in telecommunication cables in which the conductors are twisted and very close to each other.

The above remarks indicate that in the case of cables only the magnetic-field interference due to unbalances to earth is present, while in the case of open wire lines all 4 types of interference may be present at the same time.

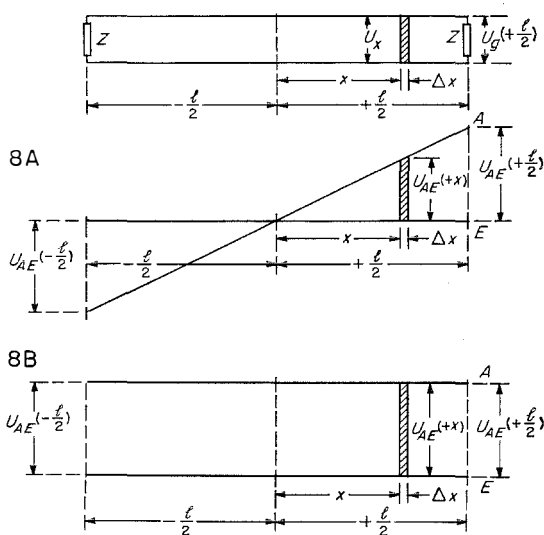


Figure 8—Distribution of the voltage U_{AE} in the cases of magnetic-field and electric-field interference. For Figure 8A, $U_{AE}(+l/2) + U_{AE}(-l/2) = 2U_{AE}(l/2)$; $U_{AE}(x) = (2x/l)U_{AE}(l/2)$. For Figure 8B, $U_{AE}(x) = U_{AE}(+l/2) = U_{AE}(-l/2) = U_{AE}(l/2)$.

The sensitivity coefficients may also be used for assessing the conditions of balance of a circuit in a group of circuits.

3. Sensitivity Coefficients

The question has been raised at meetings of the International Telegraph and Telephone Consultative Committee of the manner in which the sensitivity coefficients that enter into the calculation of expected noise interference depend on the length and the attenuation of a line. In the following theoretical investigations* it is assumed for simplicity that the power line is parallel to the entire length of the telecommunication line. It is also assumed, in accordance with practical experience, that the series unbalances of a 2-wire line may be neglected as compared with the unbalances to earth. The investigations accordingly were concerned only with magnetic- and electric-field interference resulting from capacitance unbalances to earth.

Figure 8 shows the voltage U_{AE} between the 2-wire line and earth. Figure 8A pertains to the magnetic-field interference on an electrically short line. Because of the uniform induction along the line, the voltage $U_{AE}(-l/2)$ at the one end of the circuit of length l has the same value as the voltage $U_{AE}(+l/2)$ at the other end but of opposite sign. The sum, however, is equal to the induced longitudinal voltage E . On the other hand, the voltages $U_{AE}(-l/2)$ and $U_{AE}(+l/2)$ in the case of electric-field interference, as shown in Figure 8B, have both the same value and the same sign.

In calculating the sensitivity coefficients it is necessary to make some assumptions about the distribution of unbalances to earth along the line. Two principal cases are considered.

* Author's contributions: contribution COMV-68 and addendum, meeting of Study Group V, International Telegraph and Telephone Consultative Committee, Geneva; 11-19 November 1963.

(A) The unbalances to earth per unit length are equal, but their signs are subject to the laws of probabilities.

(B) The unbalances to earth per unit length are not only equal but have the same sign.

3.1 CHANCE DISTRIBUTION OF EARTH UNBALANCES

For a chance distribution of capacitance unbalances to earth, the component noise voltages generated in the small sections Δx should, when referred to one end of the line, be added geometrically. If the complex earth unbalance of the total length l is

$$e^* = g_e + j\omega k_e \quad (1)$$

then the noise voltage at point x is

$$U(x) = U_{AE}(x) \frac{|e^*| \left(\frac{\Delta x}{l}\right)^{1/2}}{4} \cdot Z \quad (2)$$

Z being the characteristic impedance of the line.

However, in the case of magnetic-field interference

$$U_{AE}(x) = \frac{2x}{l} U_{AE} \left(\frac{l}{2}\right). \quad (3)$$

If α is the attenuation per unit length, then the noise voltage at one end of the line is in the limit

$$U_g \left(+\frac{l}{2}\right) = U_{AE} \left(\frac{l}{2}\right) \frac{|e^*| Z}{2l^{3/2}} \times \left[\int_{x=-(l/2)}^{x=+(l/2)} x^2 e^{-2[(l/2)-x]\alpha} dx \right]^{1/2}. \quad (4)$$

Because of the uniform induction along the line, the noise voltage at the other end is of the same magnitude.

The sensitivity coefficient for magnetic-field

interference is then

$$\lambda_i = \frac{2U_g \left(\frac{l}{2}\right)}{2U_{AE} \left(\frac{l}{2}\right)} \left(\frac{600\Omega}{Z}\right)^{1/2}. \quad (5)$$

By introducing (4) into (5) and integrating, we finally obtain

$$\left. \begin{aligned} \lambda_i &= K \cdot F_i \\ K &= \frac{|e^*|}{4} \left(\frac{Z}{\Omega} \cdot 600\right)^{1/2} \\ F_i &= \left\{ \frac{1}{\alpha l} \left[(1 - e^{-2\alpha l}) \left(\frac{1}{2} + \frac{1}{\alpha^2 l^2}\right) - (1 + e^{-2\alpha l}) \frac{1}{\alpha l} \right] \right\}^{1/2} \end{aligned} \right\}. \quad (6)$$

The factor F_i is a function of the line attenuation. Since the complex earth unbalance e^* relates to the entire length l , then K depends on l alone.

In the case of electric-field interference

$$U_{AE}(x) = U_{AE} \left(\frac{l}{2}\right). \quad (7)$$

According to (4) we obtain

$$U_g \left(+\frac{l}{2}\right) = U_{AE} \left(\frac{l}{2}\right) \frac{|e^*| Z}{4(l)^{3/2}} \times \left[\int_{x=-(l/2)}^{x=+(l/2)} e^{-2[(l/2)-x]\alpha} dx \right]^{1/2}. \quad (8)$$

Since the sensitivity coefficient in the case of electric-field interference is

$$\lambda_k = \frac{2U_g \left(\frac{l}{2}\right)}{U_{AE} \left(\frac{l}{2}\right)} \left(\frac{600\Omega}{Z}\right)^{1/2} \quad (9)$$

we finally obtain as before

$$\left. \begin{aligned} \lambda_k &= K \cdot F_k \\ K &= \frac{|e^*|}{4} \left(\frac{Z}{\Omega} \cdot 600\right)^{1/2} \\ F_k &= \left(2 \frac{1 - e^{-2\alpha l}}{\alpha l}\right)^{1/2} \end{aligned} \right\}. \quad (10)$$

We see that the factor K is the same as before; the factor F_k , though different from F_i , is, however, also a function of the line attenuation.

We also see that for the same unbalance to earth and the same characteristic impedance, the sensitivity coefficient λ_k is much greater than the sensitivity coefficient λ_i . If in both cases the length of line is the same, then both sensitivity coefficients will decrease as the line attenuation increases, and will therefore become more favorable as regards freedom from interference.

Since the earth unbalance $|e^*|$ increases with the square root of the length of the line, we see that the two sensitivity coefficients increase with increasing length of line if the attenuation per unit length remains constant.

From (6) and (10) the relationship can be derived between the sensitivity coefficient $(\lambda_{i,k})_1$, which was measured on a length of line l_1 , and the sensitivity coefficient $(\lambda_{i,k})_2$ of a similar line of length l_2 .

$$(\lambda_{i,k})_2 = (\lambda_{i,k})_1 \left[\left(\frac{l_2}{l_1} \right)^{1/2} \frac{F_{i,k}(al_2)}{F_{i,k}(al_1)} \right]. \quad (11)$$

The magnitudes of $F_{i,k} = (\lambda_{i,k}/K)$ can be read from the curves in Figure 9 for different (αl) values.

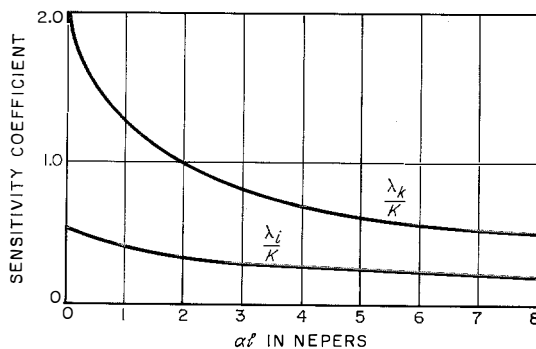


Figure 9—Curves to calculate sensitivity coefficients if earth unbalances are distributed randomly. $K = (e^*/4) \times (Z/\Omega \cdot 600)^{1/2}$; $e^* = g_e + j\omega k_e$.

3.2 EARTH UNBALANCES WITH SAME SIGN

The vectorial addition of the noise voltages leads to

$$U_s \left(+ \frac{l}{2} \right) = U_{AE} \left(\frac{l}{2} \right) \frac{|e^*|Z}{2l^2} \times \int_{x=-(l/2)}^{x=+(l/2)} x \cdot e^{-[(l/2)-x]\gamma} dx. \quad (12)$$

The sensitivity coefficient for magnetic-field interference then is

$$\left. \begin{aligned} \lambda_i &= K \cdot F_i' \\ K &= \frac{|e^*|}{4} \left(\frac{Z}{\Omega} \cdot 600 \right)^{1/2} \\ F_i' &= 2 \left(\frac{1}{\gamma l} - \frac{2}{\gamma^2 l^2} \right) + e^{-\gamma l} \left(\frac{1}{\gamma l} + \frac{2}{\gamma^2 l^2} \right) \end{aligned} \right\} \quad (13)$$

where $\gamma = \alpha + j\beta$ is the propagation constant.

Finally, the sensitivity coefficient for interference due to electric-field effects is

$$\left. \begin{aligned} \lambda_k &= K \cdot F_k' \\ K &= \frac{|e^*|}{4} \left(\frac{Z}{\Omega} \cdot 600 \right)^{1/2} \\ F_k' &= 2 \frac{1 - e^{-\gamma l}}{\gamma l} \end{aligned} \right\} \quad (14)$$

In both types of interference we can see the decisive role played by the phase angle. If we assume that the phase constant β is much

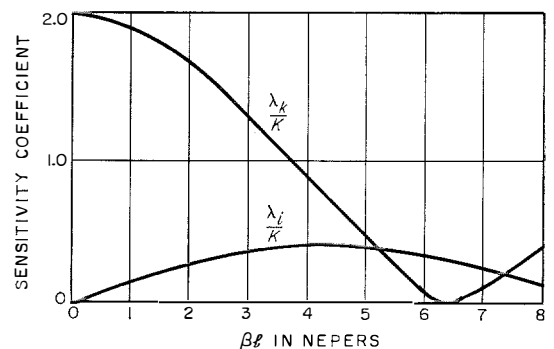


Figure 10—Curves to calculate sensitivity coefficients if earth unbalances are of the same sign. $K = (e^*/4) \times (Z/\Omega \cdot 600)^{1/2}$; $e^* = g + j\omega e$; $\beta \gg \alpha$.

greater than the attenuation constant α , we have

$$\gamma l \approx j\beta l \quad (15)$$

and magnitudes of $F_{i,k}' = \lambda_{i,k}/K$ can then be taken for different values of βl from the curves in Figure 10. As in the case discussed in Section 3.1, there is a simple relationship between the sensitivity coefficients of various lengths of line given by

$$(\lambda_{i,k})_2 = (\lambda_{i,k})_1 \cdot \frac{l_2}{l_1} \cdot \frac{F_{i,k}'(\beta l_2)}{F_{i,k}'(\beta l_1)} \quad (16)$$

For electrically short lines, λ_k is again much greater than λ_i , provided that in both cases the characteristic impedance and earth unbalance are the same.

4. Methods of Measurement

To test the theory by practical results, it was necessary to employ methods of measurement that made it possible to separate the different types of interference in the case of open wire lines. In accordance with Section 2, it is possible to do this only for a power line

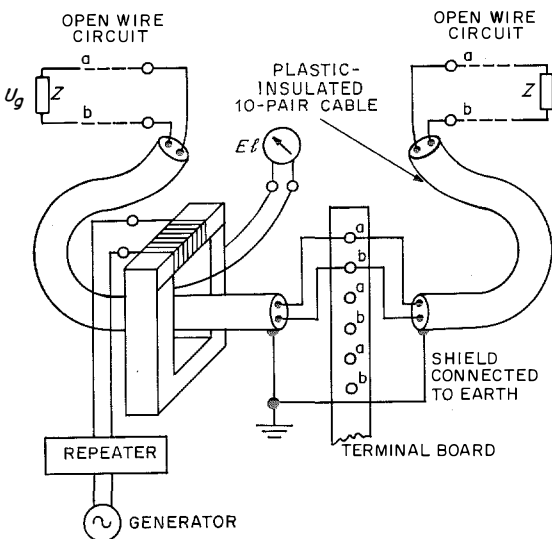


Figure 11—Measurement of magnetic-field sensitivity coefficient of an open wire line.

$$\lambda_i = |2U_o/e^2El|(600\Omega/Z)^{1/2}$$

interfering with a cable circuit, because in an open wire line all 4 types of interference may occur simultaneously and their effects are thus superimposed on each other. It is therefore preferable to use methods employing artificial induction, which of course must simulate as closely as possible the operating conditions of the circuit and also take into account the presence of other lines in the immediate vicinity (Figures 6 and 7). The following paragraphs describe such methods using the example of an open wire line 7 kilometers (4.3 miles) long and consisting of 10 pairs.

For the measurements only 2 lines were used, one of which had no transpositions, while the other had transpositions between conductors *a* and *b* at about the first and third quarters of the length. The artificial induction was effected at a pole approximately in the center of the line. At this point all the circuits were cut and reconnected by means of short lengths of shielded plastic-insulated conductors in a cable. For simplification, Figure 11 shows the connection of only one line.

Figure 12 illustrates the method of artificial induction. At the “center of gravity” of the magnetic-field interference—that is, at the midpoint of the line—longitudinal voltages

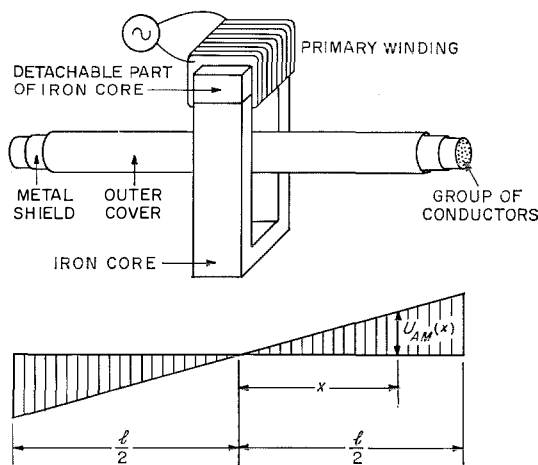


Figure 12—Artificial induction using an iron-core transformer.

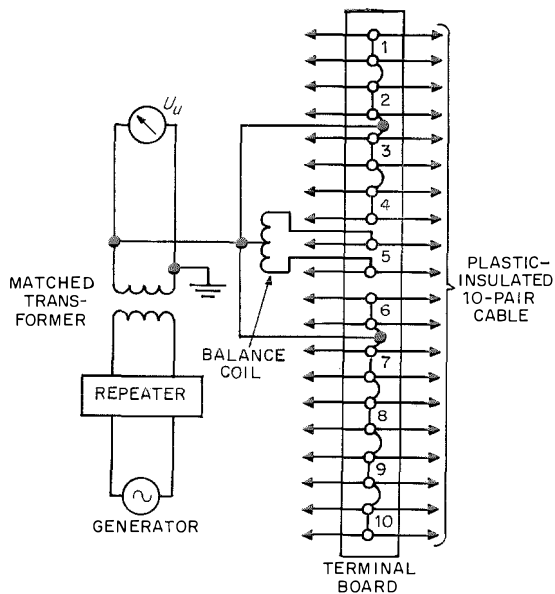


Figure 13—Measurement of the electric-field sensitivity coefficient of an open wire line.

$$\lambda_k = |2U_g/e^{\rho f} U_u| (\epsilon 600\Omega/Z)^{1/2}$$

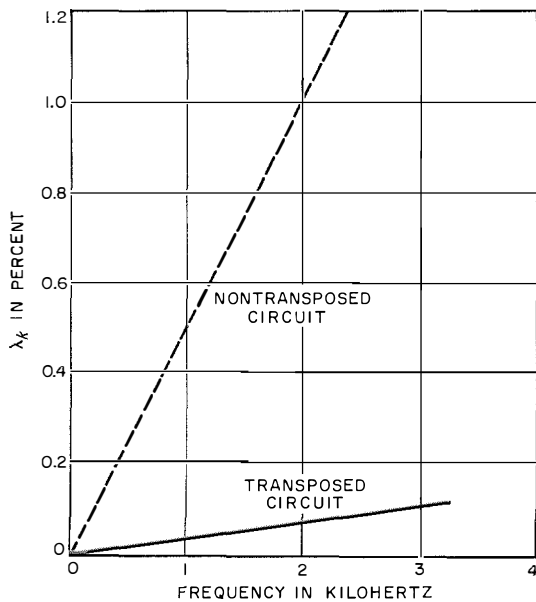


Figure 14—Electric-field sensitivity coefficient of a 7-kilometer (4.3-mile) open wire line. The neighboring lines are at the same potential.

are injected into all lines by means of a transformer that has its primary winding on a detachable iron core and its secondary winding formed by the plastic-insulated cable containing the group of 10 pairs. The induced longitudinal voltage can be measured by means of an additional winding on the iron core. Its magnitude can also be ascertained by earthing the circuit under test at the far end and by measuring the conductor-to-earth voltage at the near end. The value measured is approximately equal to the induced longitudinal voltage.

The noise voltage can be measured across the matched terminal impedances of the circuit by means of a psophometer. The distribution of the voltages $U_{AM}(x)$ along the line, as may be seen, corresponds well to the case of natural injection shown in Figure 8. In Figure 11 the measuring equipment would be located at the left end of the plastic cable. This makes it possible to apply this method also to open wire lines. The same longitudinal voltages may thus be induced in all neighboring lines in approximately the same way as in actual cases.

The terminal board shown in Figure 11 is required if the sensitivity factor is to be measured for the case of electric-field inter-

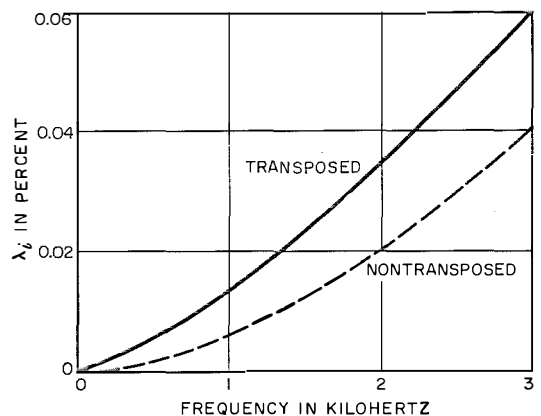


Figure 15—Magnetic-field sensitivity coefficient of a 7-kilometer (4.3-mile) open wire line. The neighboring lines have the same longitudinal voltages.

ference. The equation for the sensitivity coefficient for the case of magnetic-field interference is given in the legend.

As already stated, in the case of electric-field interference also we cannot ignore the effect of neighboring lines, which at a sufficient distance from the power line have about the same potential as the line to be tested. Figure 13 shows the circuit for measuring the sensitivity coefficient. In this measurement the conductors of the neighboring lines are connected to the midpoint that applies to the case of capacitance unbalance of the balance coil and thus is at approximately the same potential as the line under test. In the example shown this is line 5. The equation for the sensitivity coefficient applying in the case of capacitance unbalances to earth is given in the legend.

5. Results of Tests and Discussion

Figure 14 shows the electric-field sensitivity coefficient measured by the method described on a 7-kilometer (4.3-mile) open wire line as a function of frequency. The transposed line corresponds to the case of Section 3.1 and the

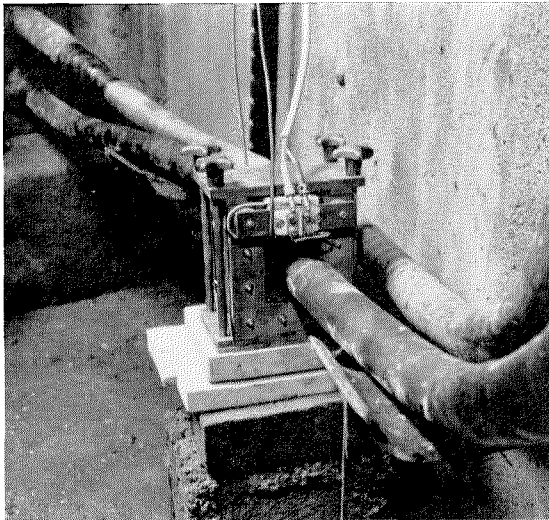


Figure 16—Measurement of sensitivity coefficient of a telecommunication cable.

nontransposed line to that of Section 3.2. We see that the nontransposed line is about 13 times as sensitive to noise interference as the transposed line. Figure 15 shows the magnetic-field sensitivity coefficient measured by the method described on the same open wire line as a function of frequency. The scale used for the sensitivity coefficient in this case is only 1/10 of that in Figure 14. Note that here the transposed line is even slightly more sensitive to noise than the nontransposed line. The systematic unbalances of the nontransposed line of one half of the total length are apparently compensated by the equivalent unbalances of the other half, which are of opposite sign.

A comparison of Figures 14 and 15 shows that for equal unbalance of the line the electric-field sensitivity coefficient is much greater than the magnetic-field sensitivity coefficient. This agrees with the theoretical conclusions shown in Figures 9 and 10. Also, the curves rise approximately in proportion to the frequency. This points to predominantly capacitance unbalances to earth and not to series unbalances, thus confirming the assumptions made in Section 3.

Figure 16 shows a cable being artificially subjected to induction. The separate leads are connected to the power amplifier and the pair goes to the voltmeter.

Figure 17 shows the cumulative curve of the magnetic-field sensitivity coefficient for the

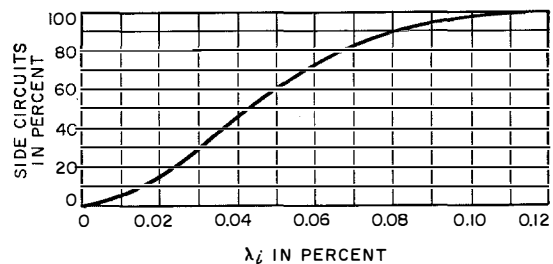


Figure 17—Magnetic-field sensitivity coefficient plotted against percentage of conductors being measured in a telecommunication cable.

side circuits in the outer layer of a 500-pair nonloaded and nonbalanced local cable containing copper conductors of 0.6-millimeter (0.024-inch) diameter. The artificial induction was produced by a buzzer placed at about the midpoint of the 6-kilometer (3.7-mile) cable. Both the noise voltage and the induced longitudinal voltage were measured by a psophometer so that λ_i is a weighted sensitivity coefficient. The 50-percent value for a length of $l_1 = 6$ kilometers is at $(\lambda_i)_1 = 0.043$ percent.

To determine the sensitivity coefficient of a similar cable of, for example, length $l_2 = 24$

kilometers, equation (11) may be used. Since for this cable the attenuation constant of the equivalent mean frequency of the buzzer can be put at $\alpha = 100$ millinepers per kilometer, it follows from Figure 9 that

$$\begin{aligned}\alpha l_1 &= 0.6 \text{ neper, } F(\alpha l_1) = 0.46 \\ \alpha l_2 &= 2.4 \text{ nepers, } F(\alpha l_2) = 0.32\end{aligned}$$

and from (11) that

$$(\lambda_i)_2 = 0.043 \times \left(\frac{24}{6} \cdot \frac{0.32}{0.46} \right)^{1/2} = 0.06 \text{ percent.}$$

The sensitivity coefficients of open wire lines can be calculated in a similar way.

Erwin Widl was born in Vienna, Austria, on 13 February 1898. In 1923, he received his engineering diploma from the Deutsche Technische Hochschule in Brno, Czechoslovakia, and in 1932 the doctorate of engineering from the Technische Hochschule in Vienna.

Dr. Widl joined the Siemens & Schuckert Cable Plant in Austria in 1924 and was soon appointed head of the long-distance-cable department. In 1938, he was placed in charge of the development department of the Deutsche Fernkabelgesellschaft in Berlin. Subsequently, he was employed with the Bergmannwerke cable plant in Berlin-Wilhelmsruh.

After several years as head of a scientific organization, he joined Standard Elektrik Lorenz in Stuttgart to organize a cable department, which became the foundation of the present Cable and Wire Division. Dr. Widl worked as chief of development for the Cable and Wire Division until his retirement. Since then he has been active for Standard Elektrik Lorenz as a consulting engineer.

Measurement of Magnetic Properties of Thin Films

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1. Properties of Magnetic Thin Films

Section 1 briefly reviews the theoretical elements of magnetism needed for a good understanding of the particular properties of magnetic thin films, such as those used at the present time for digital memories.

1.1 MAGNETIC PROPERTIES

Let us consider an isolated atom of material. This atom consists of a central nucleus around which a more-or-less-large number of electrons, divided into a certain number of shells, revolve. Each electron, besides its movement around the nucleus, rotates about itself. This spin is characterized from the mechanical point of view by a kinetic moment of spin. Since these electrons are electrically charged, their rotation will produce a magnetic moment of spin $\vec{\mu}_s$, which will be collinear to the direction of spin \vec{s} . In the same way in their movement around the nucleus, they will generate orbital magnetic moments $\vec{\mu}_l$. The resulting magnetic moment of the atom can be determined according to more-or-less-complicated rules that are related to the composition of the spins.

Aside from the loss of peripheral electrons by the atoms in the lattice of an ionic crystal, very-intense interactions called "exchange interactions" will exist between ions of the lattice that will modify their individual properties. In particular these interactions, which from the space point of view have the elements of symmetry of the crystal lattice, will be at the origin of the magneto-crystalline anisotropy. In the same way, the creation of an oriented superstructure at the time of the development of the lattice could be at the origin of an induced anisotropy.

1.2 EXCHANGE INTERACTIONS; DOMAINS

The interactions between ions of the lattice cannot be explained as being of magnetostatic origin. Only quantum mechanics can help us

understand it. The effect of these interactions is to tend to align the individual magnetic moments of the ions parallel to each other in ferromagnetic substances and antiparallel in antiferromagnetic substances. If we compare these interactions to the existence of a fictitious field to which each ion would be subjected, we find in a common ferromagnetic substance having a Curie point of the order of 300 degrees Celsius, a figure of the order of 5×10^6 oersteds. The enormous value of this fictitious field with respect to fields that can be applied externally, gives reason to predict that all the magnetic moments of a sample will tend to react as a unit to a stimulation. Therefore zones with uniform properties will be created in the material; these regions are called domains.

1.3 DEMAGNETIZING FIELD; WALLS

Let us assume a sample that is a single domain. The elementary magnetic moments make free magnetic poles appear at the extremities of the sample, and these poles create in the mass of the sample a demagnetizing field \vec{H} . If \vec{M} is the magnetization in the material, conventional magnetostatics tells us that

$$\text{div } \vec{H} = -4\pi \text{div } \vec{M}.$$

The minimum and therefore stable energy configuration is the one for which either there will be no free poles (closure domains) or the sample will be broken into a large number of regions having uniform properties that give a null-resulting macroscopic magnetization. These regions will be separated by walls in which the magnetization progressively changes direction, and which because of this contains energy. The conditions of equilibrium will in fact correspond, with respect to the different energies stored, to the condition

$$E \text{ demagnetizing} + E \text{ walls} \\ + E \text{ anisotropy} = \text{minimum.}$$

This condition will limit the fragmentation of

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the sample, which would increase the exchange energy contained in the walls.

1.4 INDUCED ANISOTROPY

By means of a particular technological process, we can produce a thin film (permalloy for example) having a privileged direction in which, in the absence of an external magnetic field, the magnetic moments of the ions will align themselves. This direction is called the "easy" axis, and its perpendicular is called the "hard" axis. The locus of the field vertices suitable for switching is called the critical curve of the material.

1.5 STATIC CHARACTERISTICS OF INDUCED ANISOTROPY FILMS

Different theories have been developed to explain this magnetic anisotropy and they agree more or less with experimental facts.

1.5.1 Kondorsky Theory

According to the Kondorsky theory, the material simulates a uniaxial monocrystal and only the component of the field applied to the axis of the crystal should be taken into consideration. The result is that the critical curve is reduced to a set of two parallels to the hard axis cutting the easy axis at points $+H_C$ and $-H_C$.

1.5.2 Stoner-Wohlfarth Theory

In the Stoner-Wohlfarth theory, the anisotropy of the material simulates the existence of an energy E_A contained in the sample and which is an even function of the angle α formed by the magnetization vector M and the easy axis. It is chosen more-or-less arbitrarily with the form

$$E_A = K \sin^2 \alpha.$$

Using this hypothesis, we compute that the critical curve is an astroid the vertexes of

which are situated on the hard axis and on the easy axis at distances $\pm H_K$, where H_K is called the anisotropy field of the material. We shall come back to the mathematical development of this theory, its main defect being that it does not show the switching of certain films for fields along the easy axis lower than H_K . We get around this difficulty by assuming that the critical curve is the combination of those given by the Stoner-Wohlfarth and Kondorsky theories.

1.5.3 Shtrikman-Treves Theory

The Shtrikman-Treves theory was initially developed to explain the magnetic properties of material constituted of acicular particles, which can be likened to an infinite cylinder or to a prolate ellipsoid.

We suppose that the prolate particle is subjected to an initial field directed along the large axis and that this field is sufficiently intense to align the magnetic moments. If this field is reversed, starting from a certain negative value, the moments will rotate in three different modes.

(A) The magnetic moments remain parallel; this is the Stoner-Wohlfarth theory.

(B) At each point of the cylinder, the moments turn in a plane perpendicular to the corresponding radius.

(C) The deviation of the moments could be carried out in parallel to a plane containing the large axis, the deviation being a periodic function along this axis.

The last two cases differ from the Stoner-Wohlfarth theory by the existence of a variable exchange energy that depends on the state considered and is caused by the non-parallelism of the moments. Complex mathematical developments permit the computation of the corresponding critical curve

$$\left(\frac{H_L}{H_C}\right)^2 + \left(\frac{H_T}{H_K - H_C}\right)^2 = 1.$$

This curve joins that of the model of Stoner-Wohlfarth for a transverse field value H_T , satisfying the relation

$$H_T = (H_K - H_C)^{3/2}$$

where H_K is the anisotropy field and H_C the noncoherent-rotation coercive field.

Experimental verifications by Doyle, Rudisill, and Shtrikman have proved that there is very-good agreement with this theory even though the assimilation of the properties of the thin films by those of an infinite cylinder is not very obvious.

1.6 DYNAMIC CHARACTERISTICS—CREEP EFFECT

Theories have also been developed to describe the behavior of a sample of material submitted to a variable magnetic field. These theories differ according to the mode chosen to describe the damping of the precession movement of the spins. One of these theories leads to the well-known equation of Landau-Lifschitz

$$\frac{d\vec{M}}{dt} = \gamma \vec{M} \wedge \vec{H} - \frac{\lambda}{M^2} \vec{M} \wedge (\vec{M} \wedge \vec{H})$$

in which the first term describes the precession movement of the spins and the second is a damping component.

However, these theories are totally unable to explain the creep phenomenon, the effects of which can reach catastrophic proportions in the magnetic thin films used in digital memories. This phenomenon appears in the following manner: When a magnetic film has been magnetized to saturation along the easy axis in a certain direction, it is sometimes possible to modify its state by subjecting it to a burst of disturbing field pulses each of which is too weak to cross the static critical curve.

The measurement equipments described in Section 2 have been built to solve the problem of plotting with sufficient precision the static critical curve, and of evaluating the sensitivity to the creep effect to determine the experi-

mental conditions of manufacture that permit elimination of the creep effect.

2. Measurement of Magnetic Properties of Films in Quasi-Static State

2.1 GENERAL

As shown in Section 1, the theory that best describes the behavior of a ferromagnetic thin film is a combination of the Stoner-Wohlfarth model for the domain of applied fields or the magnetic moments remaining parallel to each other, and of the Shtrikman-Treves model for the domain of fields causing a noncoherent rotation of the sample.

Figure 1 shows the composite critical curve thus obtained. It is characterized by certain parameters that must be known to predict the operating conditions in a memory. These different parameters are:

- (A) At the point under consideration, the average skew β of the axes of the curve with respect to a reference direction.
- (B) The dimensions of the critical curve of $2H_K$ along the hard axis, where H_K is the characteristic anisotropy field of the behavior

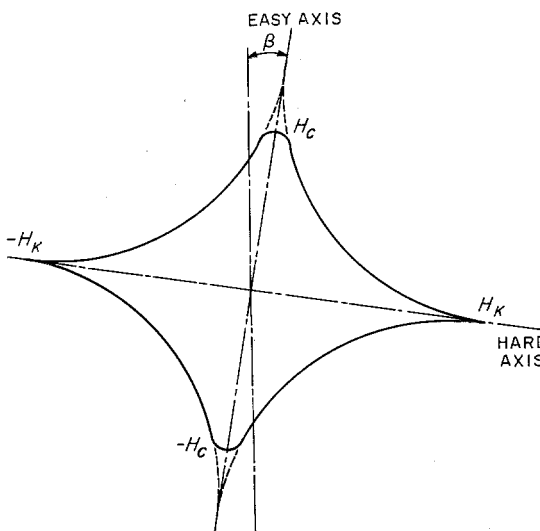


Figure 1—Critical curve.

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in coherent rotation, and of $2H_C$ along the easy axis, where H_C is the coercive field of wall movement (Kondorsky) or of incoherent rotation (Shtrikman-Treves).

All these values are subject to dispersion on the microscopic scale. The most important, on the practical level, is α_{90} , the angular dispersion.

2.2 ASTROMETER

The astrometer is an apparatus that directly plots the critical curve of a sample on the calibrated screen of a cathode-ray tube.

2.2.1 Working Principle

According to the Stoner-Wohlfarth hypothesis (Figure 2), we know that the energy E of a sample of uniaxial magnetic material immersed in an external field H has the form

$$E = \frac{|\vec{M}|H_K}{2} \sin^2 \alpha - \vec{H} \cdot \vec{M} + cte.$$

In this expression, M represents the magnetization vector of invariable module and H the applied field forming, respectively, angles α and θ with the easy axis.

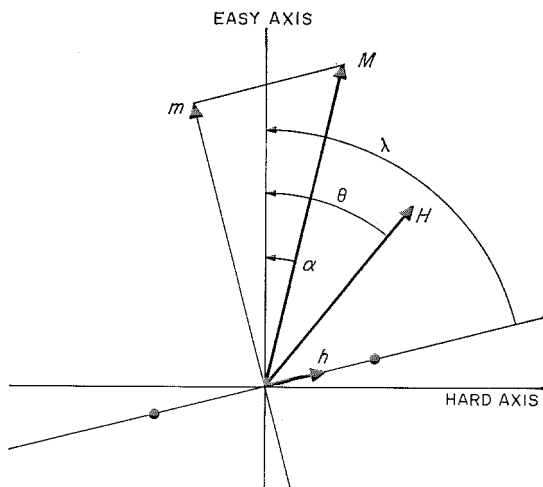


Figure 2—Vector diagram.

The stable equilibrium of the vector M can be written

$$\frac{\partial E}{\partial \alpha} = 0 \quad \frac{\partial^2 E}{\partial \alpha^2} > 0.$$

The critical curve deduced from these hypotheses is the astroid

$$\frac{H_L}{H_K} = \sin^3 \alpha$$

$$\frac{H_T}{H_K} = \cos^3 \alpha.$$

H_L and H_T are the respective projections of \vec{H} on the easy axis and on the hard axis.

From the discussion of these equations, it results that the film will switch at the crossing of the critical curve from the interior toward the exterior in the two following cases.

$$-\frac{\pi}{2} < \alpha < \frac{\pi}{2} \quad \text{and} \quad \frac{\pi}{2} < \theta < \frac{3\pi}{2}$$

or

$$\frac{\pi}{2} < \alpha < \frac{3\pi}{2} \quad \text{and} \quad -\frac{\pi}{2} < \theta < \frac{\pi}{2}$$

which signifies that the vectors \vec{M} and \vec{H} must be situated on both sides of the hard axis.

If the sample is subjected to a field \vec{H} resulting from the superposition of two fields, H_L and H_T , and if it is scanned periodically in time over a range exceeding that of the limits of the curve, the field \vec{H} will cause switching at certain times.

In the experimental device, the diagram of which is given in Figure 3, the fields H_L and H_T are created by two pairs of coils connected in series with the vertical- and horizontal-deflection coils of a cathode-ray tube, the whole device being designed so that the cathode-ray spot is always the homologue of the tip of the field vector at the sample under test.

If the signals picked up by a probe that detects the switching transients of the film is used to

modulate the intensity of the beam of the cathode-ray tube, the curve is plotted directly.

The great superiority of the astrometer over other experimental devices employing the same principle lies in the use of a system having very-good sensitivity in detecting the switching transients. The probe is composed of two small orthogonal windings between which auxiliary compensation circuits permit cancellation of coupling. One of these windings L_1 , is supplied with a high-frequency signal and creates a magnetic disturbing field \vec{h} making an angle λ with the easy axis and having an amplitude that is very low with respect to H_K . In the absence of a sample, no signal is picked up at the terminals of the second winding L_2 .

The presence of a sample produces a coupling between the windings that depends on the orientation of the magnetization vector \vec{M} . This coupling consequently undergoes abrupt variations at each switching.

In the same hypotheses, computation shows that the amplitude of the electromotive force

induced in winding L_2 has the form

$$e_m = K \frac{\sin 2(\lambda - \alpha)}{\cos 2\alpha + \frac{H}{H_K} \cos(\theta - \alpha)}$$

with

$$\sin 2\alpha = 2 \frac{H}{H_K} \sin(\theta - \alpha).$$

The discontinuities of e_m are those of α (actually, the cancelling of the denominator introduces no new discontinuity since it takes place for $\partial^2 E / \partial \alpha^2 = 0$).

The amplified and detected induced signal modulates the intensity of the spot more-or-less linearly with e_m .

2.2.2 Construction Details

2.2.2.1 High-Frequency Detector

For frequencies of the probe-disturbing field that are much lower than the Larmor precession frequency, the signal induced in winding L_2 will be approximately proportional to frequency. For these reasons, the frequency of the excitation current of the probe has been fixed at 55 megahertz. The signal induced in

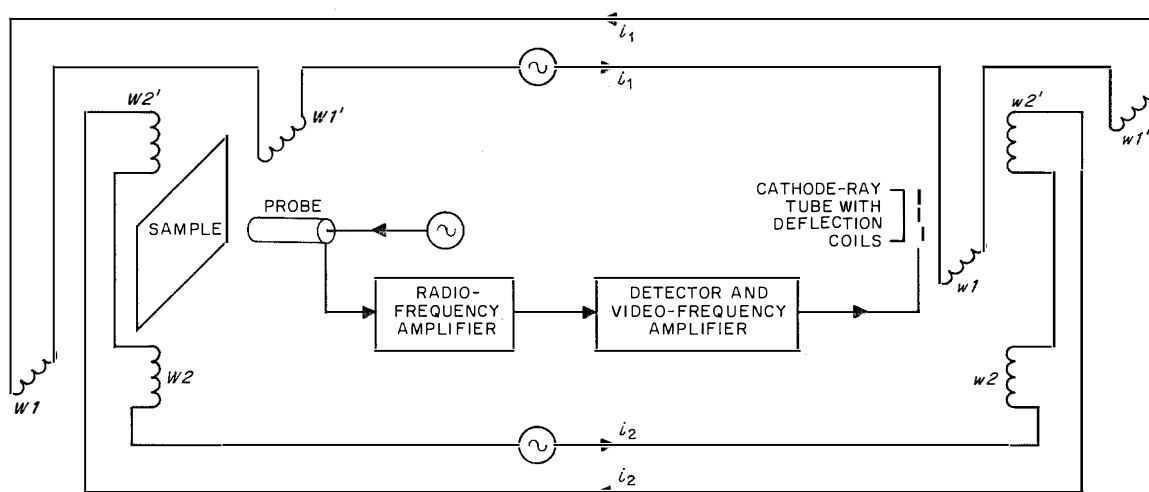


Figure 3—Diagram of astrometer.

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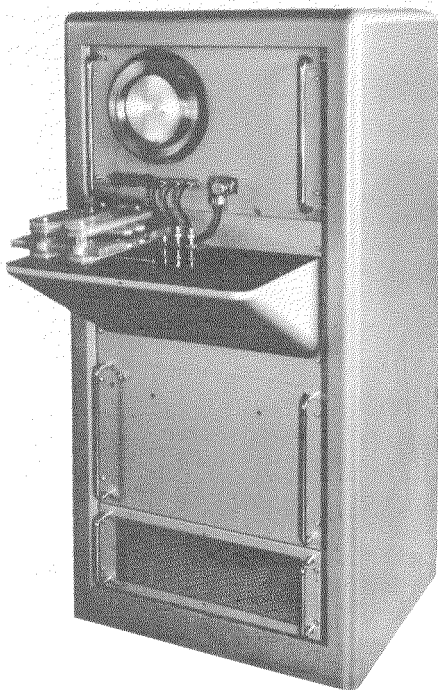


Figure 4—Astrometer.

L_2 is sent to a radio-frequency amplifier the characteristics of which are the following: center frequency, 62 megahertz; bandwidth at the 6-decibel-down points, 14 megahertz; gain at 62 megahertz, 83 decibels; and equivalent input noise, 10 microvolts.

The best conditions for detection are with an input signal of 100 microvolts.

Winding L_2 of the probe has been designed so that its output signal is 10 microvolts for an induction varying sinusoidally at 55 megahertz with an amplitude $b_m = 10^{-3}$ gauss. The excitation current of L_1 is produced by a crystal-controlled generator the output power of which is regulated by the average level detected at the output of the radio-frequency amplifier. The video-frequency amplifier has a bandwidth from 100 hertz to 19 megahertz, a gain of 36 decibels, and a maximum peak-to-peak output amplitude of 40 volts.

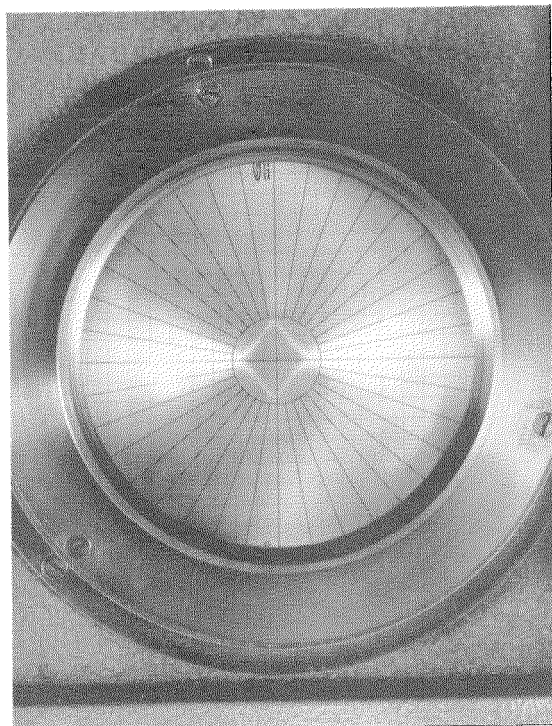


Figure 5—Critical curve displayed on astrometer screen.

2.2.2.2 Field and Deflection Coils

Two pairs of flat coils supply the vertical and horizontal components of the scanning field.

Detailed studies using a computer have led to the following results.

(A) Vertical-deflection field coils have an inductance of 0.5 millihenry; resistance, 1.6 ohms; field, 10.3 oersteds per ampere; and field uniformity over a distance of 1 centimeter, 1 percent.

(B) Horizontal-deflection field coils have an inductance of 2.3 millihenries; resistance, 2.8 ohms; field, 10.1 oersteds per ampere; and field uniformity over a distance of 1 centimeter, 1 percent.

The air-core deflection coils give, in both directions and under fixed conditions of use for the cathode-ray tube, deflection sensitivities of 7 centimeters per ampere with a

precision of the order of 0.5 percent over the entire surface of the screen.

2.2.2.3 Scanning Signal Generators

Scanning along the easy axis is accomplished by a 12.5-kilohertz triangular-wave signal generator supplying a current of 3 amperes peak to peak.

Along the hard axis, a 50-hertz sawtooth scanning generator gives a current of 2 amperes peak to peak. The scanning flyback represents 5 percent of the duration of the cycle.

These few details give an idea of the performances to be expected from this apparatus. Figure 4 is a general view of the apparatus and Figure 5 shows the critical curve of a sample as seen on the screen of the cathode-ray tube.

The accuracy of measurement is not limited by the intrinsic precision of the apparatus, which is of the order of 2 percent, but by the sharpness of the image, which depends on the microscopic dispersions of the properties measured in the sample itself.

3. Bibliography

1. E. Kondorsky, *Journal of Physics* (U.S.-S.R.), volume 2, page 161; 1940.
2. E. C. Stoner and E. P. Wohlfarth, "Mechanism of Magnetic Hysteresis in Heterogeneous Alloys," *Philosophical Transactions of the Royal Society* (London), Series A, volume 240, number 826, pages 599-642; May 1948.
3. S. Shtrikman and D. Treves, *Journal de Physique et Le Radium*, volume 20, page 286; 1959.
4. W. D. Doyle, J. E. Rudisill, and S. Shtrikman, *Journal of Applied Physics*, volume 32, number 9, pages 1785-1787; 1961.
5. W. D. Doyle, J. E. Rudisill, and S. Shtrikman, *Journal of Applied Physics*, March Supplement; 1962.
6. W. D. Doyle, J. E. Rudisill, and S. Shtrikman, *Journal of the Physical Society of Japan*, volume 17, Supplement B1; 1962.
7. Hartmann-Boutron, Laboratoire Central de Télécommunications, Internal Report PL 600 906-A; 1964.

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Magneto-Optic Astrometer for Measurement of Magnetic-Thin-Film Memories

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1. Kerr Magneto-Optic Effect

1.1 DESCRIPTION [1-3]

If a beam of plane polarized light illuminates a polished metal surface, the reflected beam is elliptically polarized, except if the plane of polarization of the incident light is parallel or perpendicular to the plane of incidence. In this case, the reflected beam is plane polarized, the plane of incidence being a plane of symmetry for the system.

This symmetry is destroyed if the reflecting surface is a ferromagnetic material that is magnetized and anisotropic; the polarization of the reflected beam then depends on the positions of the magnetization vector I with respect to the reflecting surface, and of the electric field E of the incident light with respect to the incidence plane (Figure 1).

The figure shows the polar effect (I_1) and longitudinal effect (I_2); the reflected beam is always elliptically polarized. Also shown is the transverse effect (I_3); this is zero for E_1 , maximum for E_2 , and corresponds to a slight change of the reflection coefficient.

The three magneto-optic effects are wavelength dependent. They are proportional to the magnetization and their signs change by reversing I .

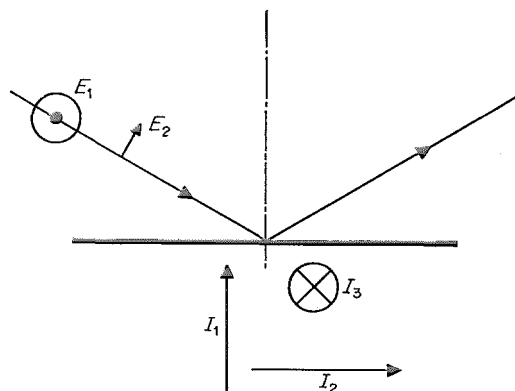


Figure 1—Kerr magneto-optic effects.

1.2 ARGYRES THEORY

These three effects, discovered by Kerr in 1876, have had many theoretical interpretations, the most-complete of which is given by Argyres [4]. The external magnetic field that would produce an equivalent effect is of the order of 10^6 to 10^7 oersteds, and the existence of such intense internal fields may be explained by the spin-orbit interaction. Macroscopically the sum of these exchange energies, present in all matter, is not zero in the ferromagnetic materials, the result being a dissymmetry between the complex refraction index of right and left circularly polarized light.

1.3 LONGITUDINAL KERR EFFECT [2, 4, 5]

In the case of sufficiently thin magnetic films, the magnetization is parallel to the film surface. The longitudinal effect has been used here, because our experiments have shown that it is more intense than the transverse effect.

The polarizer is assumed to be perfect, that is, the coefficient of transmission is 1 in the direction of maximum transmittance p , and 0 in the orthogonal direction s (Figure 2). The incident light, the irradiance of which is unity, can be represented by two incoherent components of equal amplitude $(1/(2)^{1/2})$ and plane polarized in the directions p and s . The light passes through the polarizer, is reflected from the magnetic film (p is in the plane of incidence—case E_1 of Figure 1), and then passes through an analyzer, assumed to be perfect and set at an angle ϵ with the direction s . The amplitude of the emergent beam is then

$$A = \frac{1}{(2)^{1/2}} (R_p e^{i\alpha_p} \sin \epsilon + r e^{i\beta} \cos \epsilon)$$

$R_p e^{i\alpha_p}$ being the ordinary metallic reflection coefficient and $r e^{i\beta}$ the Kerr reflection coefficient ($r \ll R_p$). The irradiance is

$$I = AA^* = \frac{1}{2} (R_p^2 \sin^2 \epsilon + r^2 \cos^2 \epsilon + 2R_p r \sin \epsilon \cos \epsilon \cos \delta)$$

where $\delta = \alpha_p - \beta$.

Terms of higher order than the first in r and the second in ϵ can be neglected; thus

$$I = \frac{1}{2} (R_p^2 \epsilon^2 + 2R_p r \epsilon \cos \delta). \quad (1)$$

The emergent beam is the sum of a direct-current component $R_p^2 \epsilon^2 / 2$ and a component varying between $\pm R_p r \epsilon \cos \delta$ since the sign of r depends on the direction of magnetization. By submitting the sample to an alternating magnetic field, it then becomes possible to detect the variations of irradiance with a photomultiplier.

The coefficient $R_p e^{i\alpha_p}$ and $r e^{i\beta}$ have been computed in terms of the complex refractive index $N = n(1 - ik)$ (n is the real refractive index and k the absorption index) and of the complex magneto-optic amplitude, proportional to the magnetization $Q = Q_0 e^{-iq}$ and the parameters n , k , Q_0 , and q have been measured by Robinson [5] as a function of the wavelength for several materials. The effect depends on i , the angle of incidence. $i = 60$ degrees is generally selected, corresponding to the maximum of r . For a permalloy thin film, the computation made according to this measurement gives, by neglecting the wavelength dispersion and by taking average values for the coefficients n , k , Q_0 , and q :

$$\begin{aligned} R_p &= 0.55 \\ r &= 0.6 \times 10^{-3} \\ \alpha_p &= -68 \text{ degrees} \\ \beta &= -44 \text{ degrees} \\ \delta &= -24 \text{ degrees.} \end{aligned}$$

If s is in the plane of incidence (case E_1 of Figure 1), the expression of the emergent irradiance is identical, but with the following reflection coefficients:

$$\begin{aligned} R_s &= 0.85 \\ r' &= r = 0.6 \times 10^{-3} \\ \alpha_s &= -18 \text{ degrees} \\ \beta' &= n + \beta = +136 \text{ degrees} \\ \delta' &= -154 \text{ degrees.} \end{aligned}$$

1.4 OBSERVATION OF DOMAINS

The Bitter technique provides nothing but static results, over a restricted temperature range, and may disturb the domain structure by the very presence of a magnetic powder [2]. The investigation by electron microscopy, which has given remarkable results at Laboratoire Central de Télécommunications [6, 7], is possible only in the case of very-thin films deposited on carbon substrates, especially made for this study.

The Kerr method of observing domains also makes possible a dynamic study while remaining uninfluenced by the substrate and the thickness of the sample as well as by the temperature.

2. Detector System

2.1 PHOTOMULTIPLIER SIGNAL-TO-NOISE RATIO

The optical arrangement is shown in Figure 3 with

- Φ = light flux falling on the polarizer
- m = ratio of photocathode current to light flux
- M = multiplication factor of the photomultiplier
- ρ_L = load resistance in the anode circuit
- G = gain of the amplifier.

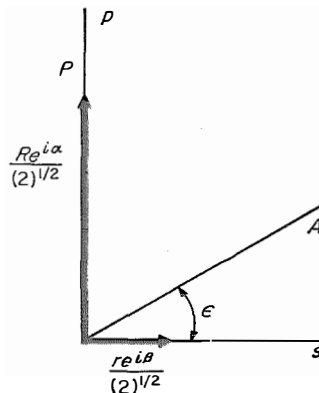


Figure 2—Vector representation of beam amplitudes.

The peak-to-peak amplitude of the output voltage supplied by the Kerr component has a value

$$S = \Phi m M \rho_L G (2\epsilon r R_p \cos \delta). \quad (2)$$

The noise in the photomultiplier is assumed to be only the shot effect of the photocathode. The noise voltage E_v due to a frequency range $d\nu$ is such that [2]

$$E_v^2 d\nu = M^2 \rho_L^2 G^2 f^2(\nu) 2e i_c d\nu$$

where e is the electron charge (1.6×10^{-19} coulomb), $f(\nu)$ the frequency response function of the amplifier, and i_c the direct-current component of the cathode current

$$i_c = \Phi m \left(\frac{R_p^2 \epsilon^2}{2} \right).$$

The mean-square noise voltage is given by

$$\begin{aligned} \bar{N} &= \left[\int_0^\infty E_v^2 d\nu \right]^{1/2} \\ &= M \rho_L G R_p \epsilon (e \Phi m)^{1/2} \left[\int_0^\infty f^2(\nu) d\nu \right]^{1/2}. \end{aligned}$$

For an ideal amplifier whose bandwidth is

$$\begin{aligned} \Delta\nu &= \nu_2 - \nu_1 \\ \int_0^\infty f^2(\nu) d\nu &= \int_{\nu_1}^{\nu_2} d\nu = \Delta\nu \\ \bar{N} &= M \rho_L G R_p \epsilon [e \Phi m \Delta\nu]^{1/2}. \quad (3) \end{aligned}$$

The signal-to-noise ratio can be computed from (2) and (3)

$$\frac{S}{\bar{N}} = \left[\frac{\Phi m}{e} \frac{1}{\Delta\nu} \right]^{1/2} 2r \cos \delta. \quad (4)$$

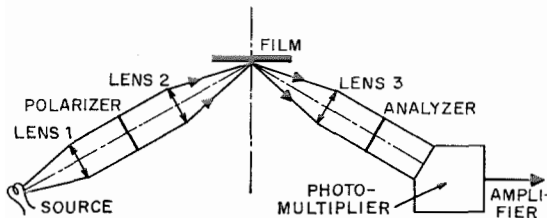


Figure 3—Optical probe.

2.2 EFFECT OF REFLECTION COEFFICIENT

The S/\bar{N} ratio seems to be independent of R_p and ϵ . However, the useful signal-to-direct-current-component ratio $4r \cos \delta / R_p \epsilon$ increases if R_p and ϵ decrease, and a more-sensitive photomultiplier may be used. The coefficient m is thus greater, as is the signal-to-noise ratio. Decreasing ϵ (setting the analyzer nearer extinction) is possible, on condition that the approximations made remain valid. ϵ must be greater by at least one order of magnitude than the quality factor of the polarizing elements (transmittance in the plane of extinction over maximum transmittance ratio—about 1 percent for the Glazebrook prisms used). To have a reflection coefficient as small as possible, the incident light is polarized in the plane of incidence (case E_2 of Figure 1), R_p being smaller than R_s , with $|\cos \delta| \simeq |\cos \delta'|$ (Section 1.3). A dielectric layer (zinc sulfide for instance) may also be deposited on the sample [2, 3], for decreasing the ordinary reflection coefficient R_p , while the successive reflections at the metal dielectric interface increase the magneto-optic component. Unfortunately this method is not very practicable for samples that must be rapidly tested before being used in a memory.

2.3 EFFECT OF LIGHT SOURCE

An improvement of contrast may be obtained by using a source of very-high intensity and by increasing the convergence of the light falling on the magnetic film.

It certainly would be interesting to use a gas-laser beam, which has a very-high energy density and provides directly a parallel plane polarized light. As this light is monochromatic besides, the effect of the wavelength dispersion would be avoided. This possibility is under study.

A zirconium concentrated-arc lamp of high light power is used at the present time. A filtering is moreover obtained, due to the

maximum of spectral response of the photomultiplier, for $\lambda \simeq 4000$ angstrom units.

The lenses must be without stress.

2.4 BANDWIDTH OF AMPLIFIER

For a given signal-to-noise ratio, the bandwidth may be computed from (4). The characteristics of the apparatus follow:

Brightness of the source:

$$L = 20 \text{ candelas per square millimeter}$$

Diameter of the source:

$$d = 0.4 \text{ millimeter}$$

Frontal distance of the objective:

$$f = 50 \text{ millimeters}$$

Useful diameter of the objective:

$$D = 5 \text{ millimeters}$$

Photon efficiency of the photocathode:

$$m = 20 \text{ microamperes per lumen.}$$

The luminous flux falling on the polarizer is thus

$$\phi = L \frac{\pi d^2}{4} \frac{\pi D^2}{4 f^2} = 2 \times 10^{-2} \text{ lumen}$$

with $r = 0.6 \times 10^{-3}$ and $\delta = 24$ degrees (Section 1.3), and to have, for instance, a signal-to-noise ratio of 10

$$\Delta\nu \simeq 30 \text{ kilohertz.}$$

The authorized bandwidth is very small.

3. Magneto-Optic Astrometer

The principle for the magneto-optic astrometer is the same as for the standard astrometer [8] except for the detection system. The optical probe shown in Figure 3 replaces the electromagnetic probe used in the standard version. The variations of the magneto-optic component are transformed into electric voltage variations, and the amplifier output signal modulates the intensity of the spot on an oscilloscope. Horizontal and vertical deflections are, respectively, proportional to the transverse component (parallel to the hard axis) and to the longitudinal component

(parallel to the easy axis) of the magnetic field applied to the film. The astroid is thus directly plotted on a suitably calibrated screen.

3.1 APPARATUS

The holders of the lenses, of the source, and of the photomultiplier are in nonferromagnetic metal. Nevertheless, to remove them as far as possible from the film and from the coils they may risk disturbing, objectives with great frontal distance have been used, which also provide light rays set at a small angle with the axis.

The pass band of the amplifier that follows the photomultiplier is about 10 hertz to 15 kilohertz. Its gain is adjustable and can reach 80 decibels. The period of the vertical sweep (sawtooth voltage) is 80 milliseconds. It has been computed so that the spot may be able to pass from the extinction to the maximum brightness over a distance smaller than its diameter (about 0.2 millimeter), taking into account the bandwidth of the amplifier.

The horizontal sweep (staircase voltage) is synchronized by the vertical scanning, with a cycle 2^7 times higher (10.24 seconds). The trace of the spot on the screen is thus constituted of parallel and equidistant lines, and the scanning speed is constant.

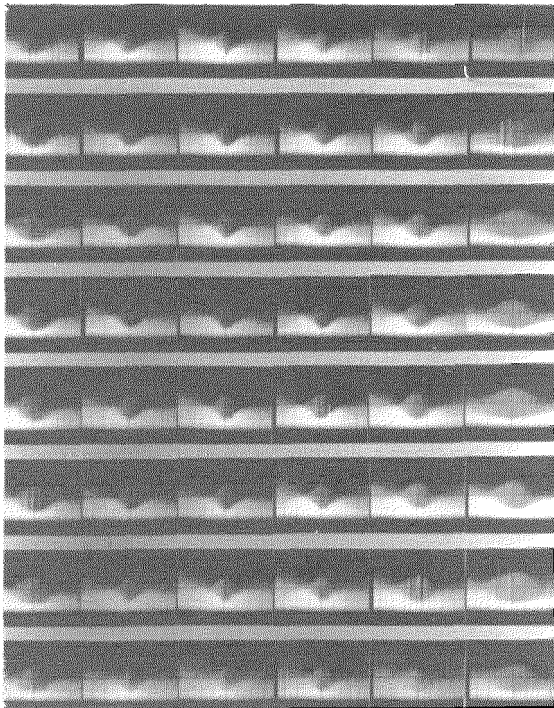
3.2 PERFORMANCES

With too fast a vertical scanning, the magnetization reverses by coherent rotation before the domain wall motion occurs. The slow scanning speed of the magneto-optic astrometer makes the observation of the wall coercive field possible.

The dimensions of the light spot on the thin magnetic film (0.4 by 0.6 millimeter), smaller and more defined than those of the electromagnetic probe (about 2 by 2 millimeters), permit a more-detailed exploration and the study of the changes, over small distances, of the characteristics of a magnetic film (coercive

Astrometer for Measuring Magnetic Thin Films

Figure 4—Detailed analysis of a permalloy spot of 3 millimeters by 4 millimeters.



field, anisotropy field, angular dispersion). Figure 4 shows the astroids read at 48 points of a permalloy rectangular spot of 3 millimeters by 4 millimeters (sensitivity, 2 oersteds per division). The easy axis is parallel to the greater dimension and the position of each astroid on the photograph corresponds to that of the point tested on the film. It has thus been shown that the magnetic properties completely change around the edges parallel to the easy axis, and the fabrication of films

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The same year, she joined Laboratoire Central

fragmented by masking during the deposition has been stopped.

This apparatus, despite its delicate use, thus shows some advantages over the electromagnetic astrometer.

4. References

1. E. W. Lee, D. R. Callaby, and A. C. Lynch, "Use of Kerr Effect for Studying Magnetization of Reflecting Surface," *Proceedings of the Physical Society* (London), volume 72, number 464, pages 233–243; August 1958.
2. P. H. Lissberger, "Kerr Magneto-Optical Effect in Nickel-Iron Films—1. Experimental—2. Theoretical," *Journal of the Optical Society of America*, volume 51, number 9, pages 948–966; September 1961.
3. M. Prutton, "Thin Ferromagnetic Films."
4. P. N. Argyres, "Theory of Faraday and Kerr Effects in Ferromagnetics," *The Physical Review*, volume 97, number 2, pages 334–345; January 1955.
5. C. C. Robinson, *Journal of the Optical Society of America*, volume 53, number 6, page 681; June 1963.
6. J. P. Auradon, Laboratoire Central de Télécommunications, Internal Report PL 600 886-A; 1964.
7. J. P. Auradon and L. Le Saec, International Symposium on Memory Technics, Paris, Paper 1–21; April 1965.
8. A. Judeinstein, "Measurement of Magnetic Properties of Thin Films," *Electrical Communication*, volume 41, number 1, pages 65–71; 1966.

de Télécommunications, where she is an engineer in the department on ultra-fast electronics.

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Expanding Global Submarine-Cable Network

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1. Introduction

This article describes the effect of introducing repeated submarine cable systems on international telecommunication and on intercontinental telephone service in particular. Much has already been written and said about the cable systems that bridge the Atlantic and stress will therefore be laid here on operational and economic aspects of submarine cables, the role they can play in global communication, and how they compare with other long-distance transmission media such as high-frequency radio and satellites.

2. Communication Means Before 1956 (TAT-1 Laid)

History most likely would have been different if communication had existed between the countries of the ancient world with the facilities, ease, and quality of today. Marco Polo would not have had to imperil his life to establish a trade monopoly with the East, as anyone today has direct access to production centres for the

procurement of essential or popular services and commodities. Trade in fact has been through the centuries the main single factor driving men to the remotest parts of our planet to benefit an individual or a nation. Today our economy demands a favourable trade balance or the growth of the country will suffer. Lack of adequate communication with the outside world affects both the trade volume and the competitiveness of a country. These are facts that can no longer be ignored or minimized.

2.1 NEED FOR COMMUNICATION GROWS

Various studies have been made to relate communication and trade volume, and a remarkable correlation was found. A conservative factor of 0.5 per cent of the trade volume between two countries was found to represent the potential communication revenue if communication facilities are efficient and charges reasonable [1, 2] (refer to Table 1). In general these prerequisites were found only if high-quality international circuits could be established with existing coaxial

TABLE 1
REVENUE CHART (1963-1964)*

United Kingdom and	Gross Revenue of United Kingdom in Thousands of Pounds Sterling				Total Revenue for Both Countries (Twice Previous Column)	Trade Between Countries in Thousands of Pounds Sterling	Percentage of Total Revenue to Trade	Cost of 3-Minute Phone Call in Shillings
	Telephony	Telex	Telegraphy	Total				
France	930	129	212	1271	2550	348 000	0.73	6
The Netherlands	510	175	77	762	1520	384 000	0.39	7
Belgium	301	84	57	442	880	193 000	0.45	7
Germany	923	369	171	1463	2930	448 000	0.65	10
Norway	190	140	69	399	800	153 000	0.52	16
Sweden	316	162	80†	558	1120	336 000	0.33	16
United States	2192	633	450†	3275	6550	859 000	0.76	60

* Courtesy of British Post Office.

† Estimated.

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cable or with microwaveradio systems requiring relatively low capital investment. If distances were longer and routes did not go over land but had to cross seas and oceans, technology first and capital outlay second prevented the introduction of similar high-quality telephone circuits. Income from the latter type of international and intercontinental communication is today merely a fraction of the potential, with in particular the major revenue-earning facility, telephony, in its infancy. Another attraction from the operating point of view is that terminal handling expenses for telephony are only about one eighth of those for telegraphy. With international trade growing at an average of 6 to 7 per cent annually, the potential revenue from international communications is clearly enormous and awaits only the introduction of efficient and high-quality transmission systems.

2.2 TELEGRAPH CABLE NETWORK

Telegraph cables took over from ships in the middle of the last century as the fastest means of long-distance intercontinental communication. Figure 1 indicates how widespread their use was. The laying of these cables was no sinecure in those days of small ships and limited technical facilities, and large sums were invested in these communication means. Virtually all cables have earned their way, whilst at the same time stimulating the evolution of global communication and the dependency of governments, businesses, and individuals on this facility. As could be expected, the submarine telegraph cables followed the established shipping routes and interconnected trade centres as the major traffic generators in developing countries. Once installed, cables of this type have provided very-reliable communication, proving virtually immune to external interference. However, they could not bring traffic directly to points inland without relaying and were limited in traffic-handling capacity.

On the other hand cables, if wisely planned, enable the operating company to pick up and drop traffic along the route thereby improving cable

exploitation appreciably. Telegraph traffic has the advantage over telephony that it is not affected by time differences, instantaneous availability of both parties, and subscriber call-back time loss, thus allowing very-high channel efficiency.

Technically, the telegraph submarine cables have not grown far beyond the 1856 state of the art. Channel splitting and in some cases the insertion of simple regenerative repeaters have increased cable capacity, but the highest number of channels known is still only 12.

2.3 HIGH-FREQUENCY RADIO

The development of radio and in particular of the vacuum valve as an amplifier led to a new generation in global communication media. Low capital cost, high-efficiency directive aerial arrays, and the possibility to work from a single station with more than one correspondent in time schedule have gained for high-frequency or short-wave radio transmission a well-deserved application popularity. Virtually all countries in the world have today at least one high-power international high-frequency station. While the original transmitters operated in the *A1* mode or on-off keying, subsequent developments have given telephony capability with a 2400-hertz bandwidth, and more recently single-sideband and independent-sideband techniques provide up to 4 commercial-quality speech channels or the corresponding number of telegraph channels. However, this type of transmission can suffer at more or less predictable times from fading effects or from so-called sunspot activity. The channel-carrying capacity of high-frequency radio is limited by the increasing congestion of the frequency spectrum for the most-favourable frequencies. High-frequency radio is undoubtedly still the most-economical transmission medium, and many countries will therefore continue for some time to rely entirely on this method for global communication because their traffic demand can be met with a few channels.

2.4 EARLY SUBMARINE TELEPHONE CABLES

The first submarine cables for telephone transmission provided only a single speech circuit per balanced cable pair. They were loaded or unloaded depending on circuit length. Most of these cables are still in use today and provide adequate transmission over the distances involved, but obviously will not meet the high standards of intercontinental circuits as regards group delay, level stability, noise performance, and zero-loss equivalent.

Before the second World War, development of a submerged repeater was undertaken independently in Great Britain and in the United States to improve and lengthen submarine-cable telephone systems.

The British Post Office installed their first rigid

2-way repeater in 1943 in an Anglo-Irish cable, powered by direct current over the cable. In 1946 a similar repeater was inserted in a cable between England and Germany [3].

Whilst to Britain shallow-water repeaters were of main interest for application around the British Isles, the American development aimed at use in relatively deep water. Here the problem of laying conventional armoured submarine cable caused the designers to adopt the small-diameter flexible "snake" repeaters, armoured with the cable. This allows continuous laying over the cable gear of the ship and free rotation to avoid kinks in the cable. However, directional filters for both-way operation on one cable could not be accommodated, and this has led to the 2-cable practice of the American Telephone and Telegraph Company. The first

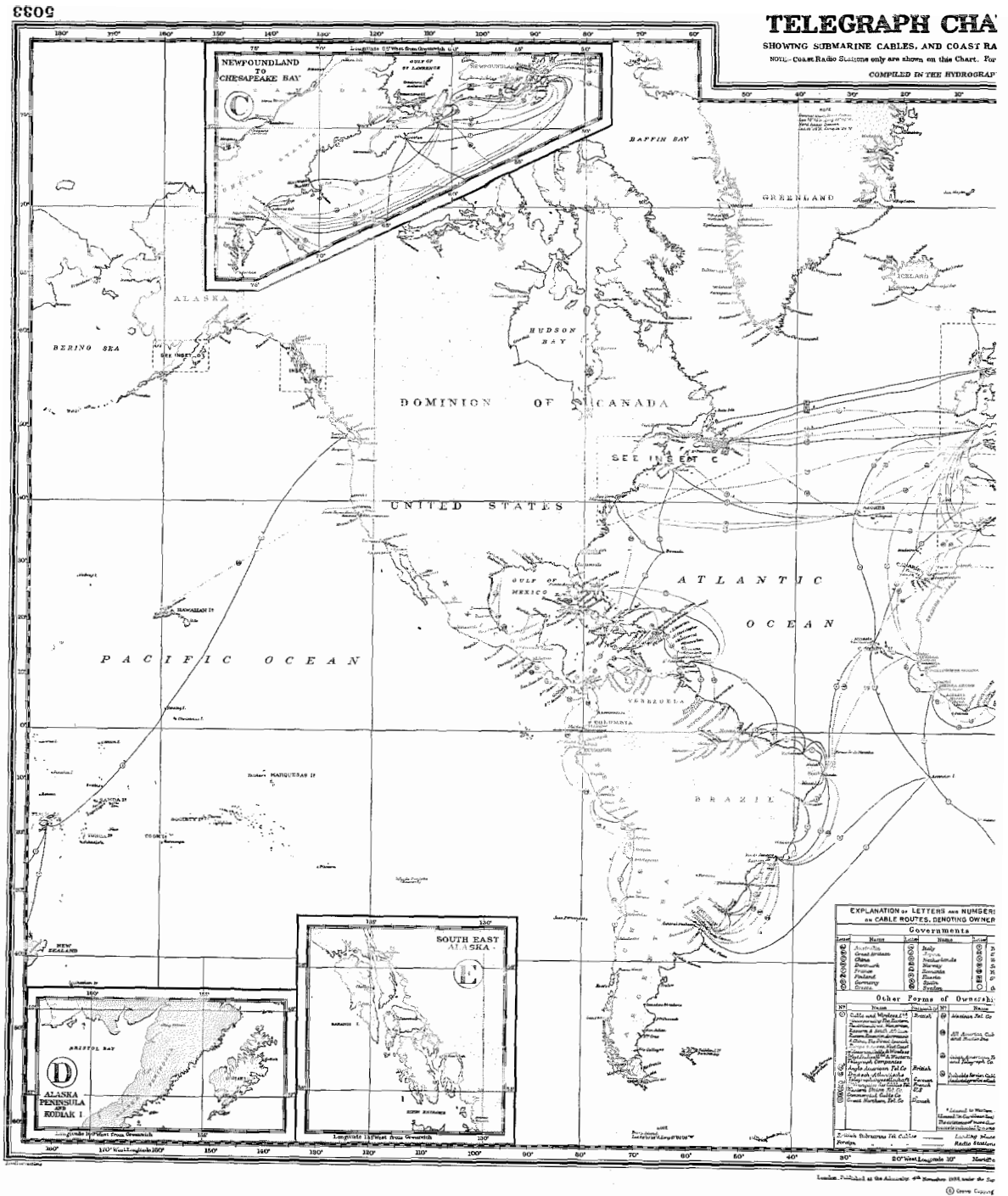
TABLE 2
EARLY SUBMERGED REPEATERS

Cable System	Anglo-German	Key West-Havana*	Dutch-Danish	Anglo-Dutch	Scotland-Norway	TAT-1* (Main Crossing)	TAT-1 (Canadian Section)
Year	1946	1950	1950	1950	1954	1956	1956
Repeater type	Single-end	Flexible	Single-end	Single-end	Double-end	Flexible	Double-end
Cable diameter in inches (millimetres)	—	0.46 (11.68)	0.935 (23.75)	0.62 (15.75)	0.935 (23.75)	0.62 (15.75)	0.62 (15.75)
Dielectric	—	Poly-ethylene	Poly-ethylene	Paragutta	Poly-ethylene	Poly-ethylene	Poly-ethylene
Capacity in 4-kilohertz channels	5	24	36	60	36	36	60
Top line frequency in kilohertz	44	108	356	552	352	164	552
Repeater gain in decibels	75	65	62	60	58.8	60.7	60
Repeater spacing in nautical miles (kilometres)	†	36 (67)	40 (74)	16 (30)	38.8 (71.9)	37.5 (69.5)	20.4 (37.8)
Voltage across each repeater	240	60	220	250	125	63	123
Line current in milliamperes	630	230	715	316	311	225	316
Supplier	British Post Office	Western Electric Company	Standard Tele-phones and Cables	British Post Office	Standard Tele-phones and Cables	Western Electric Company	Standard Tele-phones and Cables

* One-way transmission. Two cables are required to complete circuit.

† One repeater in 197 nautical miles (365 kilometres).

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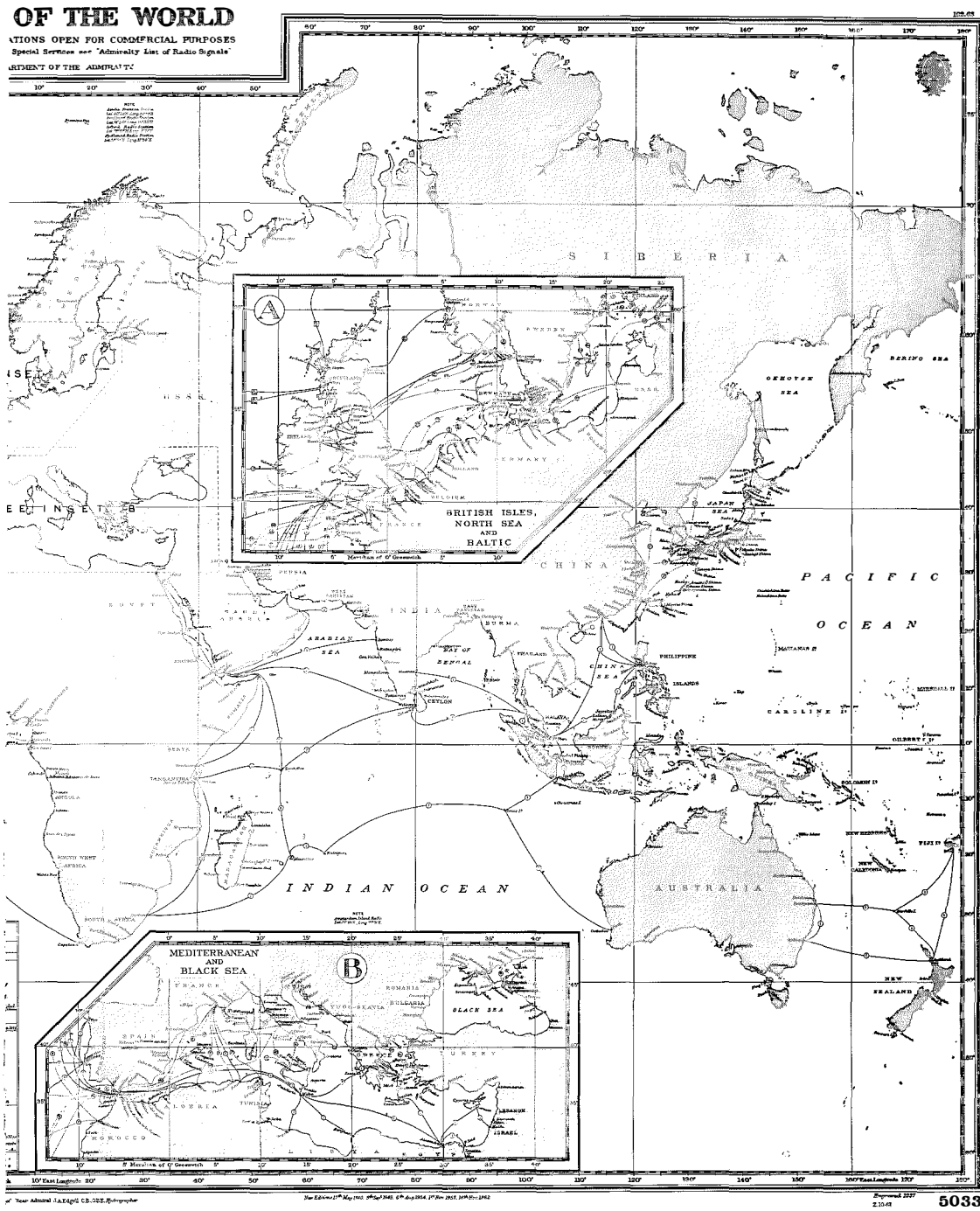


Figure 1—Telegraph cable chart of the world showing submarine cables and coast radio stations open for commercial purposes. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the Hydrographer of the Navy. Crown Copyright 1962. (United Kingdom)

Expanding Global Submarine-Cable Network

system of this type was laid in 1950 between Key West, Florida, and Havana, Cuba [4].

Encouraged by the success of the first repeater cable systems and growing demand for direct telephone circuits, Great Britain and other European countries laid several short-haul shallow-water submarine systems, using repeaters supplied by Standard Telephones and Cables. Some technical data for these repeaters and for the first transatlantic cables are given in Table 2.

3. International Submarine Cables (1956–1965)

Figure 2 indicates the rapid expansion of the global cable network for telephony during the past decade. Today there is no doubt left that submarine-cable telephone systems are economically very attractive and that early confidence in technological performance and reliability was fully justified.

3.1 BRIDGING THE ATLANTIC

The outstanding success of the short-haul cables was the basis for more-ambitious plans to ex-

tend a metallic path across the Atlantic. Great Britain and the United States combined their experience to plan, design, and engineer the first transatlantic cable known as *TAT-1* (Trans-Atlantic Telephone Cable Number 1) [5].

Flexible and unidirectional repeaters of American design were used with the conventional armoured cable of 0.62-inch (15.75-millimetre) diameter for the deep-water crossing of the Atlantic. The maximum system design voltage of 2000 volts precluded laying a direct cable between the United States and Great Britain, and therefore a shorter northern route, similar to that of the first transatlantic telegraph cable, was selected with landing points in Oban, Scotland, and Clarenville, Newfoundland.

A cable is used for each direction of transmission and originally provided 36 channels each of 4-kilohertz bandwidth, extended since the original laying date of 1956 to a total of 84 through the reduction of the channel bandwidth to 3 kilohertz [6] and the application of Time Assignment Speech Interpolation [7].

The main Atlantic crossing contains 102 repeaters, each working with a single 3-stage

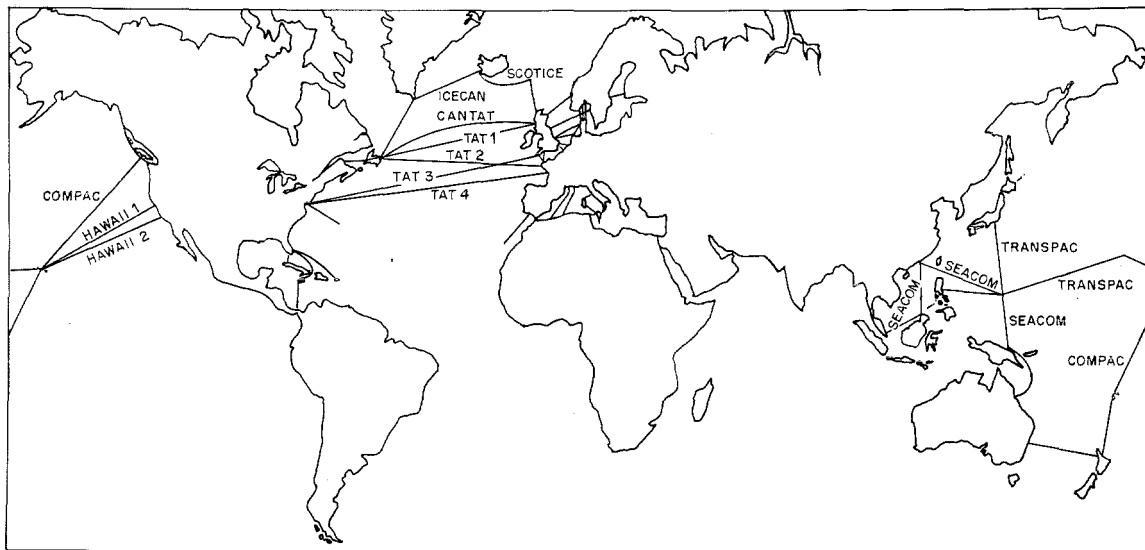


Figure 2—Global telephone submarine-cable network in 1965.

amplifier. Failure of a single valve out of the total of 306 would render the system inoperative, and an indication of the reliability achieved is that system performance is still trouble-free after 9 years of continuous service.

British experience with shallow-water bidirectional repeaters was applied to extend the main cable from Newfoundland to the Canadian mainland through provision of a single repeated cable for 60 circuits spaced at 4 kilohertz, with the excess circuit capacity available for local Canadian traffic.

Opening of the first transatlantic cable in 1956 has marked a new era in the evolution of global communications. Reliable 24-hour circuits free from atmospheric disturbances have stimulated the rapid growth of telephone traffic, which nearly doubled in the first year of operation and filled all available circuits during the busy hour.

Other cables had to be laid. In 1959 the *TAT-2* cable, a replica of the *TAT-1* system except that its European landing point is in France, was opened for direct traffic between the United States and continental Europe. This new facility again stepped up demand. Capacity working was reached within a year of operation, requiring 3-kilohertz channels and Time Assignment Speech Interpolation to be introduced.

The economic advantage of using both-way repeaters and a single cable was clearly recognized from the beginning of the long-haul-system planning; it was then impracticable only because of the problem of laying in deep water a rigid repeater spliced to an armoured cable. The solution was provided by the British Post Office invention of a light-weight cable [8]. In this cable the strength member is at the centre and is torsion free due to its construction. The inner conductor is of copper and the outer one of aluminium, whilst the sheath is only of polythene as armour wires are not required for protection in deep water.

Availability of this cable, supplemented by the development of new cable-laying machinery—

5 vee-sheaves of British Post Office design and linear cable-laying gear of American Telephone and Telegraph Company design—removed the major difficulties in laying rigid 2-way repeaters.

High-capacity single-cable systems became feasible, and in 1961 the first all-British cable system using Standard Telephones and Cables repeaters with 80 channels spaced at 3 kilohertz was laid between Canada and Scotland (Cantat) [8].

The Cantat cable increased transatlantic cable capacity to 248 voice channels. In 1962 a new cable provided the International Civil Aviation Organization with 24 channels from Scotland via Iceland and Greenland to Newfoundland [9].

The *TAT-3* system [10] using 128-channel submerged repeaters of Bell System design was laid in 1963 and directly linked the United States and United Kingdom, thus avoiding the Newfoundland area with its hazards to cables from fishing trawlers.

TAT-4, linking the United States with France, brings the total number of transatlantic cable channels to 528. Cantat, *TAT-3*, and *TAT-4* systems are capable of increasing their channel capacity further through application of Time Assignment Speech Interpolation.

3.2 COMMONWEALTH CABLE SCHEME

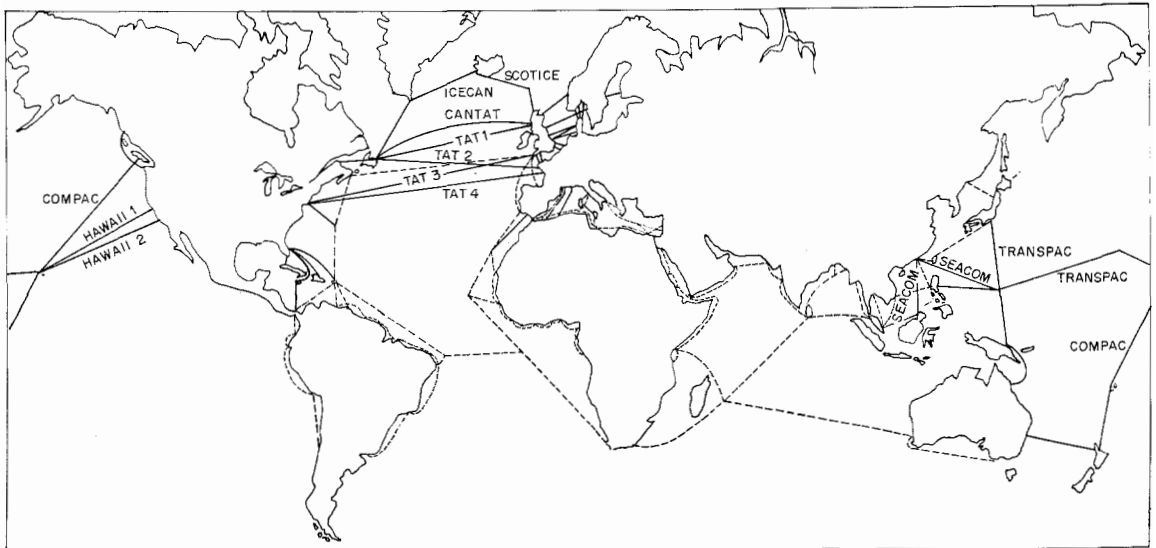
3.2.1 *Compac* System

In 1958 British Commonwealth Governments announced a proposal for a round-the-world cable system. It was based on the new light-weight cable and the 80-channel submerged repeater successfully used on the Cantat system, the first link in the proposed system.

Plans were made to link Australia and New Zealand to Canada, and in 1964 the Commonwealth-Pacific (*Compac*) system was completed, linking Vancouver to Hawaii (for

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Figure 3—Predicted submarine-cable network in 1980. The solid lines indicate existing cable, while the dotted lines indicate submarine-cable circuit requirements on new routes.



interconnection with the American cable network) and extending via Fiji to Auckland and Sydney [10].

This system uses a repeater with a gain of 55 decibels at 608 kilohertz, capable of providing 240 kilohertz in two directions of transmission plus a comprehensive supervisory system. Repeater spacing is 26.3 nautical miles (48.7 kilometres) with British Post Office 0.99-inch (25-millimetre) *Mark 1* light-weight cable.

The longest uninterrupted section of cable is between Hawaii and Fiji, with 118 repeaters in a cable 3073 nautical miles (5691 kilometres) long. Such a cable link requires that power be supplied from both ends and needs 2×6.3 kilovolts with 430 milliamperes of line current to energize the repeaters.

Excellent transmission characteristics were obtained, with a mean circuit noise between London and Sydney of less than 1 picowatt per kilometre (1.852 picowatts per nautical mile) for a route length of almost 26 000 kilometres.

3.2.2 Seacom System

The Southeast Asia extension of the Commonwealth Cable (Seacom) is scheduled for completion in 1966. The Hong Kong-Jesselson-Singapore link employs standard 80-channel repeaters and was taken into service early in 1965. The Hong Kong-Guam cable also provides 80 channels, but the Guam-Madang and Madang-Cairns sections are using a new 160-channel repeater described in detail in a companion paper [11].

3.3 BELL SYSTEM CABLES

Apart from the 4 transatlantic systems already mentioned, the American Telephone and Telegraph Company has laid several cable systems in the Caribbean area and in the Pacific Ocean. Their *SB* system, so successfully employed on *TAT-1*, was used to provide circuits to Hawaii, Puerto Rico, and Alaska.

The new design by Bell Telephone Laboratories, of a rigid 2-way repeater providing 128

channels on a single armourless cable (*SD* system) was tried out on the Florida-Jamaica-Panama route before the laying of *TAT-3*. Subsequently a transpacific system was laid between the United States and Japan via Hawaii, Midway, Wake, and Guam, with a spur to the Philippines [12].

The *SD* system uses a 128-channel repeater with a gain of 50 decibels at 1052 kilohertz. This repeater offers a 414-kilohertz band in both directions of transmission and provides system supervisory facilities. Using 1.0-inch (25.4-millimetre) light-weight cable of Bell Telephone Laboratories design, a repeater spacing of 20 nautical miles (37 kilometres) is achieved.

Nearly 1000 repeaters of this type have been laid between early 1963 and the summer of 1965. System transmission characteristics of very-high quality were obtained.

Through the transatlantic cable and Canadian and United States continental routes, European capitals are now connected to Japan, a distance of some 13 800 nautical miles (25 560 kilometres), and obtain service of quality even better than that for local calls.

The longest single cable link is 3784 nautical miles (7008 kilometres) between the United States and France, with approximately 200 submerged repeaters that require a line current of 389 milliamperes with an approximate system voltage of 3000 volts per 1000 nautical miles (1852 kilometres).

3.4 PRESENT SUBMARINE-CABLE NETWORK

The most-notable point in Figure 2, compared with the telegraph cables in Figure 1, is the development analogy. This development is doubly obvious if one considers the distribution of telephones throughout the world with heavy concentrations in North America and Western Europe. Following telephone density in importance are the international trade pattern plus political and ethnological affiliations.

Although standards of living and gross national product per capita will have considerable effect on the rate of introducing global communication links, there appears to be little doubt that if financing can be arranged by a third party, cable links will prove to be viable and a sound investment.

Based on the present charges for calls and for leased channels, submarine cables of present cost and capacities return about 15 per cent per annum on investment. On a compound-interest basis this represents repayment of a capital loan within 5 years, an attractive investment by any standard. Several cable systems now in operation will be repaid in even-shorter periods. The division of operating revenue between the cable owner and the telephone/telegraph/telex operator as established today leaves half of the gross revenue to the latter. This makes international telecommunications the most-remunerative part of the services provided by national administrations.

4. Expanding Communication Network

Figure 3 indicates the possible submarine-cable network by 1980 and is the result of our network and traffic studies on the subject. Many of the cable links have been under study for some time and a few are in an advanced stage of planning or project [2].

4.1 TRAFFIC GROWTH

Global telecommunication traffic has experienced a steady growth since 1946, and improvement of high-frequency radio facilities has given an average annual increase in overseas calls (beyond Europe) from the United Kingdom of around 10 per cent. World traffic growth, led by the United States, was slightly higher at about 13 per cent.

These percentages refer to the growth period before the first submarine cable was cut into service, whereas the growth rates have since increased considerably. Transatlantic channels

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between the United Kingdom and North America have increased from about 50 in 1956 to over 300 in 1965, or by 20 per cent annually, and these were fully loaded during the busy period within a year after installation. Some traffic growth data on United States terminated cable systems given in Figure 4 show a similar pattern. An additional phenomenon of interest is the longer call duration experienced with high-quality circuits. Caribbean and North Atlantic traffic has shown an increase from an average of 6 minutes to 8 minutes, causing a revenue and erlang channel loading increase of one-third per call. On transatlantic channels, there are still delays and calls have to be booked. The effect of on-demand service with international trunk dialing between

London and Paris (outgoing only) could represent a more-reliable indicator of traffic potential under ideal service conditions. With only London subscribers having such access, the increase was still 22 per cent or about twice that of the previous year.

An economically sound annual traffic growth rate, assuming neither over-provisioning nor longer call delays, will not be less than 20 per cent at the present tariffs. With the tendency to provide direct circuits between the international gateways of the various countries (thus creating relatively small groups of international circuits with operator-dialing service) the circuit growth will be 3 or 4 per cent less, that is, 16 per cent per annum so that channel demand

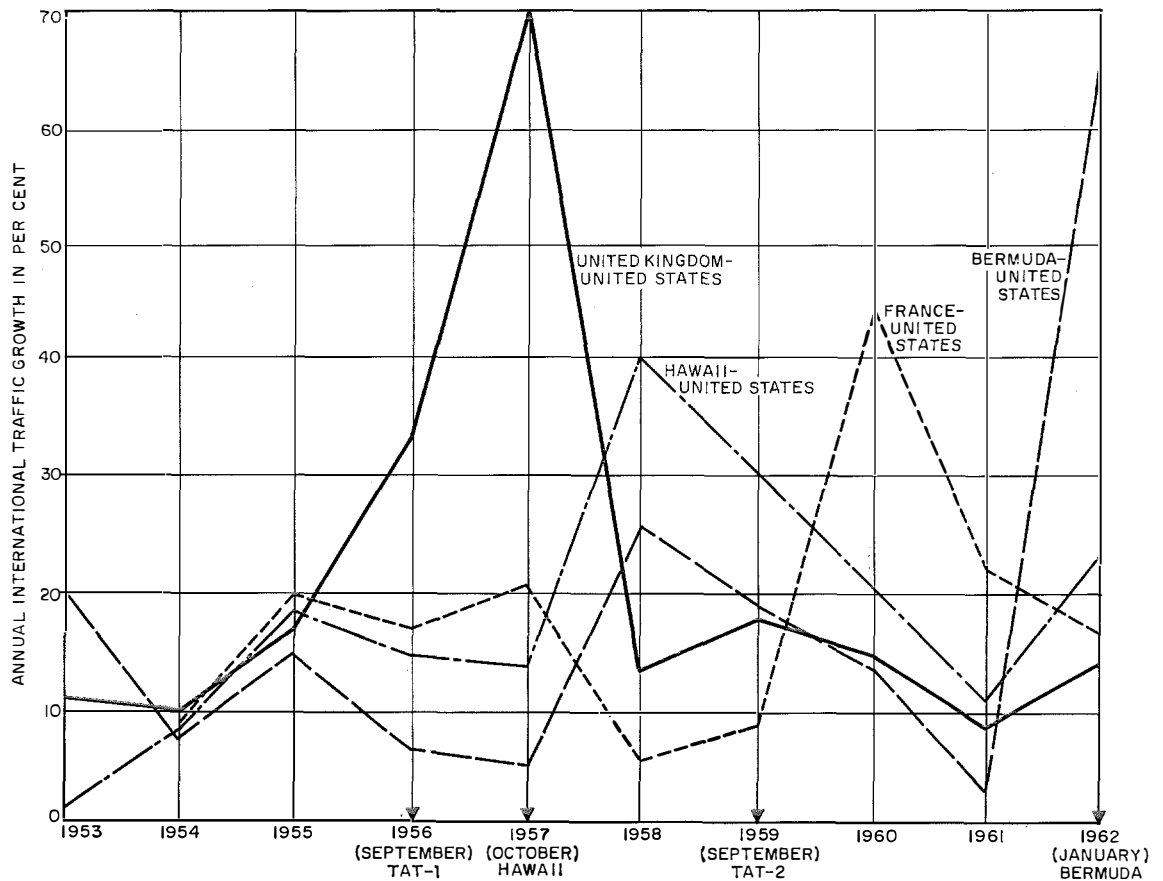


Figure 4—Annual traffic increase in per cent over 4 submarine-cable routes.

will double in approximately 4.5 years. The United Kingdom-North America route would require, for instance, another 300 to 360 circuits by 1970 to cope with this expected traffic growth.

On a global basis the International Telegraph and Telephone Consultative Committee [13], Standard Telephones and Cables [2], and others have estimated that overseas channels will double between 1965 and 1970, from about 3500 to 7000 channels. The share of terrestrial (land-based) communication is still uncertain and could vary between 50 and 80 per cent, leaving 700 to 1750 channels to be provided by other means.

4.2 TRAFFIC ROUTING

The advantage of the high-reliability submarine-cable system can be exploited to the full only if route planning receives considerable attention. Systems must not only link traffic centres, but other factors such as low maintenance, traffic drop and insertion, and geographic and

trade aspects must be considered. The existing telegraph cables are important historic guides. Figure 5 gives the existing facilities of the world traffic centres; their communication demands have led to the global cable network foreseen for 1980. The dotted lines indicate submarine-cable circuit requirements on new routes, although capacity increases will also be needed on some existing routes. The main network expansion is foreseen in the South Atlantic, Mediterranean, Indian Ocean, and Far East. It should be noted that the International Telecommunications Union has proposed a world switching plan with a number of switching centres that must be interconnected by high-quality transmission circuits.

4.3 SUBMARINE CABLES AND GLOBAL COMMUNICATION DEMANDS

Political and economic affiliations favour submarine-cable projects as the number of partners involved is limited; this eases planning, financing, and operating problems.

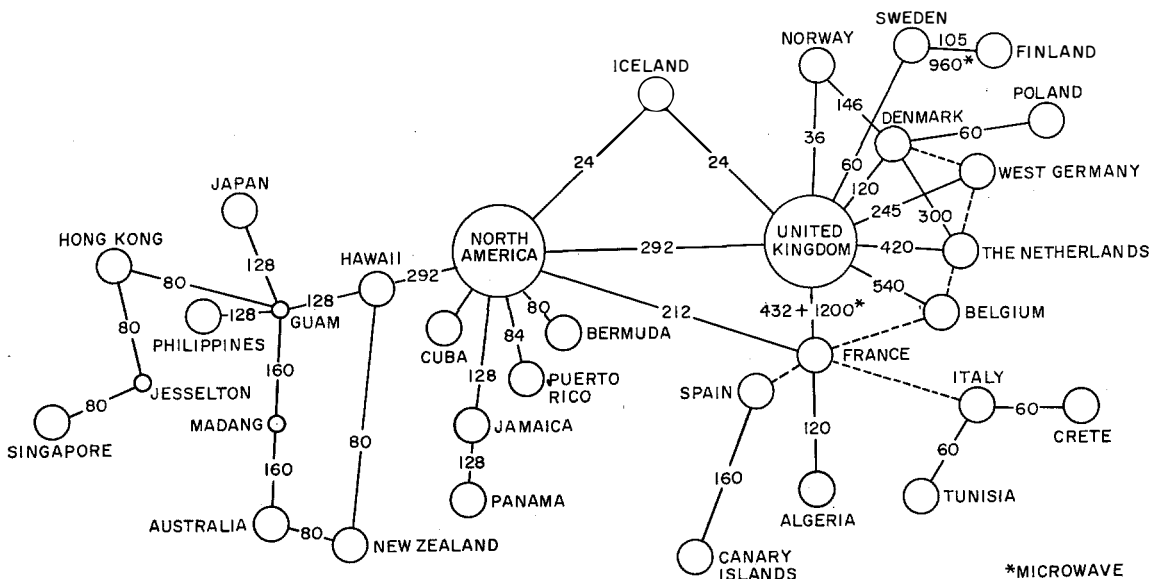


Figure 5—Traffic routing chart for submarine cables. The numbers indicate channel capacities.

Expanding Global Submarine-Cable Network

For cost and network-planning reasons the trend is to establish large-capacity trunk routes (360 channels or more) and smaller-capacity feeder or spur routes. It can be expected that over some routes a submarine-cable system will be preferred over land-based microwave or scatter systems because of the terrain to be crossed and the problems of access for maintenance and local power supply. Examples of this philosophy can be found on jungle or desert routes along the coasts of Africa, the Middle East, Australia, and South America. Submarine-cable systems allow great flexibility in circuit use and routing, as one or more channels can be re-routed at major cable-landing points to suit traffic requirements without the cost of transmission-delay penalty of tandem working. Eventually, automatic switching can be expected in major traffic centres for routing channels that are required only temporarily and infrequently.

With the growth of the global cable network in length and channel capacity, a gradual introduction of international subscriber dialing is probable.

The cost per channel-mile is a function of the channel capacity of the system, and trunk routes in the cable network will therefore have the largest available capacity for economic reasons.

The following systems are being developed to meet this demand.

4.3.1 *British 360-Channel System*

Designs are available for a repeater capable of providing 1080-kilohertz 2-way bandwidth and working at a maximum line frequency of 2964 kilohertz. A supervisory facility allows system monitoring while in service. Estimated repeater spacing is 10 nautical miles (18.5 kilometres) using 0.99-inch (25-millimetre) British Post Office *Mk 2* light-weight cable.

Designed for routes of 3500 nautical miles (6500 kilometres) with a mean circuit noise of 1 picowatt per kilometre, this system is to be employed on a number of major projects. It

is expected that over 600 repeaters of this design will be manufactured in the North Woolwich factory of Standard Telephones and Cables.

4.3.2 *Bell Telephone Laboratories SF System*

The *SF* system uses a 720-circuit repeater based on transistor amplifiers and designed for transatlantic routes. Estimated repeater spacing is 9 nautical miles (17 kilometres) on a cable of 1.5-inch (38.1-millimetre) diameter. The use of transistors reduces the requirements for very-high line voltages and enables relatively high amplification at the top line frequency of about 6 megahertz. A noise objective of 1 picowatt per kilometre has been adopted as for previous intercontinental circuits.

4.3.3 *British 1280-Channel System*

A system employing a line frequency up to 10 megahertz and transistor amplifiers is under development in Great Britain. It is anticipated that a larger-diameter cable will be used to provide repeater spacing of approximately 6 nautical miles (11 kilometres). The cost per channel of such a system is expected to come down to about \$15 per mile.

5. Comparison of Cable and Satellite Systems

During the next few years commercial satellites will directly compete with cable systems. Until the problem of multiple access is resolved, this competition is likely to apply to the heavy-traffic routes between the major traffic centres—a condition ideally suited for the submarine-cable operation. The final choice of the system will not necessarily be based on the economics alone. United States approval for cable landings may not be forthcoming until the Comsat Corporation has established a commercial satellite system with global coverage.

This appears to be the major reason why the American Telephone and Telegraph Company

has not announced plans for laying submarine-cable systems after completion of *TAT-4*.

However important the political factors are at present in the competition between cables and satellites, the economics and characteristics of the respective systems will in the end be decisive. There is no doubt about the demand for international and intercontinental circuits, but the respective shares of satellite and cable systems will depend in the long run on the technological and cost achievements of these systems.

6. Conclusions

It is yet too early to indicate the effect that satellite communication systems will have on the steady expansion of the global submarine-cable network. The achievements so far in space technology have been most impressive and deserve the greatest admiration. It can be expected that government funding of launcher and space-vehicle research and development will continue. The efficiency of the multiple-access facility, the importance of time delay and echo, the satellite lifetime, and the cost basis for the economic evaluation of a satellite system will be of major importance in the comparison with submarine-cable systems having established characteristics and channel cost trends.

High-frequency radio will continue as the most-economic long-distance link for a few channels. Submarine-cable systems have been proved, technically and economically, as satisfactory international and global communication links.

The great demand for more and better international circuits can be met by any of these media, and it appears certain that the global communication network will expand at an increasing rate.

7. References

1. J. R. Brinkley, "Economic Aspects of Space Communications," presented at the International Scientific Radio Union (URSI) Symposium on Space Communications Research, Paris; September 1961.
2. "Submarine Cable Systems Survey," internal document, Standard Telephones and Cables Limited, London; 1964.
3. D. C. Walker and J. F. P. Thomas, "British Post Office Standard Submerged-Repeater System for Shallow-Water Cables, with Special Mention of English-Netherlands System," *Proceedings of the Institution of Electrical Engineers*, volume 101, Part 1, (General), number 130, pages 190-200; (discussion) pages 201-203; July 1954.
4. J. J. Gilbert, "Submarine Telephone Cable with Submerged Repeaters," *Bell System Technical Journal*, volume 30, number 1, pages 65-87; January 1951.
5. "Symposium On The Transatlantic Telephone Cable," *Proceedings of the Institution of Electrical Engineers*, volume 104, part B, Supplement No. 4; 1957.
6. H. B. Law, J. Reynolds, and W. G. Simpson, "Channel Equipment Design for Economy of Band-width," *The Post Office Electrical Engineers' Journal*, volume 53, part 2, pages 112-117; July 1960.
7. C. E. E. Clinch, "Time Assignment Speech Interpolation (T.A.S.I.)," *Post Office Electrical Engineers' Journal*, volume 53, part 3, pages 197-200; October 1960.
8. "Anglo-Canadian Transatlantic Telephone Cable (CANTAT)," *Proceedings of the Institution of Electrical Engineers*, volume 110, number 7, pages 1115-1164; July 1963.
9. M. V. Young and W. J. Archibald, "United Kingdom-Faroes-Iceland (Scotice) Submarine-Cable Telephone System," *Electrical Communication*, volume 38, number 1, pages 76-87; 1963.
10. R. J. Halsey, "Commonwealth Transpacific Telephone Cable COMPAC," *Electronics and Power*; November 1964.
11. W. J. Archibald, B. M. Dawidziuk, and J. F. Tilly, "Submerged Repeater for the Commonwealth 160-Circuit Cable," *Electrical Communication*, volume 41, number 1, pages 91-101; 1966.

Expanding Global Submarine-Cable Network

12. "SD Submarine Cable System," *Bell System Technical Journal*, part 1, number 4, pages 1155-1459; July 1964.

13. "General Plan for the Development of the International Network—Rome 1963," International Telecommunications Union, Geneva; 1964.

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Submerged Repeater for the Commonwealth 160-Circuit Cable

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1. Introduction

The Commonwealth submarine-cable telephone system was designed by the British Post Office to have a capacity of 80 telephone circuits spaced at 3 kilohertz and transmitted in each direction over a single coaxial cable. However, after the installation of the Atlantic (Cantat) [1] and Pacific (Compac) systems it became apparent that certain sections of the Southeast Asia (Seacom) network would require a greater circuit capacity. It was therefore proposed that the sections from Cairns, Australia, to Madang, New Guinea, and from Madang to Guam should provide 160 telephone circuits spaced at 3 kilohertz. In all other respects the 160-circuit system had to be similar to the 80-circuit Cantat and Compac systems. This paper describes the repeaters designed to meet this requirement.

2. System Requirements

2.1 TRANSMISSION REQUIREMENTS

The transmission requirements were based on a hypothetical system length of 3000 nautical miles (5560 kilometres), consisting of 2800 nautical miles (5180 kilometres) of 0.99-inch (25.15-millimetre) diameter *MK1* lightweight cable in deep water and 100 nautical miles (185 kilometres) of the associated lightweight simulator cable in shallow water at each end. The deep-water cable was assumed to be at a constant temperature of 2 degrees Celsius, and annual changes of ± 3 degrees Celsius were accepted for the shallow-water sections. This results in a change in attenuation due to temperature change of ± 4.5 decibels at the top-channel frequency of 1164 kilohertz. Equalization misalignment was taken to be ± 3 decibels.

The system was planned to meet a noise objective of 1 picowatt per kilometre (1.852 pico-

watts per nautical mile), averaged over all channels in either direction of transmission when loaded at -10 decibels relative 1 milliwatt referred to a point of zero relative level per 3-kilohertz channel. This loading is 5 decibels above that recommended by the International Telegraph and Telephone Consultative Committee, and it allows a large proportion of the circuit capacity to be used for voice-frequency telegraph or for Time Assignment Speech Interpolation [2] equipment. Such relatively high channel loading is particularly applicable to long submarine-cable systems.

2.2 SUPERVISORY SYSTEM

The repeaters were required to have a supervisory system that permitted loop transmission measurements and noise and intermodulation measurements to be made from one of the terminal stations. The accuracy required was such that it should be possible to measure a change of 1 decibel in loop transmission and an increase of 15 decibels in the noise or intermodulation generated at any repeater. Such an increase in the noise of a repeater on a system containing 100 repeaters would result in an increase of 1.2 decibels in system noise.

Any supervisory circuits added to a repeater should not degrade the main transmission paths, and a failure in a supervisory circuit or component should not result in the loss of main transmission-path communication.

2.3 SUBMERGED REPEATERS AND EQUALIZERS

The submerged repeaters and submerged equalizers were required to use the same component types, employ the same techniques, and be manufactured to the same standards as the 80-circuit repeaters and equalizers provided for the Cantat and Compac systems.

Submerged Repeater for Commonwealth Cable

3. Repeater Design Considerations

The short development time available for terminal equipment, coupled with the requirements for the supervisory system and the use of component types already used in the 80-channel repeaters, led to adoption of the simplified block diagram and frequency spectrum shown in Figure 1. The transmission paths are shown in heavy lines to distinguish them from the supervisory system.

3.1 TRANSMISSION-PATH WORKING LEVELS

Preliminary system calculations indicated that

an amplifier gain of 53 decibels could be justified. This resulted in a repeater gain of 50 decibels, with a nominal repeater spacing of 17.3 nautical miles (32.0 kilometres) on the 0.99-inch (25.15-millimetre) diameter light-weight cable, and of 11.7 nautical miles (21.7 kilometres) on the 0.62-inch (15.75-millimetre) diameter light-weight simulator cable. Some details of the supporting calculations based on the four following assumptions are given below:

(A) Nominal attenuation at 1164 kilohertz of the 3000-nautical-mile (5560-kilohertz) hypothetical system is 8980 decibels.

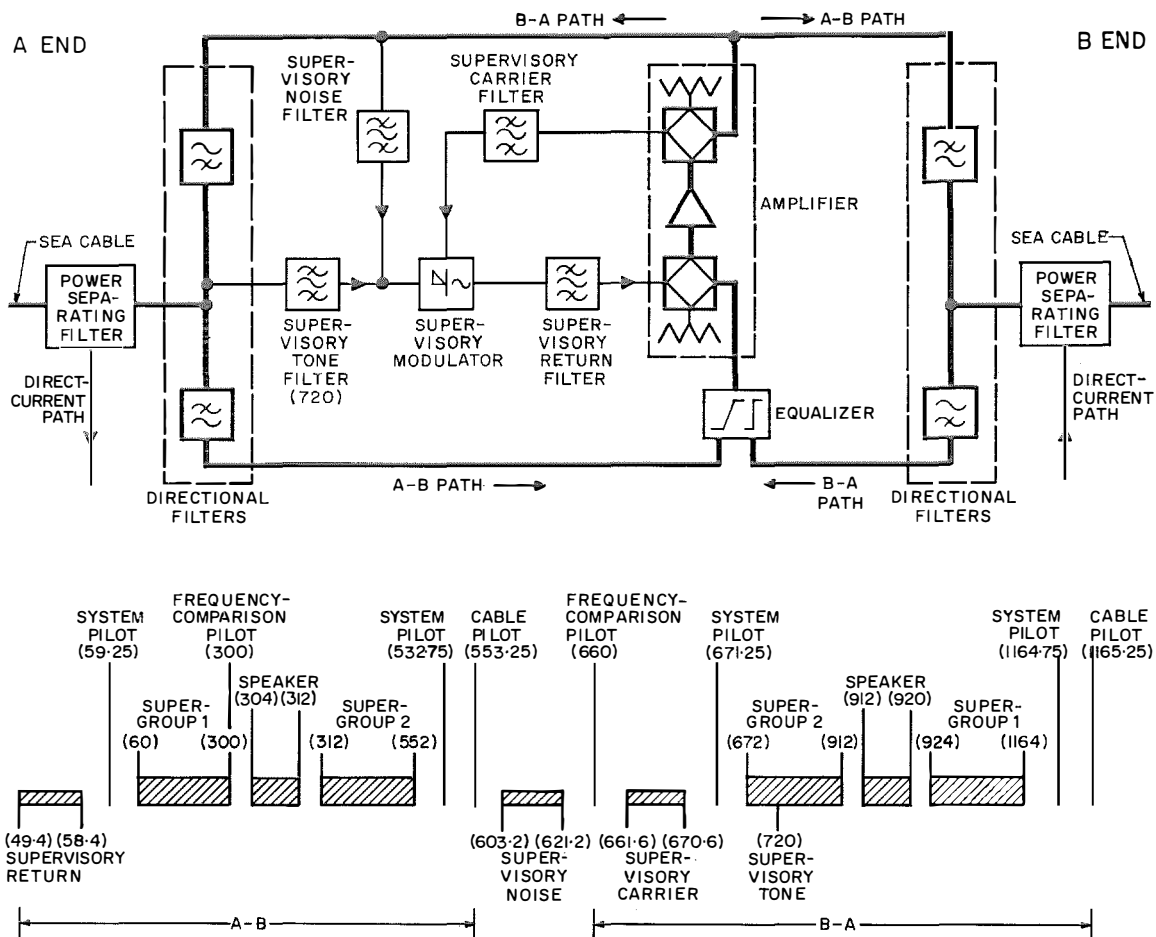


Figure 1—Simplified block diagram of repeater and the system frequency spectrum. Frequencies in kilohertz are in parentheses.

(B) Repeater gain at 1164 kilohertz is 50 decibels.

(C) Submerged equalizers spaced at intervals of 10 repeaters have a basic loss at 1164 kilohertz of 15 decibels (including a nominal loss of 9 decibels in adjustable cable simulators).

(D) End cable sections are 0.75 of a full section.

Based on these assumptions the number of repeaters and equalizers in the hypothetical system are 185 and 18, respectively. The average repeater spacing is therefore 16.2 nautical miles (30 kilometres), and the noise requirement of 1 picowatt per kilometre corresponds to 30 picowatts per repeater or -75.2 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted.

The effective thermal noise power in a 3-kilohertz band is -139 decibels referred to 1 milliwatt (weighted), and allowing 3.5 decibels for valve and intermodulation noise plus the effect of seasonal temperature variation on the attenuation of the shallow-water cable, the minimum repeater amplifier input level becomes -60.3 decibels referred to a point of zero relative level.

If M decibels referred to a point of zero relative level is the nominal mean level at the amplifier output, then with a total system loading of 18.4 decibels relative 1 milliwatt referred to a point of zero relative level, the maximum load on the amplifier is as follows:—

Power at amplifier output in decibels referred to 1 milliwatt	$18.4 + M$
Temperature-change allowance in decibels	2.0
Equalization-error allowance in decibels	2.0
Multi-channel peak factor [3] in decibels	13.0
Maximum peak power at the amplifier output in decibels referred to 1 milliwatt	$35.4 + M$

TABLE 1
NOMINAL REPEATER LEVELS*

Frequency in Kilohertz	Amplifier Output Level*	Repeater Levels*	
		Input	Output
60	-16.0	-28.9	-16.4
200	-16.0	-36.3	-16.3
400	-16.0	-45.4	-16.3
552	-16.0	-51.3	-15.9
672	-14.6	-53.4	-15.4
800	-13.6	-55.4	-14.0
1000	-10.6	-57.2	-10.9
1164	-7.0	-57.3	-7.3

* Levels are in decibels referred to a point of zero relative level.

The sine-wave peak overload on the amplifier is 25 decibels referred to 1 milliwatt, consequently $25 \geq 35.4 + M$, that is, $-10.4 \geq M$. The levels at the amplifier output are not flat, having a pre-emphasis of 7.6 decibels in the $B-A$ (high-frequency) direction of transmission. The maximum amplifier output level at the top-channel frequency of 1164 kilohertz will therefore be 5 decibels above M , or -5.4 decibels referred to the level at the point of zero relative level.

The maximum permissible amplifier gain is therefore 54.9 decibels at 1164 kilohertz. The actual amplifier gain is 53.1 decibels, providing a repeater gain of 50 decibels with levels as given in Table 1.

With the nominal repeater levels and assuming amplifier second- and third-harmonic margins at a fundamental level of 1 milliwatt to be 80 decibels and 105 decibels, respectively, detailed calculations indicated that the 3000-nautical-mile (5560-kilometre) hypothetical system would meet the noise requirements as discussed in Section 6.3.

3.2 SUPERVISORY SYSTEM

The elements of the supervisory system contained in the repeater consist of a modulator

Submerged Repeater for Commonwealth Cable

and associated filters. They are connected to the transmission paths of the repeater as shown in Figure 1 in order that a test tone of 720 kilohertz and a band of noise around 612 kilohertz, which is highly attenuated in the directional filters, may be translated into the supervisory return channel.

The repeater monitoring equipment at the B terminal of the system sweeps over the supervisory carrier frequency band and transmits the carrier to line. Each repeater has a different carrier filter, the mid-band frequency spacing being 75 hertz, providing for up to 120 repeaters. A repeater is selected for supervisory measurements on a carrier-frequency basis, and measurements of loop transmission—up to and including the repeater in question—and repeater noise can be made.

Carrier transmitted from the terminal is supplied to the repeater through the appropriate carrier filter. A band of noise from that repeater modulates the carrier and the lower sideband is returned to the terminal via the return filter. For loop gain measurement a 720-kilohertz

tone is transmitted from the terminal together with the carrier frequency. In this case the return band will contain both returned noise and returned tone; consequently the send level of the tone must be such that the level of the returned tone will be higher than that of the returned noise.

3.2.1 Supervisory Working Levels and Filter Requirements

The optimum carrier level is determined by the linearity of the modulator, the expected change in level of the carrier frequency due to temperature variations, and equalization errors. At the modulator the nominal carrier level has been set at -11 decibels referred to 1 milliwatt, giving an effective carrier level on the system of +15 decibels relative 1 milliwatt referred to a point of zero relative level. A nominal test-tone level of -5 decibels relative 1 milliwatt referred to a point of zero relative level gives adequate signal-to-noise ratio for loop gain measurement.

Requirements for the supervisory filters, shown

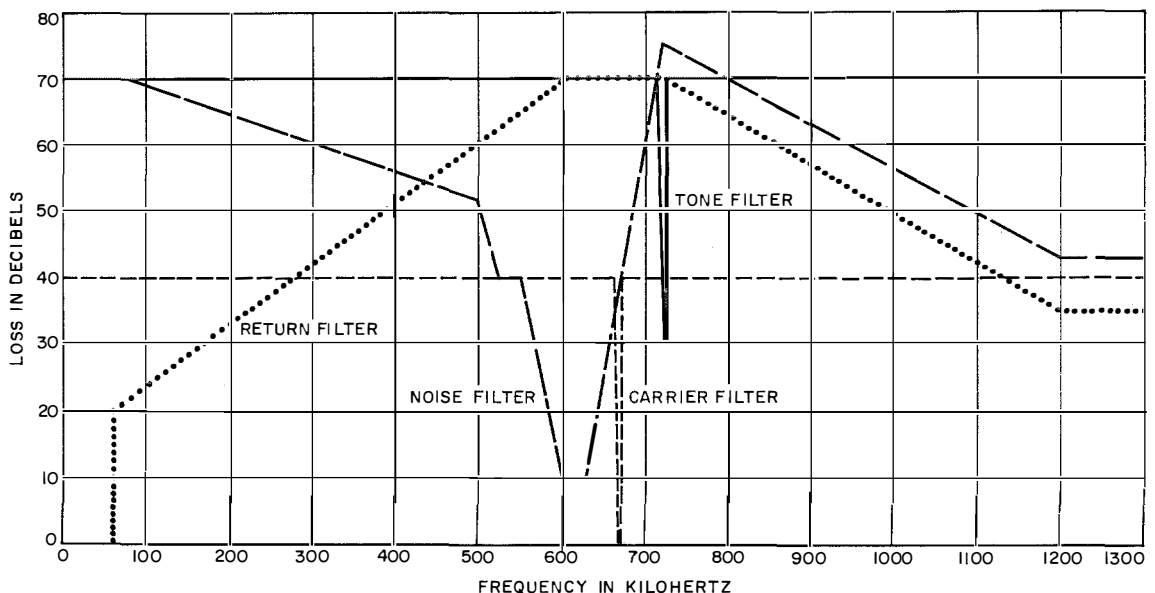


Figure 2—Requirements for supervisory filters.

in Figure 2, arise from the following considerations:—

- (A) Selection of the carrier frequencies.
- (B) Selection of the 720-kilohertz tone from the traffic band.
- (C) Loop loss requirements on singing paths round the line amplifier.
- (D) Prevention of crosstalk due to modulation processes in the modulator.

4. Repeater Circuits

The physical embodiment of the repeater is illustrated in Figures 3 and 4, which show a production amplifier unit and a repeater internal chassis in its assembly jig, respectively. All but one of the units are placed within gold-plated copper screening cans, the exception being the heater shunt and fuse assembly attached to the amplifier.

4.1 TRANSMISSION AND POWER-FEEDING PATHS

The transmission frequencies and the direct current for power feed are directed through different paths within the repeater by means of the power-separating filters at each end of the repeater.

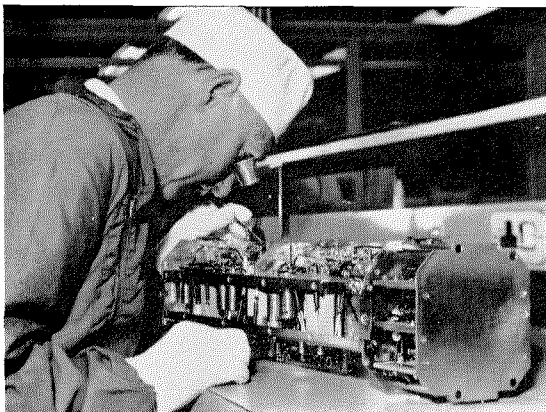


Figure 3—Amplifier undergoing visual inspection.

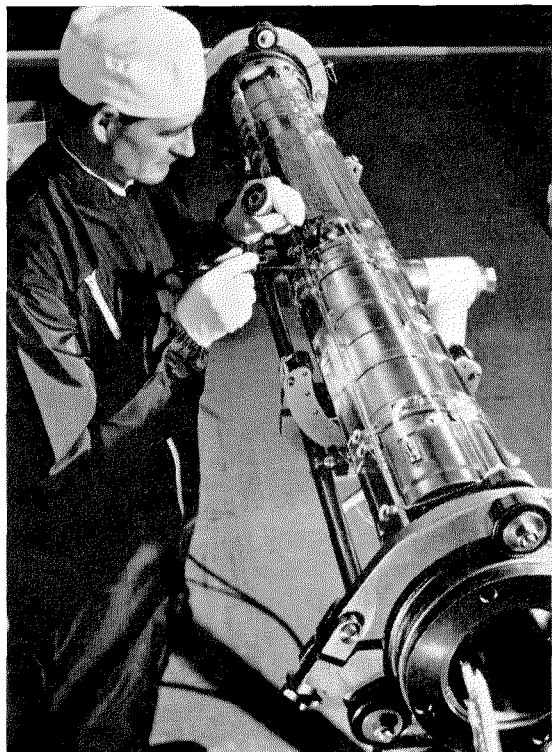


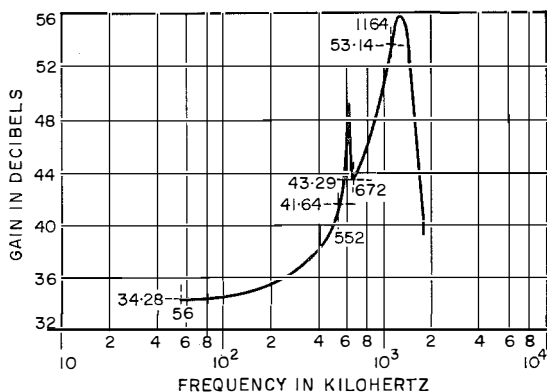
Figure 4—Wiring of repeater chassis in assembly jig.

The transmission paths use the well-established principle of a common amplifier for both directions of transmission, the amplifier and the directional filters necessary for separating the two directional bands being connected in a figure-of-eight configuration with the amplifier in the common cross-over path. The equalizer is also common to both directions of transmission and is connected in the input side of the amplifier path.

The power-feeding current of 415 milliamperes in the direct-current path from the power-separating filter at the *A* end of the repeater is routed to the complementary filter at the *B* end. This is done through a series chain of resistors and the two chains of valve heaters connected across sections of the resistor chain, the amplifier high-tension supply circuits being connected across the complete chain. The values of the resistors are selected such as to obtain

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Figure 5—Amplifier gain characteristic. The values at crossing points are in decibels and kilohertz.



the correct current in each heater chain and an amplifier high-tension voltage of 83 volts.

A special type of 4-contact fuse, as used on the 80-circuit repeater, is connected in series with the shunt resistor path across each valve-heater chain and is designed to operate if the associated heater chain becomes open-circuited. In this event the fuse contacts become permanently short-circuited, thus connecting shunt resistors to the resistor chain such as to compensate for the direct-current effects of the failure. The unaffected amplifier therefore continues to operate and the repeater gain is virtually unchanged.

The power and transmission circuits are protected by gas discharge tubes against high-voltage surges resulting from a cable fault.

The design of the directional filters is based on a conventional ring of Zobel high-pass and low-pass filters. To meet the intermodulation requirements, two of the coils in each low-pass and high-pass filter use manganese-zinc ferrite pot cores with a large air gap in the centre limb; the remaining coils use carbonyl-iron cores. The loop loss is considerably improved by the addition of a phase-reversing transformer of 1:1 ratio in the low-frequency side of one of the directional-filter paths.

The amplifier is of the conventional submerged repeater type employing two 3-stage amplifiers

connected between common input and output transformers and using a single feedback path. The gain characteristic (Figure 5) is such as to partly equalize the loss characteristic of the cable section; the "bump" in the characteristic centred near 612 kilohertz partly compensates for the pass-band distortion of the directional filters and provides additional gain for the supervisory noise band. Transmission around the feedback loop is illustrated in Figure 6, which shows adequate feedback over the transmission band and the phase and attenuation margins against self-oscillation.

The equalizer unit is common to both directions of transmission and is required to have a loss characteristic that, in conjunction with the amplifier gain characteristic, will give the required repeater gain characteristic.

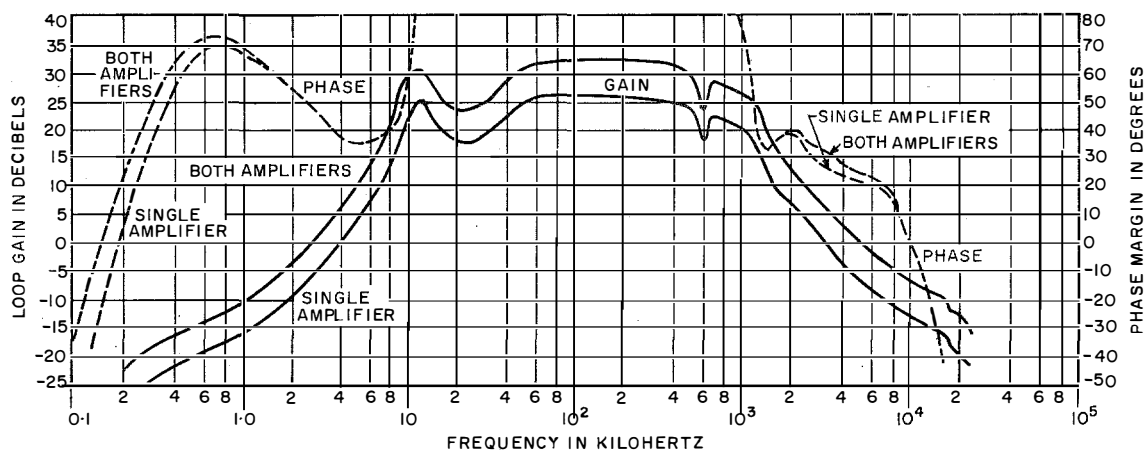
4.2 SUPERVISORY CIRCUITS

The selectivity requirements for the filters have resulted in the tone and carrier filters being crystal units. Both employ ladder networks, with the tone filter using two crystals and the carrier filter three crystals. The cut and frequencies of these crystals are similar to those used in the 80-circuit repeaters.

Aging results over 5 years on this type of crystal indicate a change of less than 1 hertz in 6×10^5 hertz. This permits the relatively close spacing of repeater supervisory carrier frequencies of 75 hertz. All other supervisory filters are of the coil-and-capacitor type.

The pick-off methods used for the tone, carrier, and noise filters are of interest. A 10-kilohm resistor is used in series with the tone filter to give protection against tone-filter failure as well as limiting the shunt loss in the transmission band to approximately 0.01 decibel. For the carrier pick-off a skew hybrid is used at the amplifier output to provide good protection against a fault in the carrier filter. The degree of skew gives a flat transmission loss in the traffic bands of 0.4 decibel. By using the elements of the susceptance network of the direc-

Figure 6—Amplifier loop gain characteristic, measured with amplifier terminated in a network simulating the impedance of the repeater circuits.



tional filter as the first section of the noise filter, the noise band is picked off in the crossover region with very little loss and contributes to the sensitivity of the noise measurement. This arrangement also ensures that the connection of the noise filter does not degrade the reliability of the directional filter.

The return filter is connected to the main transmission path via a skew hybrid coil at the input to the line amplifier so as to afford protection to the main transmission path. The degree of skew is similar to that used at the amplifier output.

The supervisory carrier pick-off and the supervisory return hybrid windings are incorporated in the output and input transformers, respectively, of the line amplifier.

A simple ring of germanium diodes is used for the modulator circuit and this employs diodes previously proved to be satisfactory for the supervisory circuits of 80-circuit repeaters.

5. Repeater Construction

The repeater was developed for deep-water application, all of the components being of

types previously developed for the earlier 80-circuit deep-water long-haul repeaters used in the Cantat [1] and the Compac systems.

The mechanical construction of the repeater capsule is very similar to that of the 80-circuit repeater. The repeater components are assembled in cylindrical gold-plated copper cans mounted between four Perspex bars as shown in Figure 4, the complete assembly then being placed in a polythene tube having a wall 0.25 inch (6.35 millimeters) thick and hermetically sealed in a brass cylinder. The repeater capsule so formed is then housed in a high-tensile steel case.

The housing is 119 inches (3 metres) long, and has an external diameter of 10.5 inches (266.7 millimetres) and an internal diameter of 8 inches (203.2 millimetres). The housing has brazed-in bulkheads to resist water pressure and is of the British Post Office type [1]. A moisture detector (humidity-sensitive resistor) inside the housing is used for monitoring the relative humidity after the housed repeater has been subjected to a water pressure of 5 long tons per square inch (32 776 kilograms per square centimetre) to confirm the effectiveness of the seals.

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Figure 7—Change in repeater gain with failure of one amplifying path (dotted curves) and equalization error with 17.3 nautical miles (30.0 kilometres) of 0.99-inch (25.15-millimetre) diameter light-weight cable (solid curves).

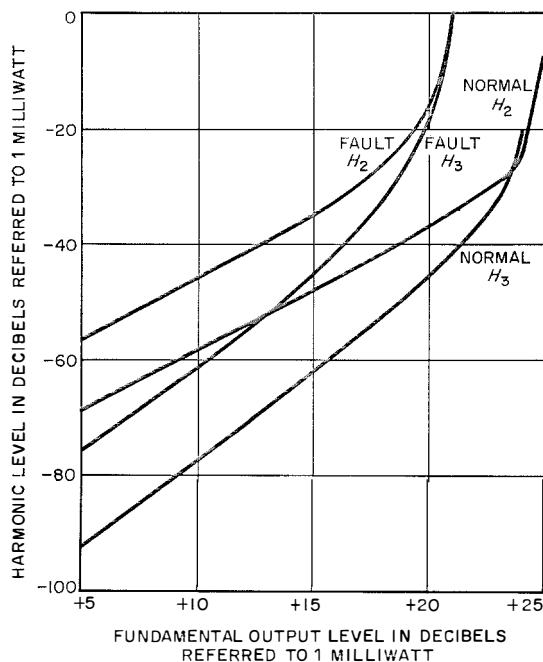
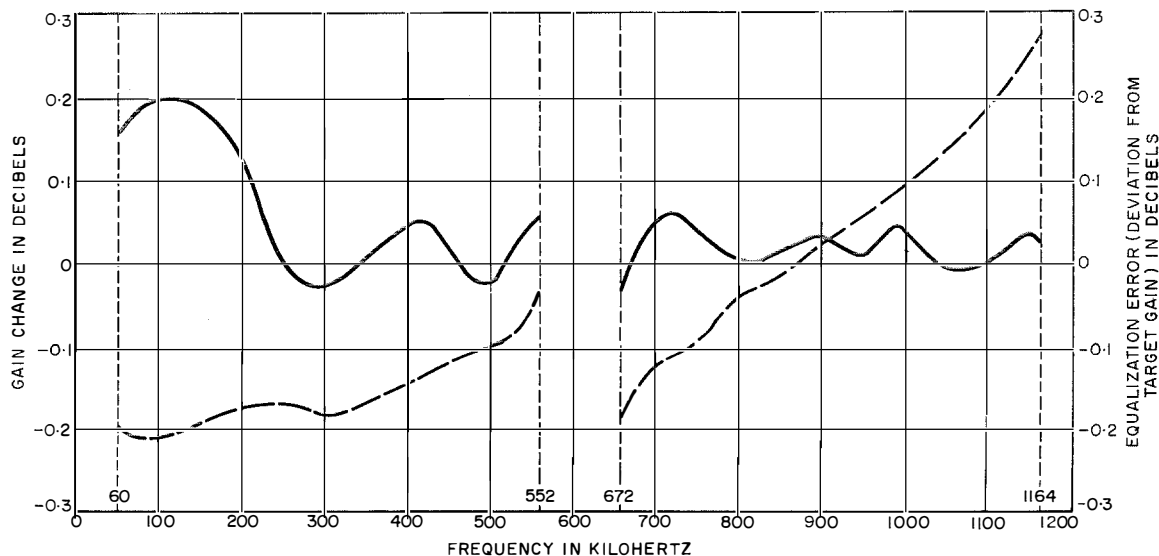


Figure 8—Amplifier harmonic distortion characteristic. $H_2 = 2f_0 = 720$ kilohertz and $H_3 = 3f_0 = 1080$ kilohertz, where $f_0 = 360$ kilohertz, the fundamental frequency.

6. Performance

6.1 TRANSMISSION SYSTEM

Figure 7 shows the change in repeater gain due to the failure of one amplifying path and the equalization error against the target characteristic for 17.3 nautical miles (32.0 kilometres); of 0.99-inch (25.15-millimetre) diameter light-weight cable. The target gain was established in conjunction with the British Post Office Engineering Department and took into account the changes in cable loss due to temperature and pressure based on the design specification for a depth of 2000 fathoms (12 000 feet) and a mean temperature of 2 degrees Celsius.

The amplifier second- and third-order harmonic distortion characteristics under normal and fault conditions are indicated in Figure 8. The fault condition represented is complete failure of one of the parallel-connected amplifying paths—and indicates a degradation of second- and third-order distortion close to the theoretical figures of 12 and 18 decibels respectively. The

characteristics also indicate the reduction in overload point of approximately 3.5 decibels due to the failure of one of the amplifying paths.

The variations of repeater noise and overload level with frequency are shown in Figure 9.

6.2 SUPERVISORY SYSTEM

The nominal level of the returned tone during a loop gain measurement is -23.4 decibels relative 1 milliwatt referred to a point of zero relative level, whereas the returned noise level in the 9-kilohertz return channel is -50 decibels relative 1 milliwatt referred to a point of zero relative level.

For a 3000-nautical-mile (5560-kilometre) system, assuming at worst a system noise of 1.852 picowatts per nautical mile (1 picowatt per kilometre) per 3-kilohertz channel, the background noise in the return channel will be -45.4 decibels relative 1 milliwatt referred to a point of zero relative level.

Hence the returned tone will be clearly detectable above the background noise. Also, for a normal system the noise returned from a single repeater will not be seen against the background noise until the repeater noise increases by 5 decibels. This increase is well within the basic requirement to identify a repeater showing an increase in noise of 15 decibels.

6.3 SYSTEM NOISE

Curves of the expected system, thermal, and intermodulation noise for a system of 100 repeaters are shown in Figure 10. The calculations for these curves were based on noise and harmonic measurements made on the first model amplifier and nominal operating levels for the repeater. For a system noise of 1 picowatt per kilometre, the noise per channel on a system of 100 repeaters would have to be -55.2 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted. This limit is indicated in Figure 10.

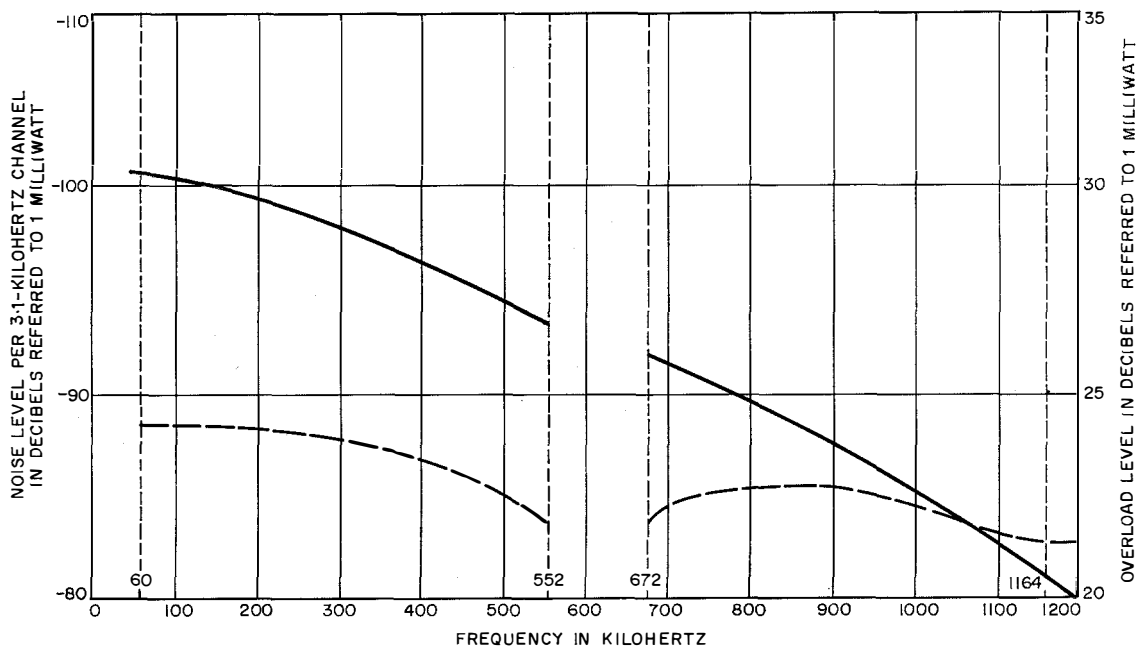
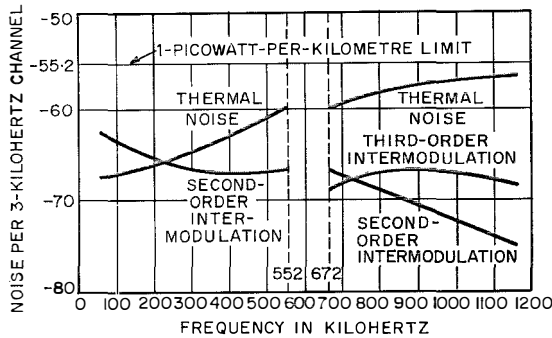


Figure 9—Variation with frequency of noise level (solid curves) and overload level (dotted curves) at repeater output.

Submerged Repeater for Commonwealth Cable

Figure 10—System noise in decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted, for a system of 100 repeaters.



7. Conclusions

A 160-circuit submerged repeater has been developed as a replacement for the 80-circuit repeater for certain sections of the Commonwealth cable. By the choice of a frequency spectrum providing economic use of the bandwidth, all the components used, including quartz crystals, are of types fully proved in the 80-circuit Commonwealth cable repeaters. It was thus possible to develop a reliable repeater in the relatively short period of seven months in accordance with the overall procurement schedule.

The transmission performance of the repeater meets the requirements for a 3000-nautical-mile (5560-kilometre) system. However, the present design limits the maximum system length because of the 6.25-kilovolt rating of the capacitors used in the power-separating filters and the number of available supervisory carrier frequencies.

The 6.25-kilovolt capacitors, the repeater voltage drop of 86 volts, and the cable-section voltage drop of 21 volts limit the system to 117 repeaters. Under this condition the operating voltage supplied from each terminal would be 6.25 kilovolts.

The 9-kilohertz bandwidth allocated to the supervisory carrier band provides sufficient carrier frequencies for making loop gain and noise

measurements on any one of up to 120 repeaters. Some carrier frequencies must of course be reserved for spare repeaters and for supervisory units at the shore-based terminals; consequently the supervisory requirement limits the system to 110 repeaters. Since the overall mean repeater spacing is 16.2 nautical miles (30.0 kilometres), the maximum route length of the present design is 1780 nautical miles (3297 kilometres). For routes up to 3000 nautical miles (5560 kilometres) higher-voltage power-separating filters and an extended supervisory system are employed.

System-noise calculations based on the measured values of amplifier noise and harmonics indicate that, provided the misalignments are kept within the allocated limits, the system noise averaged over all channels should meet the figure of 1 picowatt per kilometre, which is some 4.8 decibels below the figure of 3 picowatts per kilometre recommended by the International Telegraph and Telephone Consultative Committee.

8. Acknowledgments

The authors wish to thank members of the British Post Office Engineering Department with whom much profitable discussion has taken place during the development of this repeater. They also express their appreciation to Mr. M. R. Wright and other colleagues who conducted the laboratory work.

9. References

1. F. Scowen, D. C. Walker, and S. A. Taylor, "Anglo-Canadian Transatlantic Telephone Cable (CANTAT) Repeaters and Equalization," *Proceedings of the Institution of Electrical Engineers*, volume 110, number 7, pages 1134-1139; July 1963.
2. K. Bullington and J. M. Fraser, "Engineering Aspects of TASI," *Bell System Technical Journal*, volume 38, number 2, pages 353-364; March 1959.

3. H. Williams, "Overall Survey of Transmission-Performance Planning," *Proceedings of the Institution of Electrical Engineers*, volume 111, number 4, pages 727-743; April 1964.

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J. F. Tilly was born in England in 1930. He was educated at St. Catharine's College, Cambridge, and graduated in 1953 with a B.A. degree in mathematics.

In 1953 he joined the transmission division of Standard Telephones and Cables at North Woolwich. He became a member of the design group of the Submerged Repeater Systems Division in 1963.

Les détecteurs de rayonnement infrarouge (Infrared Radiation Detectors)

G. Chol, Y. Marfaing, M. Munsch, and P. Thorel

This book analyzes methods of infrared radiation detection and their limitations, compares the characteristics of available detectors, and supplies information on detection practice.

The first section, Principles of Infrared Detection, deals with noise sources, which limit the power level that can be detected. It evaluates a factor of merit for various types of detectors and analyzes their functions in detail.

The second section, Characteristic Properties of Detectors, is devoted to methods of measuring the parameters that characterize the per-

formance of each detector so that a suitable detector can be selected for a particular need.

The third section is on Detector Practice. It gives examples of detector applications and of equipment associated with these devices.

This paperback book includes a large number of characteristic curves, as well as an up-to-date bibliography. It contains 296 pages and is 15.5 by 24 centimeters (6.1 by 9.4 inches) in size. It is available from Dunod, Editor, 92 rue Bonaparte, Paris 6e, at 32 francs per copy.

Recent Achievements

Videx System Transmits Gemini-5 Recovery Pictures—An important gap in televising the Gemini-5 satellite journey was the lack of television pickup at sea to report visually on the recovery of the astronauts and the capsule immediately after splashdown on 29 August 1965.

The Videx slow-scan television system transmitted almost 100 still pictures (Figure 1) by radio from the *U.S.S. Lake Champlain*, the recovery vessel, to a receiving station on Long Island from where they were sent over a voice-



Figure 1—Two stages in the reception of a Videx picture as broadcast by television in reporting on the recovery of the Gemini-5 astronauts and capsule at sea.

grade telephone channel to Houston, Texas. As a picture was built up line-by-line across the Videx screen in Texas, it was picked up by a television camera and broadcast over the entire country. About 40 seconds were required for complete transmission of a picture. The image could be held for as long as 15 minutes if desired. As one picture was being viewed by the television camera, the next picture was being reproduced on a second Videx receiver.

Interposed between a modern self-developing camera and the Videx picture transmission system was a primitive transport device to carry each picture from the deck of the aircraft carrier to the Videx transmitting room up in its island—a bucket and a long piece of rope. It, too, worked well.

*ITT Industrial Laboratories
United States of America*

Gemini-5 Splashdown Interphone—The interphone shown in Figure 2 is dyed a fluorescent orange for high visibility, floats in water, and is sealed by thin rubber to withstand the pressure of water 33 feet (10 meters) deep. It was carried by the frogmen who attached the flotation collar to the Gemini-5 capsule immediately after splashdown. Plugged into a receptacle on the capsule, it permitted the frogmen to converse immediately with the astronauts on arrival and before opening the escape hatch.

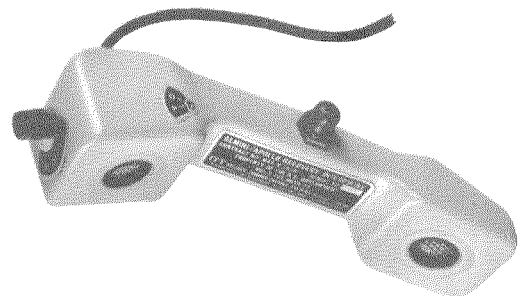


Figure 2—Interphone used by frogmen in conversing with Gemini-5 astronauts immediately after splashdown.

The interphone weighs 14 ounces (400 grams) and is housed in a plastic foam material having a hard thin skin. A 12-foot (3.7-meter) cord is terminated in a connector that also encloses a mercury battery. It is designed for use in the high noise produced by a rescue helicopter hovering overhead.

*ITT Telecommunications
United States of America*

Optical Link Monitors Current Transients in Extra-High-Voltage Lines—In the past, measurements of current transients in extra-high-voltage power lines have been made by means of current transformers, which must be insulated to ground for the full line voltage. The need for this insulation may be eliminated by an alternative method that makes use of an optical data link to bridge the high-voltage gap.

Such an optical link has been successfully demonstrated at Dungeness nuclear power station during tests being carried out by the British Central Electricity Research Laboratories. The model used employs a single-channel pulse-width-modulated system capable of handling a modulation bandwidth of 1 megahertz. The light-emitting device is a gallium-arsenide noncoherent source of an advanced type still under development, and the photodetector is a *PC1AF* fast silicon photodiode.

The mechanical design of the two optical heads was chosen to give a high level of immunity to stray fields. Lenses were used to enable both the source and the detector to occupy positions deep within their respective housings. Each unit is completely self-contained, the head accommodating the input and output amplifiers, pulse circuits, and power supply batteries. All are enclosed by a nesting assembly of spaced copper and permalloy screens. The transmitter (shown in Figure 3) and receiver heads are identical in external appearance.

Optical links of the type described are likely to have other applications involving transmission of data across regions of intense field

strengths such as the measurement of high voltage using an air-spaced capacitor potential divider.

*Standard Telecommunication Laboratories
United Kingdom*

Remote Control of Marseilles Harbor Area Power Grid—Late in 1964 the first stage in providing fully electronic centralized control of the harbor area of the Marseilles power grid was cut over. About 350 units in 11 transformer and distribution substations are now controlled from and signal their operating conditions to a central control station. As there are about 325 different signals and alarms, the number of items of information that may be sent to the central station totals about 2000. A second control station is connected to the central control station to ensure the supervision of the whole network.



Figure 3—Wide-band optical data-link transmitter for use over paths that are inaccessible by more-conventional means.

Recent Achievements

After a second section is placed in operation in 1965 and a third in 1966, the installation will serve 27 stations with a total of nearly 1000 units that must be reported on and controlled remotely. Some 750 signals of various kinds will produce nearly 6000 items of information. The complete system will use about 15 000 transistors.

*Compagnie Générale de Constructions Téléphoniques
France*

Stuttgart International Exchange—The Stuttgart international exchange, installed in the autumn of 1965, has been designed for ultimate use in worldwide fully automatic telephone service. It now handles subscriber-dialed traffic to Austria, Switzerland, France (Paris zone), Benelux countries, and Great Britain. Fully automatic telephone service will be extended further as soon as the necessary international agreements have been reached.



Figure 4—Quadradar installation for surveillance, final approach, height finding, and air-traffic taxi information.

Charges for international calls are determined on the basis of conversation time and distance. For international accounting, facilities have been provided that record the conversation times by destination areas. Both call charges and international accounting data are derived without considering the route chosen for a connection.

The equipment units for route and tariff selection (registers, translators, markers), which are used only during call establishment, have been centralized.

Through-switching of calls is effected by Herkon directional arrays designed to incorporate conditional selection, which denotes that an input of a directional switch is seized only after verifying that it has access to a free trunk in the desired direction.

*Standard Elektrik Lorenz
Germany*

Quadradar—Based on the earlier ground-control-approach radar, Quadradar serves as a complete air-traffic-control system. It provides surveillance, final approach, height finding, and air-traffic taxi information. It makes use of recent advances in antennas, incorporating side-lobe suppression to eliminate many problems found in beacon systems. The entire system may be operated by one man, who may readily select any one of the four functions.

The Quadradar weighs only 4600 pounds (2087 kilograms) and may be seen in Figure 4. It is used by all branches of the United States military, is operating at air bases in more than 20 countries, and has been purchased by 11 European countries.

An addition to Quadradar is a new Identification Friend or Foe system that provides rapid identification of a target. The two antenna systems, for identification and for Quadradar, may scan independently of each other while their outputs are displayed on a single indicator.

*ITT Gilfillan
United States of America*

Elevator Control—A fully automatic elevator control equipped with call-storing facility is shown in Figure 5. It uses only electronic components and hermetically sealed relays equipped with Herkon dry-reed and mercury-wetted contact units. Application of the Standard Equipment Practice for ITT Europe* permits simple assembly with plug-in units. All components are mounted on printed-circuit boards.

The equipment is easily adapted to particular requirements, as it uses only a few types of plug-in units. An outstanding advantage is compactness; a complete elevator control including call-storing facility for 10 to 20 floors is only 50 × 20 × 36 centimeters (19.7 × 7.9 × 14.2 inches) in size.

*Standard Elektrik Lorenz
Germany*

Programed Wire-Wrapping Machine—A machine capable of automatically laying out wires on a board and making wrapped joints at the terminals according to a program on punched

tape is shown in Figure 6. A numerically controlled coordinate-positioning table carries the panel to be wired in a horizontal plane. A fixed work head and its associated hydraulically actuated mechanism feeds out, strips, cuts, bends, and wraps the wire. There are two interconnected control systems, one of which controls the functions of the work head while the other provides position information for the table. All information required to operate the machine is provided by a single 8-channel punched tape. The machine is able to deal with terminals on a 0.2-inch (0.5-centimeter) module and with the terminal spacings used in the standard equipment practice for ITT Europe and in other equipment practices. The total available X- and Y-coordinate motion is 20 by 15 inches (50.8 by 38.1 centimeters).

*Standard Telephones and Cables
United Kingdom*

* F. Beerbaum, J. Evans, and F. Leyssens, "Standard Equipment Practice for ITT Europe," *Electrical Communication*, volume 39, number 2, pages 199-211; 1964.

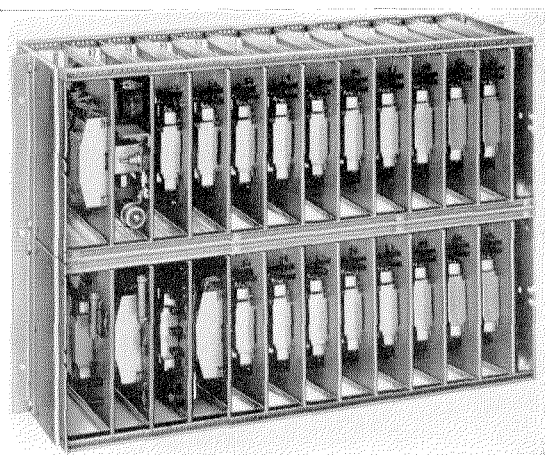


Figure 5—Elevator control including call-storing facility for 18 floors.

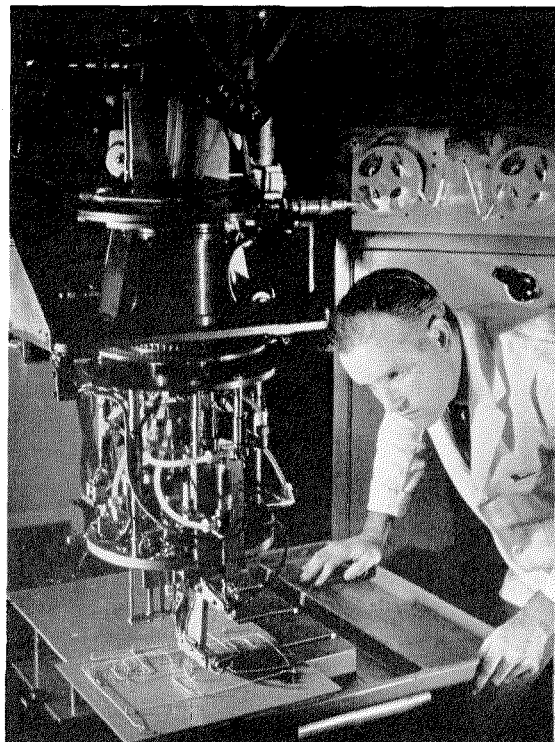


Figure 6—Programed wire-wrapping machine.

Recent Achievements

Automatic Letter-Sorting Machine—The equipment shown in Figure 7 scans postal check envelopes photoelectrically and sorts them into 10 groups in accordance with code signs previously printed on them. Rejects are delivered to a separate compartment. Refined sorting is then done by this machine or by supplementary ones.

The bundle of printed sealed envelopes is placed by hand on the slide of the delivery unit. The

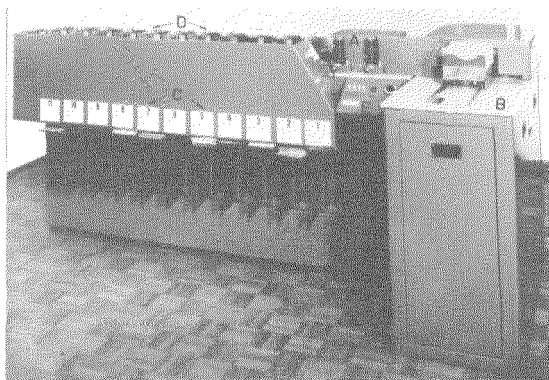


Figure 7—Automatic letter-sorting machine. *A* is the scanner; *B*, delivery unit with slide; *C*, compartments; *D*, clutches; and *E*, control panel.

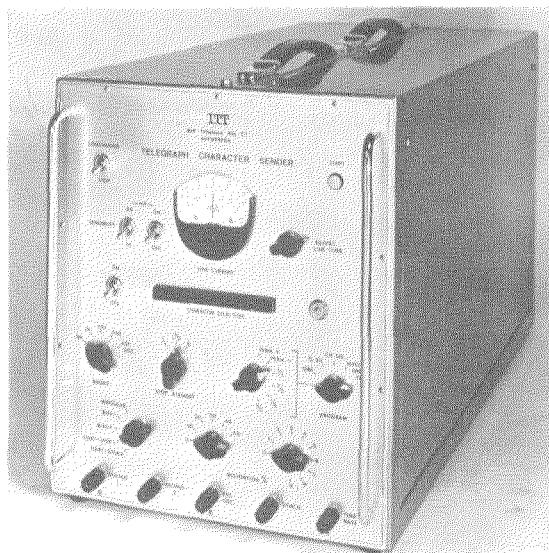


Figure 8—Portable telegraph character sender.

envelopes are drawn pneumatically onto a moving track, their code signs are scanned, and 11 clutches controlled by the decoder sort the envelopes into the 11 compartments.

The moving track can be arranged to carry 2 letters at a time for faster operation.

*Standard Téléphone et Radio
Switzerland*

Telegraph Character Sender and Distortion-Measuring Set—A telegraph character sender and a distortion-measuring set have been developed that comply with the most-stringent requirements of telegraph administrations.

The telegraph character sender shown in Figure 8 provides for a wide variety of tests on telegraph lines and teleprinters with either synchronous or start-stop systems operating at 50, 75, 100, or 200 bauds. Several kinds of preset signals are provided, but any desired signal whose code has been inserted by means of a keyboard can be transmitted. The signals may be sent with or without distortion. Figure 9 is an internal view of the sender.

The distortion measuring set, which also operates at 50, 75, 100, and 200 bauds, enables a complete analysis to be made of a received signal. It will display on indicator tubes the maximum distortion of a series of telegraph characters, the distortion of significant instants between mark and space and between space and

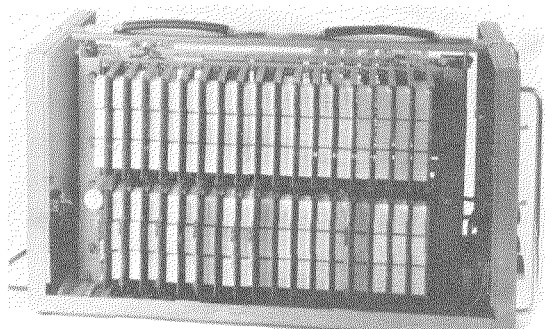


Figure 9—Internal view of telegraph character sender.

mark, and the distortion of each significant instant selected by a keyboard. The measuring set can be controlled from a subscriber station and will print simultaneously on its teleprinter all data about the measured distortion.

Each set is a portable unit fitted with handles but may be obtained for rack mounting. Operating power of about 50 watts is obtained from the mains. Logic-circuit blocks are fitted on plug-in printed-circuit boards. Each equipment is 35 × 30 × 68 centimeters (13.8 × 11.8 × 26.8 inches).

*Bell Telephone Manufacturing Company
Belgium*

Oslo Automatic Toll Exchange Cut Over—The Oslo automatic toll exchange (Figure 10) has recently been cut over for national automatic and international semiautomatic toll traffic. The exchange, which is of the 8B crossbar type, is equipped initially with 900 incoming and 900 outgoing lines for national toll traffic and 140 incoming and 140 outgoing lines for international toll traffic. It was designed by and manufactured jointly with Bell Telephone Manufacturing Company (Antwerp).

*Standard Telefon og Kabelfabrik
Norway*



Figure 10—View of 2 of the 21 rows of equipment in the Oslo automatic toll exchange.

Centralized Control Selectronic 701—The Selectronic 701 supervisory remote-control equipment can accommodate 256 command selections and monitor 3072 indications and 256 measurements. It uses fast time-division-multiplex techniques to send commands from a control station to outstations and to receive alarms, indications, and meter readings from them. Connection between the stations may be radial, omnibus, radial with tandem stations, et cetera, and further additions can be made. Transmission can be via telephone link, power-line carrier, or radio. Commands include circuit-breaker operation, opening and closing of valves, operating solenoids, and switching motors.

All supervised parameters are continuously scanned. Indications may be of the state of circuit breakers or valves, for example, and alarm signals may be presented on a console or mimic diagram at the control station using colored lights or semaphore indicators.

Measurements of voltage, current, fluid flow, levels, et cetera, appear on analog or digital indicators. Audible and visual alarms can be

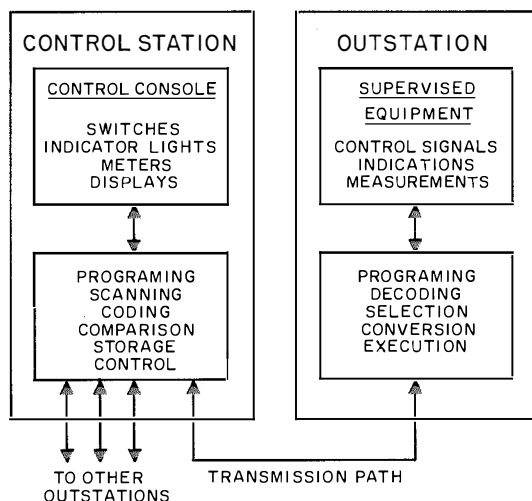


Figure 11—Function of the Selectronic 701 control system. The control station can send 256 command selections and monitor 256 analog or digital measurements and 3072 indications.

Recent Achievements

incorporated as required. The system is modular and follows the standard equipment practice for ITT Europe. A function diagram is shown in Figure 11.

*Standard Telephones and Cables
United Kingdom*

Multiplex for Low Traffic Density—The *K65B* multiplex telephone equipment provides 12 or 24 voice channels using either 2-wire or 4-wire terminations. Built-in signaling may be at either 3825 or 2600 hertz, the latter being compatible with Western Electric *E3B* equipment.

Silicon transistors, mercury-wetted reed relays, silver-mica capacitors, and etched circuit boards of glass-epoxy assure long life. Filters and frequency translators are hermetically sealed.

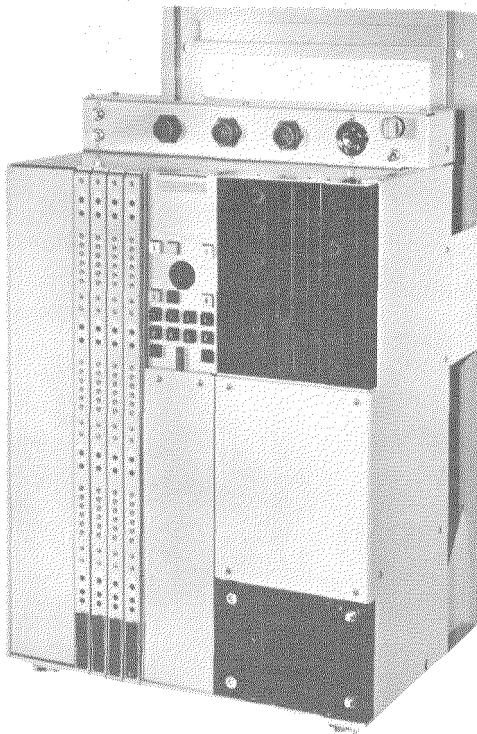


Figure 12—Multiplex telephone equipment for 12 or 24 channels.

Mounted on a standard 19-inch (483-millimeter) rack, the unit shown in Figure 12 requires 22.75 inches (576 millimeters) of vertical space and is 9 inches (229 millimeters) deep. Shock mounting is available. Connections are accessible from the front. It may be expanded to 960 channels by using *K65A* common equipment and additional *K65B* units.

The *K65B* conforms to the recommendations of the International Telegraph and Telephone Consultative Committee, United States Defense Communications Agency, and the Australian Post Office.

*ITT Telecommunications
United States of America*

Computer Program to Calculate and Sort Interplanar Spacings in Crystals—Published crystallographic data are usually confined to lattice parameters and the space group. For identification purposes a list of d values for the various reflections, such as is given in the Power Diffraction File of the American Society for Testing and Materials, is required. To calculate such a list for low-symmetry systems is extremely tedious and is best carried out on a computer. A program has accordingly been written in Stantec Zebra Simple Code to calculate and sort d values from lattice parameters.

The program is entered, and the upper and lower limits of d required may be dialed in. The data are simply a list of the lattice parameters, $a, b, c; \alpha, \beta, \gamma$. The required d values are calculated and stored, then sorted. They and their Miller indices are printed or punched as they are extracted during the sort routine (largest d first).

The program automatically calculates the range of Miller indices required and eliminates all reflections that are equivalent owing to the symmetry of the system. On picking up h, k, l , it enters a dummy subroutine that returns it to the main program. This subroutine may be replaced by one that will eliminate reflections that are absent due to the space-group sym-

metry. After d is calculated, the value is checked and is rejected if not within the required range. Required d values are stored along with $h k l$ encoded in the adjacent location of the number store. Sorting and output begin on completion of this step.

The computing time increases with the complexity of the system for a given range of d values and comparable cell dimensions. Typical times for an output of 50 values in the case of tetragonal or hexagonal systems with values of d down to 1 angstrom unit are 10 to 15 minutes, and for monoclinic systems with $V \approx (6 \times 6 \times 9)$ cubic angstrom units, about 30 minutes.

*Standard Telecommunication Laboratories
United Kingdom*

Piezoelectric Crystals for Modern Transceivers

—The stability required in modern transceivers will not tolerate long-term frequency drift. Such aging can be minimized by eliminating unstable materials (such as those that are subject to polymerization, oxidation, et cetera) from the

envelope around the crystal and by perfectly clean and tight encapsulation. This technique results in remarkably high Q values. If necessary a great accuracy of frequency adjustment can be added.

Figure 13 shows two lines of glass-enclosed crystals corresponding to the metal-case miniatures and subminiatures for which the MIL references are *HC 27* and *HC 26*, respectively.

Microminiature radio designs call for crystals of even-smaller dimensions. The metal-enclosed unit in Figure 13 is only 0.07 cubic centimeter (0.0042 cubic inch) in volume, with a base area of 0.14 square centimeter (0.022 square inch).

Figure 14 shows examples of crystal applications.

*Le Matériel Téléphonique
France*

Automatic Message Recording for Bologna Exchange

—An electronic apparatus has been installed in the *7D* rotary exchange of Bologna

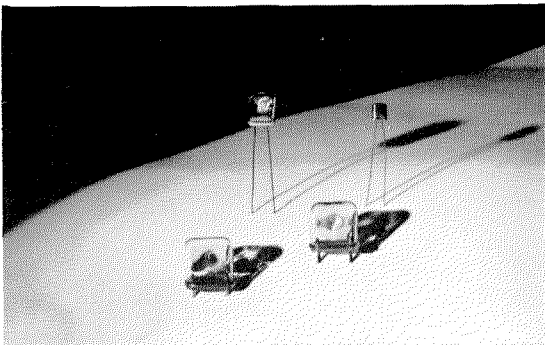


Figure 13—Three of these crystals are sealed in evacuated glass envelopes. The two front units are miniature type *HC 27* oscillating at 5 megahertz ± 0.0001 percent on 3rd overtone with a $Q > 10^6$ and stability of 10^{-6} over 1 year. The crystal at left rear is subminiature type *HC 26* and operates at 8 megahertz ± 0.0005 percent. The microminiature crystal in the metal case has a fundamental frequency of 22 megahertz and a series resistance of approximately 25 ohms.

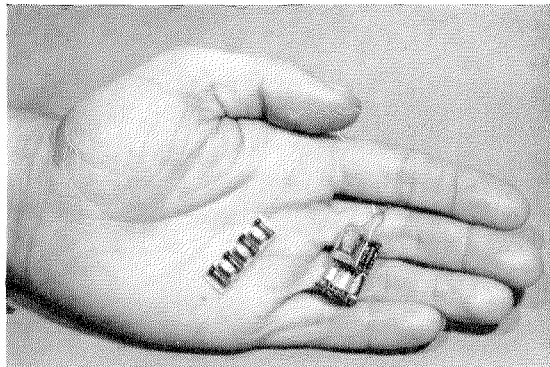


Figure 14—At left is a ladder filter using 3 microminiature crystals. Its bandwidth of 10 kilohertz is centered at approximately 22 megahertz. Minimum attenuation outside of the pass band is 40 decibels. At right is a Clapp oscillator operating at 8 megahertz at 75 degrees Celsius with an *HC 26* glass-envelope crystal.

Recent Achievements

to record data for the billing of telephone calls, including those placed by direct distance dialing.

This apparatus records the total number of toll calls and the total number of calls to free and to charged-for special services. For each call placed by direct distance dialing, it records the number of the called subscriber, length of call, date and time, and the total charge for the call.

*Fabbrica Apparecchiature per Comunicazioni
Elettriche Standard
Italy*

Pisa Exchange Cut Over—A toll transit exchange for Pisa was cut into service in July 1965. This Pentaconta exchange, with an initial capacity of 616 incoming junctions and 779 outgoing junctions, carries district, regional, and interurban transit traffic. It includes a 4-wire transit switching group for the interdistrict and interregional traffic and an outgoing switching group for traffic to the Pisa area.

For incoming traffic to the Pisa area, the exchange is connected through special adapter circuits to permit the new Pentaconta crossbar switches to work with the existing 7D rotary urban exchange.

The cutting over of this exchange presented unusual difficulties as it occurred during the peak of the tourist season in this historical city, which attracts unusually large numbers of visitors.

*Fabbrica Apparecchiature per Comunicazioni
Elettriche Standard
Italy*

Herkomat Private Automatic Branch Exchange

—The Herkomat system introduced to the public during the International Exhibition of Transport and Communications in Munich employs quasi-electronic techniques. It uses Herkon dry-reed switches for through-switching of the speech path and for some control functions. The Herkon contacts are sealed in a glass tube filled with a protective gas. These

contacts offer high operating speed, good switching capacity, extremely long service life, and immunity from external influences.

In addition to a number of new service features, the Herkomat exchange permits operation with push-button telephone subscriber sets.

*Standard Elektrik Lorenz
Germany*

Pulse-Code Modulation for 625-Line Television

—An experimental broad-band pulse-code-modulation system for television samples the signal at 12.5 megahertz and uses a parallel encoder to generate an 8-digit unit-distance code providing 81 quantization levels. The encoder is linear. Only one level is used for the television synchronizing pulse. Earlier attempts to encode television frequently employed an electron-beam coding tube, but in the present instance discrete solid-state components are used throughout.

The encoder, shown in Figure 15, is divided into 14 identical subunits, each of which discriminates a group of 6 adjacent levels. The subunit outputs are interconnected to produce the appropriate codes. Each subunit is preceded by a coarse discriminator that offers to it a range of signals only slightly exceeding the range it encodes.

Serialization results in a digit stream of 100 megabits per second. Transmission problems are eased by converting to a balanced ternary-

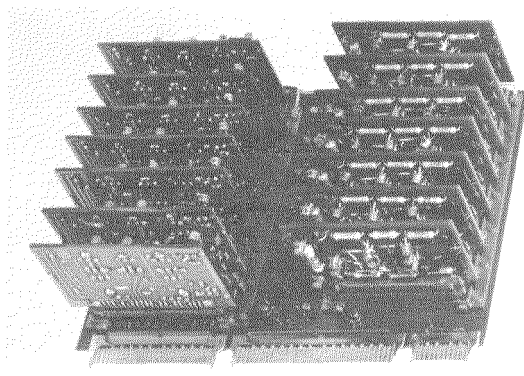


Figure 15—Parallel encoder for television.

based binary code in which the number of consecutive ones or zeros cannot exceed 4. Thus direct-voltage restoration is not required, low-frequency components are reduced, and frequent transitions for the extraction of a timing signal are guaranteed.

Any transmission medium that provides adequate bandwidth may be used, and a repeater (Figure 16) has been built for 4-millimeter (0.163-inch) coaxial cable. This repeater is regenerative and will handle low-disparity data at 100 megabits per second. The amplifier section has a gain of 65 decibels and is followed by slicing and retiming circuits. Retiming is obtained by filtering out the pulse repetition frequency in a coaxial helical resonator with a loaded Q of about 400. The regenerator is fitted with an equalizer for 880 meters (2880 feet) of 4-millimeter coaxial cable.

At the decoder, character synchronization is achieved by detection of the television synchronizing pulse. The transmitted code may be decoded directly by weighted addition of the stretched digits after deserialization, but better results are obtained by first translating to another code.

Subjective observation of 625-line monochrome pictures indicates that on most types of program material quantizing effects are not apparent, and the quality is adequate provided that im-

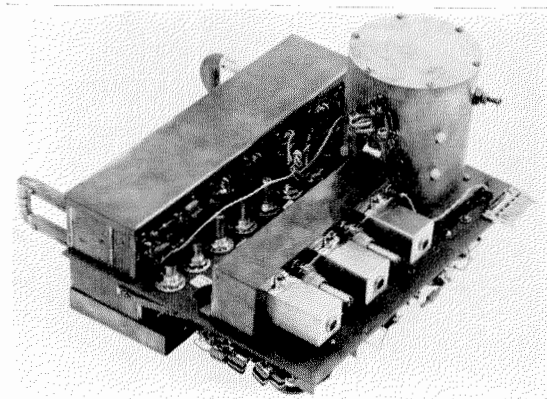


Figure 16—100-megabit-per-second regenerator.

pairments are not compounded by operating independent links in tandem.

*Standard Telecommunication Laboratories
United Kingdom*

Code Teleswitch FZE 02—The Code Teleswitch *FZE 02* shown in Figure 17 is a new electronic switching device designed for use in teleprinter networks. Under the control of code words transmitted over the telegraph circuit, it actuates contacts to initiate further operations.

Employing electronic circuits on plug-in printed-wiring boards, the device is practically maintenance-free. Its telegraph speed is adjustable to 50, 75, and 100 bauds, or optionally to 100, 150, and 200 bauds. It is inserted between the teleprinter and the telegraph line by means of connectors.

The Code Teleswitch *FZE 02* is used for remote control of equipment, selection of information, connection and disconnection of teleprinter lines, and many similar functions. It can also be used to initiate, from a central

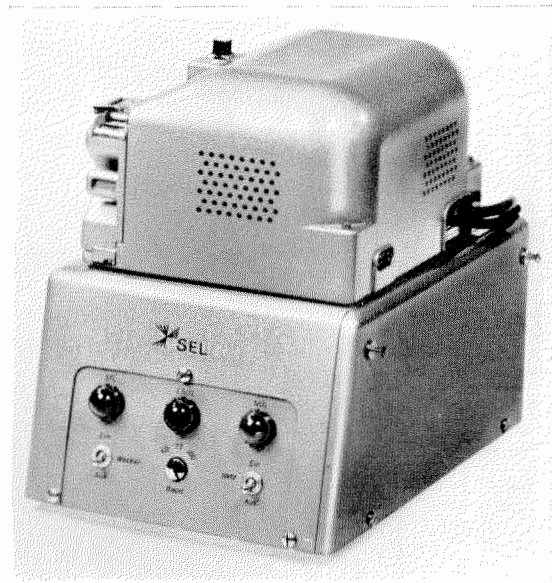


Figure 17—Code Teleswitch *FZE 02* with tape transmitter.

Recent Achievements

station, the transmission of messages stored on tape or in other memories at remote unattended substations.

*Standard Elektrik Lorenz
Germany*

Ship-Shore Telephone-Rate Display—An illuminated display on the liner Queen Mary gives the cost of a 3-minute radiotelephone call to New York, London, Rome, and Paris at that point in the voyage. The rates, which depend on the ship's location, are shown in shillings and pence and in dollars and cents. The display is in the form of four telephones typical of

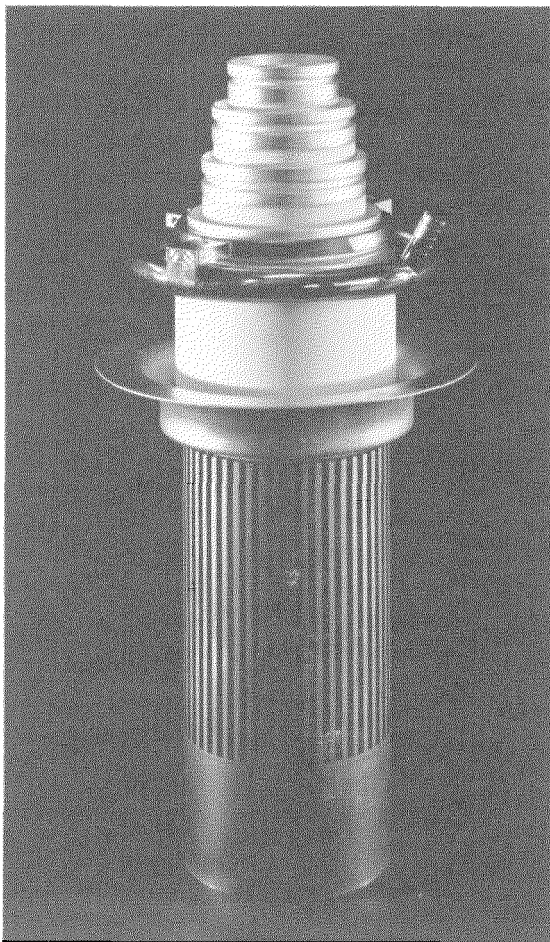


Figure 18—Power tetrode with improved linearity.

those in use in each of the cities named. Under each telephone is a panel that lights at the same time as the appropriate charge appears on the central display screen. Each charge is displayed for 15 seconds and the sequence is repeated every minute.

*International Marine Radio Company
United Kingdom*

Power Tetrode with Improved Linearity—The main feature of the tetrode shown in Figure 18 is its improved linearity. Maximum anode rating is 14 kilovolts at frequencies up to 30 megahertz. The valve is available in two forms: forced-air-cooled type *4JC/300J*, which dissipates 30 kilowatts; and vapor-cooled type *4ZC/300J*, which dissipates 40 kilowatts. Working in class- AB_1 the valve can deliver 60 kilowatts of peak envelope power.

*Standard Telephones and Cables
United Kingdom*

Silicon Transistor for 400 Megahertz—The *3TE350* silicon transistor develops 5 watts output at 400 megahertz using an 18-volt supply without the necessity for emitter tuning. The same power is produced at 150 megahertz with input of only 13.5 volts.

The transistor is mounted in a stud package for soldering into stripline circuits. It has low-inductance leads and is designed for grounded-emitter operation. The unit will give 7 decibels of power gain and full output power in 400-megahertz broad-band amplifiers.

*ITT Semiconductors
United States of America*

Oscillator and Measuring Sets—The complementary pair of portable battery-operated equipments shown in Figure 19 generate signals and measure levels over the range from 300 hertz to 300 kilohertz for use on multichannel telephone systems.

The 74254-A oscillator has an output level adjustable in 1-decibel steps from 0 to -49 decibels referred to 1 milliwatt into circuits of 75, 125, 140, and 600 ohms. The output-level accuracy at 20 degrees Celsius is ± 0.1 decibel at 0 decibels output over the whole frequency range, although at other attenuator settings an extra error of ± 0.2 decibel may arise. The harmonic content of the output will not exceed 1 percent. The frequency dial is 5 inches (12.7 centimeters) in diameter and has a single engraved scale reading only between 300 and 3000 hertz. A range switch indicates multipliers of 1, 10, and 100 to provide ranges of 300 to 3000 hertz, 3 to 30 kilohertz, and 30 to 300 kilohertz. The frequency accuracy is ± 1 percent. The oscillator draws about 50 milliamperes from eight 1.5-volt dry cells. It weighs 12 pounds (5.4 kilograms) with batteries, and is $12\frac{1}{4} \times 8 \times 7\frac{1}{8}$ inches ($31.1 \times 20.3 \times 18.1$ centimeters) in size.

The 74255-A level-measuring set is for use in conjunction with the oscillator and has the same frequency range. The measuring range is from +21 to -51 decibels referred to 1 milliwatt, and it can be used on circuits of 75, 125, 140, and 600 ohms. Both through and terminated levels can be measured with an accuracy of ± 0.25 decibel at the temperature of calibration. The use of negative feedback gives a flat response/frequency characteristic and a high-impedance feed to the meter. The meter is calibrated from +1 to -11 decibels in 0.2-decibel steps and works in conjunction with a switch that enables an input-level range of 72 decibels to be covered. The level-measuring set weighs $12\frac{1}{2}$ pounds (5.7 kilograms). Its dimensions are the same as those of the oscillator and it draws 40 milliamperes from eight 1.5-volt dry cells.

*Standard Telephones and Cables
United Kingdom*

Gallarate Exchange Cut Over—In July 1965 a new transit center for Gallarate, northwest of Milan, was cut into service. This Pentaconta exchange, which replaces the previous 7A rotary exchange, presently allows the connection of 5800 normal subscriber lines and 500 two-party lines for a total of 6800 subscriber numbers.

This is the first Pentaconta exchange in Italy of urban type intended to handle both local calls and transit traffic originating from satellite exchanges. Circuits for determining the charges for transit calls from satellite offices are in the Gallarate exchange. The present exchange is of

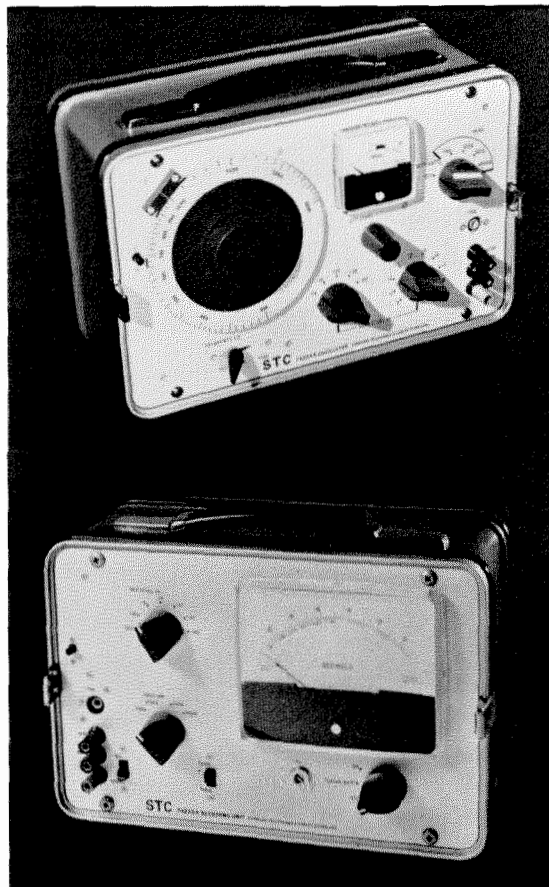


Figure 19—Oscillator (top) and measuring set.

Recent Achievements

tertiary rank but it is intended to upgrade it in the near future to secondary rank.

*Fabbrica Apparacchiature per Comunicazioni
Elettriche Standard
Italy*

Numerically Controlled Drilling Machine—A numerically controlled drilling machine, type *NC100*, has been licensed for outside manufacture. It can drill, tap, countersink, or ream holes of several sizes in a work piece. Controlled by a 5- or 8-track punched tape, which is read while positioning units are prepared for the next operation, the maximum time between operations is only 1.5 seconds.

Two models of the machine will be available: one with a turret (Figure 20) and the other for drilling up to 4 work pieces simultaneously. The turret has 6 spindles, and the speed and feed of the selected spindle is controlled by the tape over a speed range of 450 to 6300 revolutions per minute and a feed rate of 1.5 to 30 inches (3.8 to 76.2 centimeters) per minute. Drilling capacity is up to $\frac{3}{8}$ -inch (0.94-centimeter) diameter in steel. The electrical control

units are constructed on a modular system and the tool is hydraulically operated.

*Standard Telephones and Cables
United Kingdom*

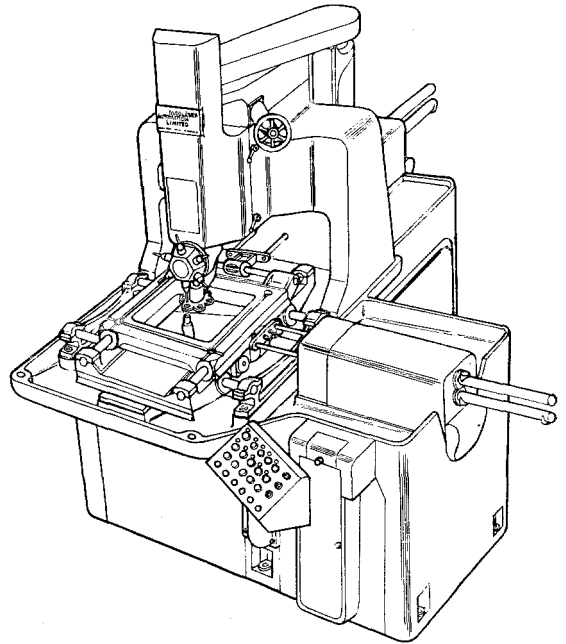


Figure 20—*NC100* numerically controlled drilling machine produced under license by Middlesex Automation Limited.

United States Patents Issued to International Telephone and Telegraph System; November 1964–January 1965

Between 1 November 1964 and 31 January 1965, the United States Patent Office issued 38 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

H. Adelaar, F. Clemens, and R. De Smedt, Bell Telephone Manufacturing Company (Antwerp), Signalling System for Substation Apparatus, 3 164 680.

H. P. Birkemeier, ITT Bell and Gossett Hydronics, Snow Melting Control Apparatus, 3 157 358.

R. Bowen, ITT Cannon Electric, Contact Mounting, 3 138 424.

M. P. G. Capelli, Standard Telephones and Cables (London), Radio Altimeters, 3 167 767.

H. Castelijn, Bell Telephone Manufacturing Company (Antwerp), Electro-Dynamic Motor Operated Valve, 3 167 094.

K. W. Cattermole and J. C. Price, Standard Telecommunication Laboratories (London), Transfer Circuits Using Saturable Magnetic Cores, 3 162 843.

K. W. Cattermole, Standard Telecommunication Laboratories (London), Communication System Employing Phase Shifters and Quantizers to Reduce Noise, 3 161 828.

L. A. DeRosa, Federal Telecommunication Laboratories, Multi-antenna Direction Finder, 3 167 774.

B. Dietrich, Clevite, Voltage Divider, 3 162 802.

A. Gerlach and K. H. Wilke, Clevite, Shift Register, 3 162 776.

W. Grooteboer, Mix & Genest Werke (Stuttgart), Ferrite Matrix Storing Devices With Individual Core Reading and Interference-Pulse Compensation, 3 161 860.

P. W. Hemminger, ITT Kellogg, Called-Line Tone-Signaling System, 3 156 781.

R. A. Hill and A. W. Stirling, Standard Telecommunication Laboratories (London), Electrical Circuit Elements, 3 160 944.

H. L. Horwitz, J. E. Cox, and S. J. Westhead, ITT Kellogg, Balanced Lockout Line Circuit, 3 156 777.

A. M. Ioakimidis and D. E. Hutson, ITT Kellogg, Telephone Converter, 3 156 775.

A. Irmisch, Standard Elektrik Lorenz (Stuttgart), Pulse-Current Generator, 3 161 783.

J. E. Jennings, Jennings Radio Manufacturing Corporation, Push-Pull Oscillator Power Supply Having Parallel-Connected Transistors, 3 164 784.

J. E. Jennings, Jennings Radio Manufacturing Corporation, Vacuum Switch and Envelope Construction Therefor, 3 166 658.

L. B. Jozefowski, ITT Kellogg, Manually Operated, Multi-Button Inter-Locking Pushbutton Key Set, 3 164 688.

E. W. Kuehl and I. E. Robb, ITT Cannon Electric, Two Way Quick Coupling Structure, 3 165 340.

P. L. A. Lemonnier, Le Matériel Technique Industriel (Paris), Reversing Relays Having Increased Cut-Off Power, 3 155 790.

A. Lieb, Standard Elektrik Lorenz (Stuttgart), Indicator Tube Having Two Indication Systems, 3 161 800.

J. W. Maston, ITT Cannon Electric, Retention System for Electrical Contacts, 3 165 369.

J. L. Masure, Bell Telephone Manufacturing Company (Antwerp), System for Determining and Selecting Free Aligned Telecommunication Channels, 3 158 689.

R. W. Neibaur, Jennings Radio Manufacturing Corporation, Fixed Capacitor, 3 156 852.

H. Oden, Mix & Genest Werke (Stuttgart), Information Storage Device, 3 159 820.

R. G. Peterson, G. J. Panek, and F. E. Schulte, ITT Cannon Electric, Auxiliary Locking Device for Quick Disconnect Umbilical Connector, 3 156 512.

R. G. Peterson, G. J. Panek, and F. E. Schulte, ITT Cannon Electric, Peripheral Tang Lock for Quick Disconnect Umbilical Connector, 3 156 513.

W. A. Ray, ITT General Controls, Laminated Core Electromagnet, 3 157 831.

J. Y. P. R. Rosenoer and R. E. A. Sprangers, Bell Telephone Manufacturing Company (Antwerp), Calculating Apparatus, 3 161 762.

W. Schiebeler, Standard Elektrik Lorenz (Stuttgart), Printing Arrangement for High-Speed Teleprinters, 3 167 166.

W. G. Shequen, ITT General Controls, Cooling Means for Thermostats, 3 157 801.

A. G. Van Alstyne, B. Cutler, and D. C. Davis, ITT Gilfillan, Automatic Landing Control System Using Scanning Interferometer Scanning Beams, 3 159 837.

J. Villiers, Purchased Invention, Air Navigation Information System, 3 167 759.

M. C. Vosburgh and J. Murgio, ITT Laboratories, Doppler Radar System, 3 167 762.

G. N. Willis, ITT Cannon Electric, Crimping Tool, 3 156 139.

E. P. G. Wright and J. C. Emerson, Standard Telecommunication Laboratories (London), System for Coordinating a Plurality of Synchronized Time Division Multiplex Systems, 3 157 744.

N. H. Young, Jr. and P. K. Spahr, ITT Federal Laboratories, Frequency Shift Keyer With Automatic Frequency Control, 3 167 712.

Contact Mounting

3 138 424

R. Bowen

This patent covers a detachable connector in which the contact terminal may be inserted in the rear of a supporting block and locked in position by internal resilient devices. It may be released by a tool inserted from the rear so that access from the front of the supporting block is unnecessary.

Radio Altimeters

3 167 767

M. P. G. Capelli

In an altimeter of the frequency-modulation type in which altitude is measured by the beat frequency between the signal reflected from the earth and the signal transmitted at the time of such reception, a continuous calibration check is maintained. This is done by providing a second receiver to which is applied the transmitted signal over a known delay line and the undelayed transmitted signal. The output of this last named receiver is compared with the altitude-indicating beat frequency.

Communication System Employing Phase Shifters and Quantizers to Reduce Noise

3 161 828

K. W. Cattermole

To reduce noise in a coded quantized signal, the input signal waveform is used to produce two or more phase-displaced waveforms. These two waveforms are separately quantized and the quantized signals transmitted. The received quantized signals are converted to the original signal waveform and combined.

Vacuum Switch and Envelope Construction Therefor

3 166 658

J. E. Jennings

This is a vacuum switch in which the contacts are mounted on end wall plates, interconnected by a cylindrical envelope of alternate ceramic and metallic bellows rings. One of the end wall plates is fixed to a dielectric housing and the other mounted within the housing to permit relative movement for opening and closing the switch contacts.

Paris Network and Numbering Plan
Introduction of Pentaconta Switching in Paris
Pentaconta System Remote Line Units
Pentomat T Private Automatic Branch Exchange
Flexible Routing Plans
Sensitivity Coefficients as Criteria for Noise in Telecommunication Lines
Measurement of Magnetic Properties of Thin Films
Magneto-Optic Astrometer for Measurement of Magnetic-Thin-Film Memories
Expanding Global Submarine-Cable Network
Submerged Repeater for the Commonwealth 160-Circuit Cable

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