

# **ELECTRICAL COMMUNICATION**

**ITT**

VOLUME 40 • NUMBER 1 • 1965

# ELECTRICAL COMMUNICATION

Technical Journal Published Quarterly by

INTERNATIONAL TELEPHONE and TELEGRAPH CORPORATION

320 Park Avenue, New York, New York 10022

President: Harold S. Geneen

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Subscription: \$2.00 per year

50¢ per copy

## This Issue in Brief

**Telecommunications in Western Europe**—The distinctive character of each major national telecommunications operating agency in Europe is analyzed, followed by a brief survey of the national networks and of their interrelation. Telephone and telegraph public networks and sound and picture broadcasting are considered. For telephony and telegraphy the most-typical transmission and switching systems are introduced, and a summary of recent developments is presented. The author concludes that there are in Europe a multiplicity of methods and designs offering a wealth of information.

**Transistor Carrier Multiplex Equipment**—Multiplex equipment represents a high proportion of the cost of multichannel carrier telephone systems and therefore must offer economy as well as high performance and reliability. Many aspects of performance are covered by recommendations of the Comité Consultatif International Télégraphique et Téléphonique, but individual requirements of the national administrations must also be provided for.

**Part 1** describes the salient electrical features of transistor equipment having capacities of up to 960 channels and, in combination, of up to 2700 channels. The multiplex equipment was designed to translate 12 individual channels into a basic group by single modulation or double modulation. All carriers for frequency translation are derived from temperature-controlled quartz crystals having long-time frequency stabilities appropriate to the bandwidth of the particular system. Provision is made for in-band, out-band, and no signaling.

**Part 2** describes the deep-rack construction. The 450-millimeter (17.7-inch) deep racks are compatible with double-sided racks in existing installations.

A rack is fitted with support rails to hold equipment shelves into which printed-wire circuit

boards are plugged. The shelves are slightly tilted to improve cooling. All equipment mounted on a shelf is factory wired. Station cabling runs in the space between the shelves and the back of the rack.

**Part 3** describes a construction suitable for back-to-back and wall mounting of racks in which front leadout of wiring makes access to the rear of the rack unnecessary. The racks are 225 millimeters (8.85 inches) deep. Subracks mount the printed-wire circuit cards and are factory wired. They are screwed to the office racks and may be installed in any convenient order. The filled subracks are still open at top and bottom for heat dissipation. Wiring to subracks uses detachable connectors extensively. Cabling between racks runs horizontally on overhead supports and vertically along the sides of the subracks. It is installed before the subracks are mounted.

In **Parts 2 and 3** the features of typical equipment combinations are given with consideration to the size of installations.

**Statistical Method of Analyzing Long-Term Tropospheric Loss**—Weather variables that cause signal-strength variation on tropospheric-scatter paths are analyzed for the purpose of developing a prediction equation applicable to all paths.

This analysis indicates that the general refractive index is not the only weather variable that affects signal strength, and possibly it is not even the most significant. The results indicate that the height at which the pressure is 500 millibars is a better predictor of signal strength.

This study also shows that substantial and unexplained variations still exist among prediction equations for different paths. If more-careful methods of analysis can isolate the weather factor that causes signal strength to change, a universal prediction equation may emerge.

**Standard Telecommunication Laboratories—**

Within the International Telephone and Telegraph System, there are two main laboratories in Europe devoted to long-term research and development: Standard Telecommunication Laboratories (STL), situated at Harlow near London, and Laboratoire Central de Télécommunications (LCT) in Paris. Their purpose is to stimulate the future economic growth of the System, and their efforts are coordinated so that duplication of work is avoided.

STL, which was founded in 1945, now has a complement of well over 600, comprising a closely knit organization of top-level scientists and administrative staff. Its structure includes two main groups concerned with exploratory research and advanced development planning, besides four advanced development divisions covering transmission systems, digital systems, materials and components, and acoustics. Administrative, personnel, and technical services account for about one third of the total staff.

Close contact is maintained with universities and government departments. Contract work for the latter accounts for about 17 percent of the laboratory effort, the remaining 83 percent being passed directly to the development departments of associated manufacturing houses. STL maintains at all times close connections with all companies in the ITT international network so that it is in a good position to contribute to their future welfare.

**Multiplier Phototubes for Single-Electron Counting—**

Typical operating characteristics of special-purpose multiplier phototubes are described, with emphasis on the ability of these tubes to count single photoelectrons with minimum interference from dark noise. This ability, of particular significance in the detection of low-energy quanta, including single photons, follows from the Poisson-like output pulse

height distribution observed in the tubes. A well-defined most-probable pulse amplitude appears and is compared with a more-complex but lower-amplitude dark noise pulse height spectrum.

Other features of these tubes, such as adjustable cathode size and shape, electric deflection for automatic gain calibration, alignment and image tracking, and reduction of dark noise with cooling, are also described.

**Determination of the Probability Distribution of the Number of Secondary Electrons—**

It is shown that the probability distribution  $p(i)$  of the release of  $i$  slow secondary electrons after the incidence of a primary particle of any sort (such as electrons, photons, ions, et cetera) can be determined by the use of a multistage electron multiplier. This electron multiplier amplifies to an easily measurable level the effect produced by the process to be investigated.

First, the single-electron response of the electron multiplier (the pulse height distribution  $\Phi(x)$  in the output) is experimentally determined. Next, the pulse height distribution  $F(x)$  is taken when the secondary electrons of the process to be measured enter the input. During the calculation of  $p(i)$  from  $\Phi(x)$  and  $F(x)$ , the moments of the distributions are used. This has the advantage that the successive calculation of the first few moments of  $p(i)$  gives information (average, variance, skewness, et cetera) of primary interest in many cases.

Extension of the calculation to higher moments allows the determination of  $p(i)$  via the combinatorial moments. Experimental data taken for an electron multiplier with silver-magnesium dynodes show that the secondary-emission curve for 230-electron-volt primaries is somewhat broader than a Poisson distribution.

**Visual Presentation for Flight Simulators—**A further improvement in flight simulators is the



## **This Issue in Brief**

inclusion of a closed-circuit television system so the pilot can perform visual landings, even on the deck of an aircraft carrier.

A model carrier is viewed by a television pickup system, which corresponds to the aircraft. Their

relative positions are under constant control of a computer, which activates the television system when the carrier is within sight of the pilot. Aircraft pitch and roll are produced by optical prisms in the viewing path and yaw by a rotating motion of the camera.

## **Busignies Receives Electronics Award**

The Institute of Electrical and Electronics Engineers conferred on Henri Busignies for "outstanding contributions to electronic systems, especially in the fields of direction finding and air navigation," the David Sarnoff Award in Electronics.

Dr. Busignies, who is General Technical Director of International Telephone and Telegraph Corporation, was the inventor of the high-frequency direction-finder system called Huff-Duff that produces useful indications of the direction of arrival of very-brief radio signals. To avoid radio detection during the second

world war, submarines compacted their reports into extremely brief "spurts" of transmissions on which existing direction finders were unable to take bearings. Huff-Duff gave bearings on these transmissions that permitted the day-to-day positions of submarines to be plotted and future positions to be estimated.

For many years he has directed extensive research activities in this general field, some of which resulted in the development of the Tacan and Vortac systems now in worldwide use for both military and civilian air navigation.

## Recent Achievements

### Nimbus Satellite Takes Photographs in Dark—

The Nimbus meteorological satellite of the National Aeronautics and Space Administration is equipped for both night and day mapping of the earth.

Nighttime photography is based on the infrared radiation that varies with the temperature of all surfaces. Warm bodies of water such as oceans and seas photograph very dark. Land is cooler at night than the seas and appears somewhat lighter. Clouds are generally much colder than water and land and photograph as light gray and white. Clouds at the highest altitudes are coldest and appear brightest. Thus, not only can the approximate temperatures of water and land be estimated but also the approximate height of cloud tops.

When Nimbus is on the dark half of its polar orbit, a special high-resolution infrared radiometer developed by a division of International Telephone and Telegraph Corporation is operated. A strip of earth perpendicular to the path of the satellite and about 1500 miles (2400 kilometers) wide is scanned by a continuously rotating mirror. The mirror sweeps across this strip about 75 times every 100 seconds, thus covering the entire dark path with about 2300 scans. A photoelectric cell converts the radiation reflected from the mirror into electrical signals that are stored on magnetic tape. On command these signals are transmitted by radio to the ground station.

In the photograph of Italy shown in Figure 1, intensive clouds appear over the Alps and Central Europe as well as scattered clouds over the Mediterranean and North Africa. Taken from an altitude of about 275 miles (450 kilometers), features larger than 5 miles (8 kilometers) may be discerned.

*ITT Industrial Laboratories Division  
United States of America*

### Railroad Geographic Switching Systems Installed

—During the past year, three railroad switching systems of the *SpDrL 30* type were placed in service in West Germany.

One, replacing five earlier systems, is supervised from Völklingen on the Saarbrücken–Trier–Cologne line and can handle 320 through and 600 shunting operations per day. It controls 118 switches and track blocks, as well as 13 advance, 23 main, and 95 shunt signals. Most of the ore for the Saarland steel industry is transported by this railroad. Control of traffic for the Rochling steel works can be electrically transferred from the central tower to a local control tower.

A second system is at the Solingen-Ohligs station and can control 395 through, shunt, and auxiliary routes incorporating 78 switches, 101 through and shunt signals, and 84 track sections. The third installation is at Bönen on the same Cologne–Wuppertal–Hamm–Hannover line.

*Standard Elektrik Lorenz  
Germany*

**Command and Control System 465L**—Designed for the United States Strategic Air Command, project 465L combines high-speed transmission, computers, and projected displays to give the commander all needed information with which to exert positive control in great depth over the fighting forces at his disposal.

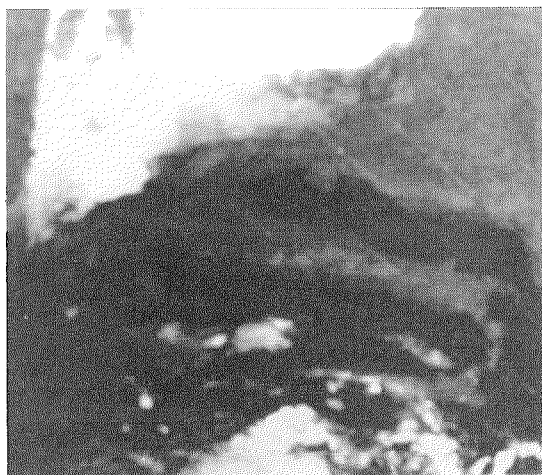


Figure 1—Infrared picture of Italy taken at midnight by Nimbus meteorological satellite.

## Recent Achievements

Two-way communication systems connect the Strategic Air Command headquarters at Omaha, Nebraska, with its bases and stations around the country. Information on weather, aircraft, missiles, tankers, personnel, et cetera, is converted into computer data and sent via switching computers to the central computer. Such information can be called for by the commander and certain emergency information is forced to his attention.

Information is projected on large wall displays as shown in Figure 2. Three images of each message are produced on positive film in less than 15 seconds. A light beam that projects the images is first split into the three primary colors, and through selection and combination seven distinct colors are available to indicate various types of information

*ITT Data and Information Systems Division  
United States of America*

**Field Trial of Subscriber Push-Button Sets—**With the inauguration of the new Søndersborg Pentaconta telephone exchange, a field trial of 25 push-button subscriber sets was started by the Danish Post and Telegraph Administration. This 6000-line local and toll exchange is equipped with registers that can work with many types of signaling systems.

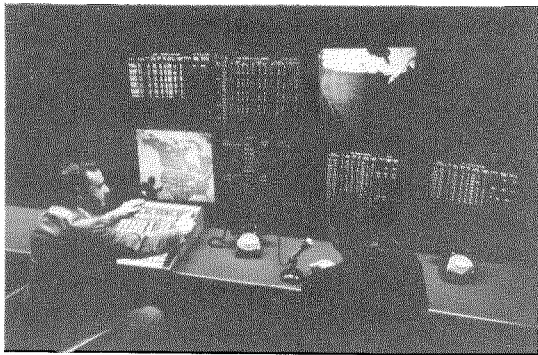


Figure 2—Information received from all bases of the Strategic Air Command is processed by computers, and the essential elements are projected to permit immediate response by the commander to changing conditions.

Multifrequency-code signaling is used. Two frequencies are transmitted simultaneously, each being selected from a group of four frequencies. The upper frequency group is between 2000 and 3000 hertz. The trial will be extended to 1000 subscribers and will use new signal frequencies, all of which will be below 2000 hertz so as not to conflict with the recommendations of the Comité Consultatif International Télégraphique et Téléphonique.

*Standard Electric  
Denmark*

**Water Vapor in the Atmosphere of Venus—**Two essential functions were performed by a pair of *FW-118* infrared detectors, shown in Figure 3, in observations of the upper atmosphere of Venus.

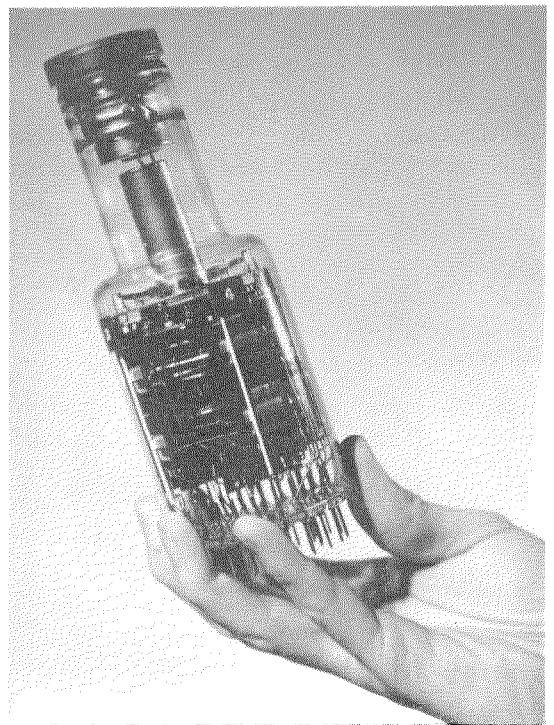


Figure 3—One of these *FW-118* multiplier phototubes provided four simultaneous outputs for telescope tracking and another was used for detecting the effects of water vapor on sunlight reflected from Venus.

A large balloon launched by scientists of Johns Hopkins University directed by Dr. John Strong rose to 16.6 miles (26.7 kilometers). Under control of one of the detectors, a telescope was kept pointed at Venus within 1 second of arc for 2 hours despite daylight conditions that always hamper star trackers.

The second low-noise high-sensitivity infrared detector permitted determination of the absorption by water vapor of certain infrared wavelengths in the sunlight reflected by the cloud layers of Venus. The results of the test were in direct contradiction to previous measurements made with spacecraft and, Dr. Strong said, “. . . force us to re-examine every previous calculation made concerning the possibility of some sort of life existing on the planet.”

*ITT Industrial Laboratories Division  
United States of America*

**Lifeboat Rescue Transceiver**—For rescue service a new transistor lifeboat radio set transmits and receives on 500, 2182, and 8364 kilohertz.



Figure 4—Operation of lifeboat rescue radio set.

The receiver may also be tuned over the 8-megahertz marine band to work with shore stations. Speech, a two-tone alarm signal, or manual or automatic telegraph code may be transmitted. As shown in Figure 4, it may be operated by one man. Power is obtained from a built-in hand generator or a 16.5-volt dry battery.

The whip antenna, headphones, and microphone are stowed in the fiberglass case of the set, which is 27 by 11.5 by 9 inches (69 by 29 by 23 centimeters). Weighing less than 30 pounds (14 kilograms), the set can tolerate a 30-foot (9-meter) drop and will float in the sea. Tests have shown a range of about 1500 nautical miles (2800 kilometers).

*International Marine Radio Company  
United Kingdom*

**New Audio Line Repeating Coils**—Line transformers or repeating coils face the same pressure for reduced size as do all other components used in large quantities in telephone exchanges.

High-permeability core material cannot be used because of the repeated occurrence of strong direct-current pulses of short duration that would magnetically bias the cores. By combining several core materials and with suitable dimensioning, pretreatment, and grouping, a volume decrease from 785 to 304 cubic centimeters (47.9 to 18.5 cubic inches) has been obtained. See Figure 5.

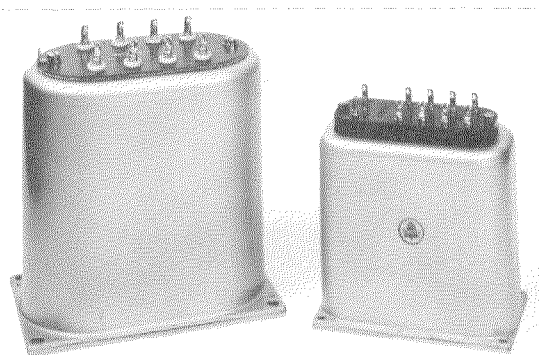


Figure 5—Conventional and smaller new design of telephone repeating coils.

## Recent Achievements

Improved manufacturing makes unnecessary the pairing of these coils for 4-wire terminations of line and network.

*Standard Téléphone et Radio  
Switzerland*

**Ferrites Exhibiting Re-Entrant Loops**—If the field  $H_n$  required to nucleate a domain wall in a magnetic material exceeds the coercive field  $H_c$  required to drive a wall through it, a re-entrant hysteresis loop can result. Such a material has only two stable states, corresponding to single domains throughout the specimen, and exhibits no minor loop.

A search has been made for such re-entrant hysteresis loops in ferrite systems normally exhibiting rectangular loops. They have been found in magnetically annealed, cobalt-containing ferrites of precisely controlled composition. Before annealing, these ferrites exhibit the constricted loops shown in Figure 6 and after annealing have the highly re-entrant loops of Figure 7.

In the best samples,  $H_n$  exceeds  $H_c$  by over 30 percent and no hysteresis loop is obtained until the applied field, either alternating or unidirectional, exceeds  $H_n$ . If the ferrite is biased with a field between  $H_c$  and  $H_n$ , a small pulse suffices to switch the direction of magnetization. Thus,

these materials have promising applications in all-magnetic logic.

*Standard Telecommunication Laboratories  
United Kingdom*

**Battlefield Surveillance Radar**—The French military organization "Direction des Études et Fabrications d'Armement" (SEFT Section) has given the Laboratoire Central de Télécommunications the responsibility for the development of a battlefield surveillance radar named SDS radar, some features of which can now be published. It is a pulse radar using Doppler effect for cancelling stationary targets. For moving targets it has a range of 30 kilometers (18 miles). The accuracy is of the order of a few mils in azimuth and a few tens of meters in range.

Targets are first acquired in a surveillance mode in which moving targets appear as bright spots on a cathode-ray screen while fixed targets can be displayed or eliminated as desired. The operator can then use manual tracking while listening to a loudspeaker that reproduces Doppler sounds allowing identification of the target (wheel or track vehicle, one or more pedestrians, et cetera).

The equipment shown in Figure 8 had been transported by helicopter. This equipment has

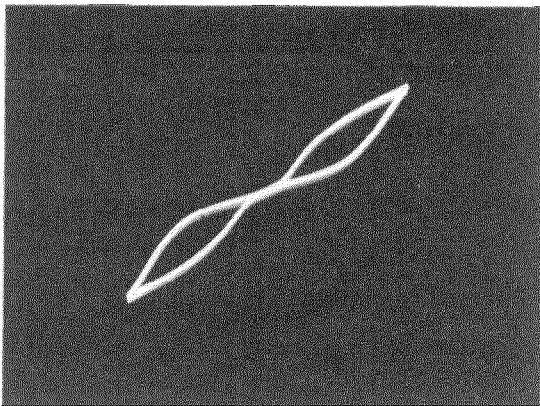


Figure 6—Constricted loop for unannealed ferrite. Measured at 50 hertz.

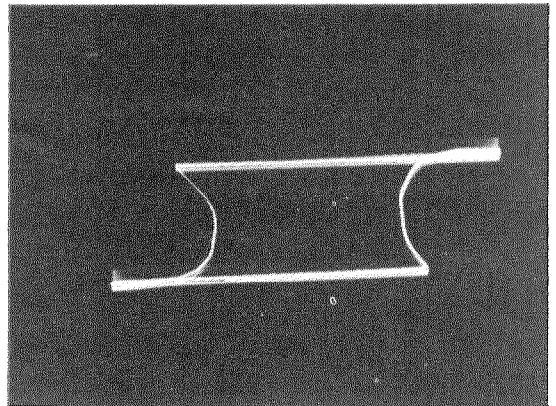


Figure 7—Re-entrant loop obtained with magnetic annealing of the ferrite.  $H_n = 1.3 H_c$ .



been delivered to the French army where it has been in service for several years.

*Laboratoire Central de Télécommunications  
France*

**Solid-State 7-Gigahertz 24-Channel Radio-Link Equipment**—

The *BFM24-7000* equipment produces 50 milliwatts at 7 gigahertz and accepts 24 frequency-modulated voice channels, each of which may be replaced by 24 telegraph channels. Using a small paraboloidal antenna, links up to 50 kilometers (31 miles) may be spanned.

All active components are solid state. The transmitter and receiver require only 30 watts from a 24-volt battery, which avoids cooling problems even with compact design. The radio equipment may be mounted in a single cabinet with the associated telephone multiplex system, as shown in Figure 9, or separately in a weatherproof housing. It meets all recommendations of the Comité Consultatif International Radio.

*Bell Telephone Manufacturing Company  
Belgium*

**Microwave System Between London and Lille**—

Stand on the pavement almost anywhere in London and you can see the new 600-foot (180-meter) tower erected by the General Post

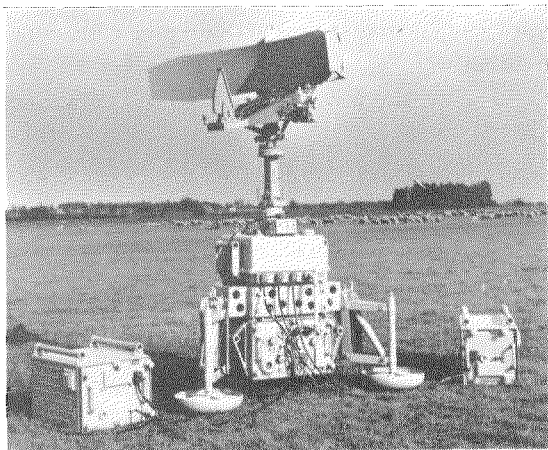


Figure 8—Battlefield surveillance radar.

Office near Tottenham Court Road. It is the London terminal of a microwave radio system

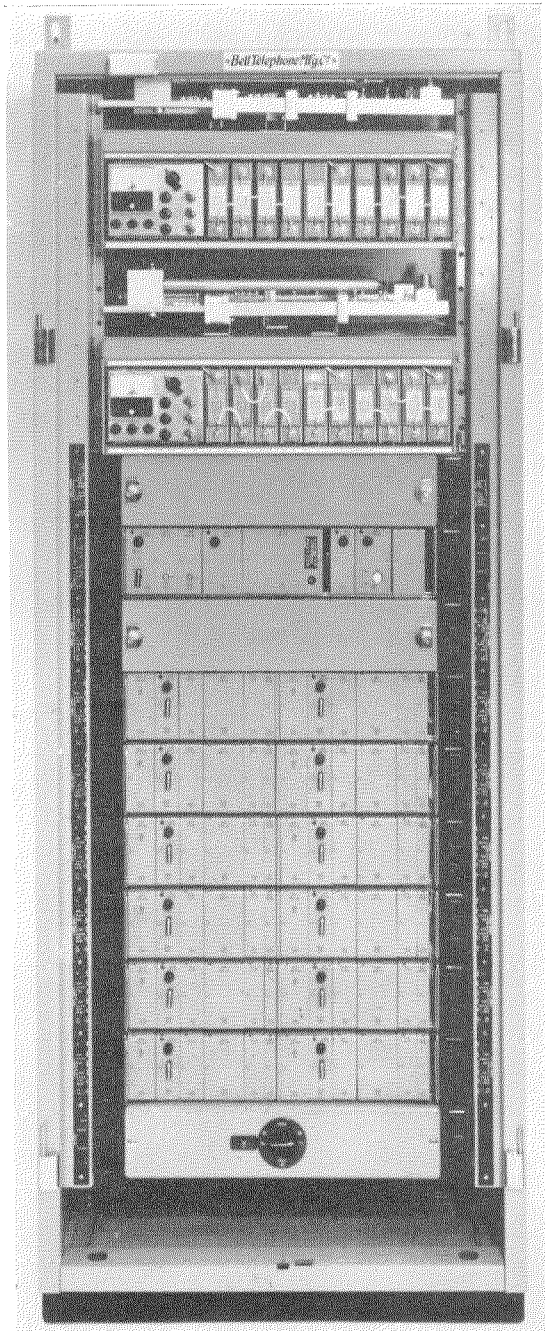


Figure 9—Solid-state 7-gigahertz 24-channel radio transmitter and receiver mounted with the telephone multiplex equipment.

## Recent Achievements

that has its other terminal at Lille in northern France. It provides telephone channels and a permanent 625-line Eurovision circuit.

The first part between London and Folkstone uses the new 6-gigahertz *1800/TV* transistor equipment. Some existing installations supplemented by new equipment will connect Folkstone and Lille. Work on the French side of the channel is being done by *Le Matériel Téléphonique*, recalling the joint efforts that some 33 years ago demonstrated the feasibility of micro-rays, as microwaves were then called, for communication across the English Channel.

*Standard Telephones and Cables  
United Kingdom*

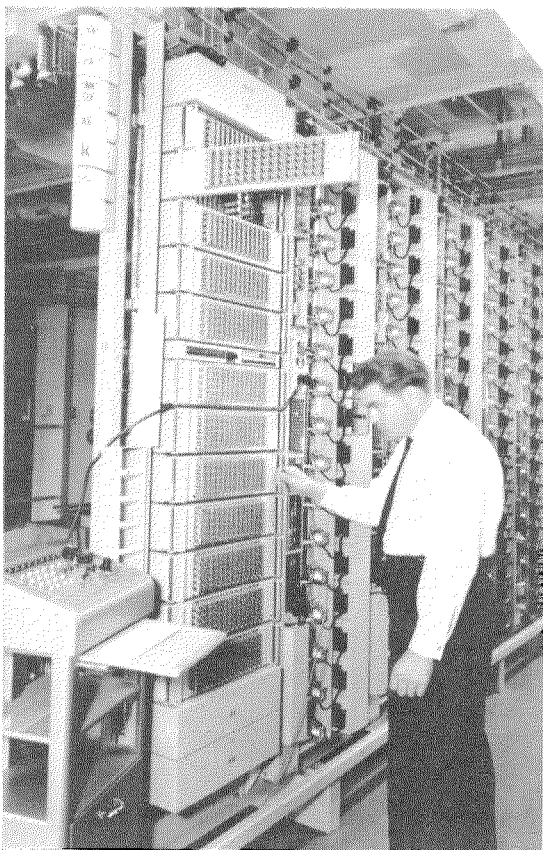


Figure 10—Route-selector rack in Hamburg telex center.

**Sealed Pump (Without Stuffing Box)**—A 3-kilowatt electric motor drives a pump in the swimming-pool reactor called *Melusine* at the Nuclear Research Center in Grenoble, France. It pumps an organic liquid called terphenyle at temperatures between 400 and 500 degrees centigrade.

The squirrel-cage-type motor needs no electric connection to its rotor, on which the pump impeller is directly mounted. Both are fully immersed in the pumped liquid, thus avoiding the need for a stuffing box or a mechanical seal. All parts touched by the liquid are made of stainless steel. Ball bearings are used.

To cool the motor, the fully enclosed stator jacket is filled with oil that is circulated by pump through a heat exchanger. The stator windings are insulated with Teflon. Thermocouples at various points monitor the operating temperatures.

*Le Matériel Téléphonique  
France*

**Telex Route Selectors Installed in German Network**—The German telex network has completely meshed regional centers, which are connected radially to sectional centers and terminal exchanges. The traffic is therefore handled by so-called last-choice routes, that is, through at least one regional center.

Figure 10 shows route selectors recently installed in the Hamburg regional center to connect traffic via those direct routes that are available and to use the last-choice routes only if all direct routes are engaged. The use of direct routes reduces telegraph distortion as

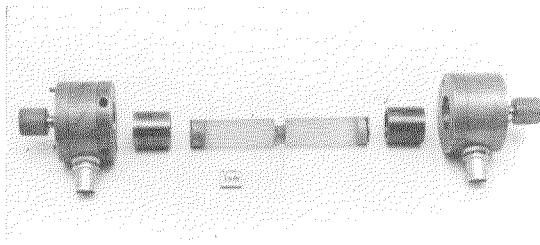


Figure 11—Components of an acoustic amplifier.

there are fewer transmission sections in the circuit. Also, the route selector can convert dialed signals into keyboard signals to save time in making calls to countries that use keyboard selection.

*Standard Elektrik Lorenz  
Germany*

**Acoustic Amplifier**—A study is being made of the acoustic amplifier shown in Figure 11 as part of an investigation of the properties of bulk semiconductors.

The amplifier consists of a cadmium-sulphide piezoelectric crystal to which sufficient voltage is applied to make the drift velocity of the electrons in the crystal equal to the speed of sound in the crystal. Under these conditions, a sound signal applied by a quartz transducer at one end is amplified as it passes through the cadmium-sulphide crystal to a quartz transducer at the other end. Gains of 70 decibels have been obtained in the cadmium-sulphide crystal.

The interaction is inherently very broad band but the transmission bandwidth is limited by the input and output transducers. Conventional quartz transducers not only have narrow bandwidths but introduce high losses. Despite this, net gains of 15 decibels have been observed at 60 megahertz. The bandwidth and operating frequency might be increased by making the

transducers integral with the cadmium-sulphide crystals.

*Standard Telecommunication Laboratories  
United Kingdom*

**Assistant Subscriber Sets Approved in Germany**

—The intercommunication subscriber sets designated Assistent 1-2 and Assistent 1-5, series *K*, have been approved as standard by the German telephone administration. These sets provide access to 1 city trunk and to 2 and 5 extensions, respectively. Both are built into the standard German subscriber-set housing and follow the style of our Assistent set as shown in Figure 12.

*Standard Elektrik Lorenz  
Germany*

**Demonstration 6-Gigahertz Radio Link**—A

demonstration unit has been set up for the new 6-gigahertz 1800/TV radio link system. A closed-loop technique provides 6 transmission hops with only 2 sets of antennas. By changing antenna gain at one end and frequency and polarization after each hop, a normal distance of 30 miles (48 kilometers) can be simulated with antennas only 2 miles (3.2 kilometers) apart. Each such transit is repeated 6 times to simulate the international reference distance of 175 miles (282 kilometers).

*Standard Telephones and Cables  
United Kingdom*



Figure 12—Assistent 1-5 and 1-2 series-K subscriber sets.

## Recent Achievements

**Fast Adaptable Tape Reader**—The model 35 tape reader is capable of reading 5-, 6-, 7-, and 8-hole fully punched tape. It operates step by step or synchronously at speeds of 35 and 40 characters per second, respectively, stopping within one character interval at these speeds. An external signal controls the direction of tape travel and full operation is available in either direction. The reader is shown in Figure 13.

*Creed and Company  
United Kingdom*

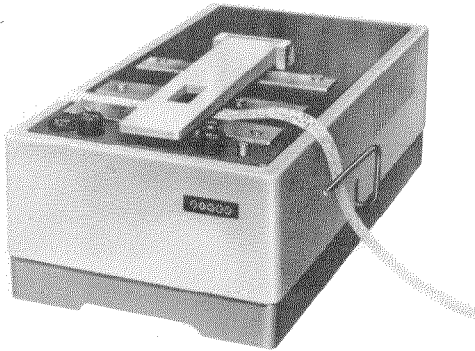


Figure 13—Creed model 35 tape reader.

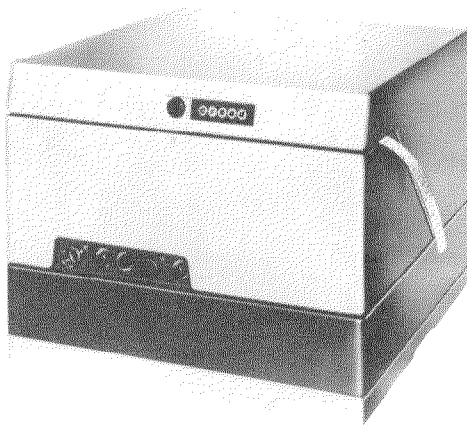


Figure 14—Creed model 100 tape punch.

**Tape Punch for 5 to 8 Tracks**—The model 100 tape punch shown in Figure 14 perforates 5-, 6-, 7-, and 8-hole tracks interchangeably at 100 characters per second without adjustment. A canted roller system forces the tape against a guide so as to accommodate all widths of tape.

*Creed and Company  
United Kingdom*

**From Telecommunications to Land Drainage**—Claytile pipes are normally used for land drainage but they are in short supply. With our long experience in extruding plastic cables and with available plant, we are producing plastic pipe that has the approval of the British Ministry of Agriculture.

Called Pipaway, they are extruded in 20-foot (6-meter) lengths with a diameter of 2 inches (5 centimeters). Their light weight, only about 3 percent of the claytile equivalent, is evident in Figure 15. One bell-shaped end on each length permits joining by simply pushing a plain end into a bell. Made of Shell Carag material, they flex with earth movements and are virtually unbreakable.

*Standard Telephones and Cables  
United Kingdom*

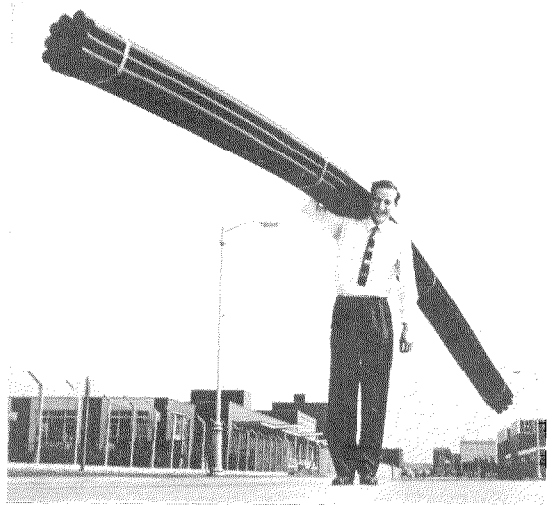


Figure 15—Pipaway, extruded plastic pipe for land drainage, is extremely light.

**P-Addie**—P-addie is a probabilistic adaptive element that performs by digital means the function of an adaptive element such as the Memistor. Probabilistic sampling of a binary input signal leads to an appreciable economy in the number of digital components required. Developed specifically for the Stelia learning machine, P-addie promises to have wider applications in other fields such as quality control. A microminiature version of the P-addie, which at present consists of conventional circuits, gives it promise of increased use.

*Standard Telecommunication Laboratories  
United Kingdom*

**Mobile Radiotelephones Aid in Road Maintenance**—In East Sussex, England, 43 road-maintenance vehicles are being equipped for radiotelephone communication. The fixed stations are connected by ultra-high-frequency links with the administrative office. Transmitter powers are either 10 or 25 watts as needed.

*Hudson Electronic Devices  
United Kingdom*

### **Kurth Receives Papers Award**

Carl Kurth received the 1964 award of the Nachrichtentechnische Gesellschaft for four papers on filter and network theory that were published in *Archiv der Elektrischen Übertragung*. A prize of DM 1000 was part of the award.

Mr. Kurth is chief of the basic research laboratory of the Transmission and Navigation Division of Standard Elektrik Lorenz. He has been engaged in applying computers to network design since 1960 when he joined the company.

He is a Senior Member of the Institute of Electrical and Electronics Engineers.

### **Ulrich Receives Papers Award**

Friedrich Ulrich was the recipient of the 1964 award of the Nachrichtentechnische Gesellschaft for his paper "Some Methods for Electronic Message Recording in Telephone Switching Systems." The award included a prize of DM 1000.

Mr. Ulrich is chief of the laboratory of digital basic circuits in the Telephone Division of Standard Elektrik Lorenz. He joined the company in 1957 and has been concerned with the development of electronic telephone switching equipment.



# Telecommunications in Western Europe\*

E. M. DELORAINE

Laboratoire Central de Télécommunications; Paris, France

## 1. Introduction

We live in a period in which European communities are progressively being built up, but while powerful supranational authorities have controlled for some years such basic fields as coal, steel, and atomic energy, there has been no such development in telecommunications. The establishment of an international authority in this area is not foreseen for many years.

## 2. Perspectives

Telephony is by far the largest activity in European telecommunications. Telegraphy represents investment and revenue of the order of 6 percent of telephony, while facsimile and data transmission account at present for less than 1 percent.

The telephones of the world divide roughly as follows: Somewhat more than half are found in North America, a quarter in Europe, and the balance in the rest of the world, of which remainder Japan has about a third.

Translated in terms of the average number of telephones per 100 inhabitants, North America has 42.2, Europe 11.2, and the rest of the world 1.2. Three countries included in this last average stand out: New Zealand with 34, Australia with 22, and Japan with 7.7 telephones per 100 inhabitants.

Of interest is the average percentage rate of growth in the total number of telephone stations in service. For the past 5 years these percentages are 28.6 for North America, 37.3 for Europe, and 59 for the rest of the world. Again Australia and Japan stand out with percentages of 70 and 188, respectively [1].

The low density of telephones in Europe compared with North America creates a greater

demand for new installations, a demand thus far not satisfied by the expansion programs.

## 3. Coordinating Influences

Considerable difficulty would have been experienced if the nations of Europe had established their telephone or telegraph networks after the first world war without a certain degree of coordination.

International communication in Europe presents more-severe problems than interstate communication in the United States because each country has its own language and its own engineering and operating practices. A communication link between Paris and Amsterdam via Belgium involves important differences in engineering and administrative methods, whereas an equivalent connection from Newark to Baltimore, although also involving three states, enjoys a common language and uniform practices.

This problem was appreciated by the national operating authorities and action was taken to relieve it in 1923. Responding to a proposition made by Sir Frank Gill in his presidential address to the Institution of Electrical Engineers of Great Britain, the Director of the French Post, Telegraph, and Telephone proposed the creation of the Comité Consultatif International Téléphonique to study the administrative and technical problems in international connections. The statutes of this organization assumed that each nation would remain completely independent in the development of its national network, but would follow the recommendations of the Comité in the establishment of international connections.

This separation, although considered essential by each national authority, turned out to be somewhat theoretical. In the years before the second world war many discussions within the Comité led to recommendations that influenced the characteristics adopted for the national networks. One example can illustrate this. An important decision was the frequency band to be

\*Presented at 1964 International Symposium on Global Communication of the Institute of Electrical and Electronics Engineers held in Philadelphia, Pennsylvania, on 2-4 June 1964; reprinted from *IEEE Transactions on Communication Technology*, volume Com-12, number 3, pages 22-33; September 1964.

transmitted over the international lines. This recommendation was established on the basis of numerous measurements, taking into account the state of the art. Practically all operating agencies in Europe specified the same curve for their national trunk lines, whereas the Bell System did not consider it a standard to which everything must conform. As we shall see later on, this may be one of the reasons why carrier systems over trunk lines are used much more extensively in the United States than in Europe.

The Comité Consultatif International Téléphonique was followed in 1926 by the Comité Consultatif International Télégraphique and in 1927 by the Comité Consultatif International des Radio-Communications. Today the first two have been amalgamated as the Comité Consultatif International Télégraphique et Téléphonique.

These international committees have rendered great service, especially during the periods when major recommendations had to be issued. The method followed was to organize a number of subcommittees, each dealing with a specific aspect. These subcommittees included men from both the operating branch and from the industry. The American Telephone and Telegraph Company became a member in 1929 and was a valued contributor to all study groups. One may say today that the broad recommendations reached as a result of this work have withstood the test of time excellently. The subcommittee recommendations were generally adopted without change at plenary assemblies of the International Telecommunication Union.

The international recommendations dealt for the most part with specifications applicable to telephone and telegraph transmission. There was almost no consideration of the particular structure of national networks, numbering schemes, type of equipment, and signalling methods within and between offices, at least not until recently when direct international dialing called for greater cooperation across national boundaries.

The international recommendations frequently followed the Bell System practices, although they often differed in minor respects.

The Comité Consultatif International Télégraphique et Téléphonique has grown progressively as more countries have joined in its activities. A new association known as the European Conference of Postal and Telecommunication Administrations [2] was set up recently to help the European telephone agencies solve their future problems more independently of the recommendations of the Comité Consultatif International Télégraphique et Téléphonique.

The technical staffs of the operating agencies in the common market have also established direct relations within the Federation of European Telecommunication Engineers [3].

#### 4. National Characteristics

Although the European countries have established several useful links, the fact remains that each country operates its telephone and telegraph services in accordance with its own rules and practices. These vary widely from country to country in accordance with history, political considerations, and the character of the population.

Europe has no privately operated telephone or telegraph service in the American sense; in all cases public telecommunications are monopolies with various degrees of government control.

The relations between the telecommunications operating organization and the state vary. At one extreme (Italy) telephone service is provided by separate concessionary companies, although some long lines and the telegraph network are owned and operated by the state. At another extreme (Finland) perhaps 100 concessionary companies are linked by a state network of long-distance lines. In Denmark the telephone service is supplied in part by a state-owned and -operated company and by concessionary companies. The opposite concept, found in Germany, France, and The Netherlands, is direct control by a regular ministry, covering not only all telecommunications but also other

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services, such as post, postal checks, and a national savings bank.

Between these extremes are intermediate solutions in which telephone and telegraph are operated by a government agency with a large degree of autonomy distinct from the post or postal services. This is the case in Sweden and Belgium.

In Spain the solution adopted was to let private investors take a majority interest in the national telephone company, but the state is a very-large shareholder and has supervisory powers. The postal and telegraph services are state owned and operated.

Finally, in several countries we find the combined operation by the state of post, postal checks, savings bank, and telecommunications by departments, which, however, operate with a great degree of financial autonomy. This is the case in Great Britain and Switzerland [4].

This short outline indicates the difficulties we may expect when attempting to analyze and compare conditions in Europe. We propose, however, to consider whether the various national conditions or types of organization have a direct influence on the state of telecommunications in each country.

The telephone density in Europe varies from 40.3 telephones per 100 inhabitants in Sweden and 35.2 in Switzerland, at the high end of the scale, down to 9.2 telephones per 100 inhabitants in Italy, 7.3 in Spain, 6.5 in Ireland, 5.1 in Portugal, 3.6 in Greece, and 1 in Turkey.

The other countries have telephone densities between these limits in the following decreasing order: Denmark, Iceland, Norway, United Kingdom, The Netherlands, Finland, Belgium and Luxemburg, Germany, Austria, and France. These relative densities follow approximately the classification of income per capita in the countries under consideration (see Figure 1).

In fact, this is the situation for the majority of European countries as can be seen from the

average curve drawn as reference. There are two outstanding exceptions, Germany and France, in which telephone densities are lower than the corresponding average.

We may attempt a second relation of cause and effect, a relation between telephone density and the form of telephone operating organization. We have listed Sweden and Switzerland as being very different in their type of organization. This does not prevent both telephone densities from being high and not far apart. We have listed also France and Italy as having very little in common organizationally; however, they are both at the low end of the list and have almost the same telephone density.

This supports a second conclusion, namely, that the type of organization does not appear to have a controlling effect on national telephone density in Europe.

Perhaps we can draw a parallel between telephone density and the financial status of each operating company or entity. It seems at first sight that it should be easy to establish the financial status of the different European telephone agencies, as each issues yearly detailed records.

Unfortunately, as organizations are different, their presentation of accounts is also different. Nevertheless, by careful study, one can get a fairly clear view of the telephone or telephone-plus-telegraph profit-and-loss situation in each country. The conclusion is that in each country the combined local and long-distance tariffs are at a level sufficient to bring a profit, which in some cases is fairly substantial. However, in several instances most if not all of the profit is produced by the long-distance rates.

This is often not the case for the postal and postal banking activities in countries where they are part of the same organization as telecommunications. The general rule in this case is that the whole organization must remain profitable; in consequence, part of the profits from telecommunications is used to compensate

for losses in other departments and is thus diverted from financing plant improvements.

These facts are more or less apparent in the available financial records, and may be a cause of delay in the development of telecommunications in certain countries.

Executives in charge of telecommunications are limited in their opportunities for action in several directions. The tariffs, the authorized investments, and often the salaries are fixed by government action, or even by parliament. The statutes in certain cases oblige the departments to pay taxes, and the profits are normally returned to the state. It would be tedious to examine these situations country by country,

but it is interesting to glance at the organization of a few selected countries.

Sweden's telecommunications department forms a separate economic entity without links with postal and financial departments. The director of this department reports to a Minister of Communications. He is expected to keep his organization profitable, pay interest to the state on treasury loans, and return a profit to the state. The telephone fees are imposed by the state and are low. The operation has proved profitable. The investments are financed mostly by internal means, and depreciation seems calculated at rates higher than necessary for mere replacement of obsolete equipment.

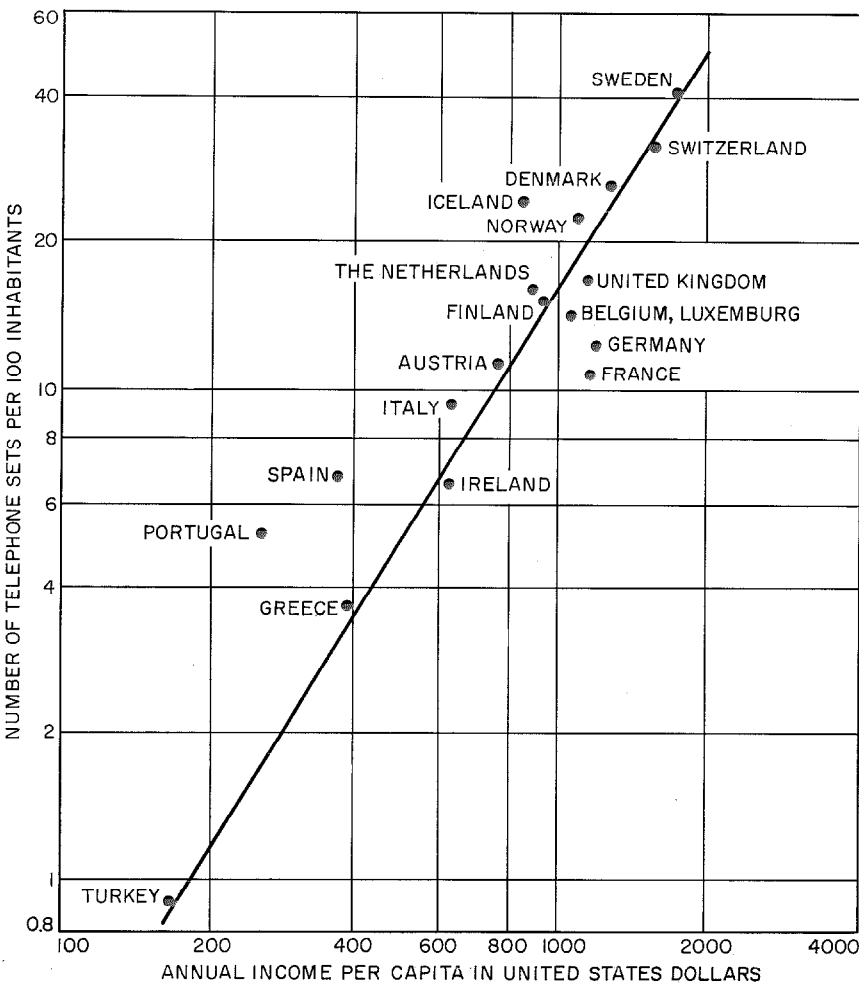


Figure 1—Telephone development in Europe as a function of income per capita [47].

Great Britain has reorganized its telecommunications, postal, and financial departments as a separate state enterprise. Salaries are controlled by the government, but the Post Office Director is now able to plan many years ahead. The Post Office issues accounts in a commercial way and pays taxes, which are sometimes not remitted for special reasons. Tariffs are discussed with the government. Each department is intended to operate at a profit.

The three major activities are closely linked in France under a single Ministry of Post, Telecommunications, and Banking (postal checks and savings accounts). Personnel and salaries are controlled by a central authority for all departments. There is a national plan for investments to be made over the next several years, but these figures may be modified if national financial considerations make this necessary.

We have seen that practically all telecommunication departments in Europe are profitable although tariffs are widely different. The costs of local and long-distance calls vary by as much as 3 to 1, depending on the country (these costs take into account fixed fees and are based on an average number of calls). The situation resembles that of merchants side by side selling very much the same service at prices varying from 3 to 1, all doing reasonably well. With Europe economically integrated and with greater appreciation of the respective situations, these differences will probably tend to even out in the long run.

In the meantime, it is difficult to analyze the exact causes of existing discrepancies. Our opinion is that the variations in telephone density in Europe are in part explainable by previous history and local habits.

A trend, however, is clearly discernable. The countries of Europe are comparing their relative development and the quality of various services more and more. In consequence, pressure is rising in countries with low development in a particular field to match those with higher development. This will tend in the long

run to eliminate some of the exceptional situations.

### 5. Configuration of the European Network

It is clear even from a superficial examination that the European telecommunication network is characterized by the divisive effect of national frontiers. Each nation forms a dense network, but the equivalent to United States interstate traffic is very low by comparison. This should be expected as the trade between European countries and their social contacts are still minor despite the improvements that have resulted from the common market of six countries.

The different languages also retard the development of international communication within Europe. A few examples illustrate this point.

Countries such as Belgium, The Netherlands, and Germany may be expected to have a maximum percentage of international traffic because of their location. Nevertheless their international calls represent only 1.2 percent of their national toll calls.

The case of Switzerland is even more surprising. Despite her central location, international calls to and from Switzerland represent only 0.5 percent of the national toll traffic [5].

However, the rate at which international traffic in Europe increases from year to year is much higher than the corresponding national rates [6].

Each network is evidently well concentrated within its national borders, with a comparatively low density of interstate circuits. Each national network has in turn its own characteristics. These are determined in part by the switching plans adopted, which also influence the numbering schemes.

### 6. Transmission and Switching Systems

It will be seen from what follows that transmission systems used in Europe do not differ



very much from those in the United States; the variations in design are of secondary importance. This is particularly true of the long-distance coaxial and radio networks that form the backbone of European communications. The designs in practically every country are closely related to those found in the United States. We shall see also that most European types of switching systems are not duplicated in the United States.

It is suggested that there is less opportunity for a multiplicity of competing designs in transmission systems than in automatic switching equipment. For instance, there is little leeway in determining the optimum dimensions of a coaxial cable or the distance between repeaters. This holds also for a pair or a quad of wires in multiconductor cables as well as for ultra-high-frequency wide-band radio links, which all look alike irrespective of their origin. In each case the cause of similarity is likely to be the ease with which one may compute the best combination of the elements involved.

It is so far practically impossible to calculate a switching system in advance. Experience indicates that a variety of solutions have been applied successfully over long periods of years, and furthermore that in active competition, especially in export territories, these solutions have each met with some success. Again perhaps the reason is simple. Every central-office automatic switching system must meet the same basic requirements, and this must be achieved with investment and maintenance costs comparable to those of other systems. Any solution costing appreciably more than the established level is eliminated before long, usually after just-enough installations to determine the large-scale costs.

There is in Europe no real large-scale production of telecommunication cables or equipment, compared with the corresponding rates of production in the United States. There are two reasons for this. One, already indicated, is that the total European cable and equipment manufacture is about half of that of the United

States. More important, however, is the fact that so far, with few exceptions, telecommunication cables and equipment are produced in each country by several separate companies to meet the local needs, plus exports if possible. Some of these national companies have financial or technical links, but this only avoids complete duplication and permits but a limited degree of technical coordination.

In each country there are usually several companies producing the same equipment competitively. To prevent unnecessary duplication within one country, we find that the operating authorities coordinate these companies to varying degrees, in some cases even pooling their patents and techniques via a common organization in which the authorities have a controlling interest.

Europe has approximately 63 separate companies producing loop cable. This is reduced to 37 for toll cable. For central-office switching equipment, we can list approximately 40 manufacturers. This number is considerably larger if we include private branch exchanges.

Thus far the subscriber sets in many countries are considered to be suitable for small-scale production, and the national requirements are met by numerous small manufacturers. There are examples, such as Great Britain, where the most-critical parts (transmitter and receiver) are manufactured in one plant.

### 7. Landlines and Cables

The local and toll networks in Europe are characterized by the extensive use of underground cables rather than aerial cables or open-wire lines. Many countries have very little open-wire construction, particularly The Netherlands and Switzerland.

In general the trend is away from open-wire lines, especially as they are highly susceptible to interference from high-voltage power lines and the electrification of railroads, both of which are expanding rapidly. The competition

from radio links and cables, and the vulnerability of open-wire lines to mechanical damage with the resulting high cost of maintenance, are also determining factors in this trend.

The local cables use wire diameters between 0.4 and 1 millimeter (0.02 and 0.04 inch); smaller diameters have been found less suitable and are not used in Europe.

Classical paper insulation has been almost universal, but this is being progressively replaced by plastic insulation. The pulp process has never been used in Europe for lack of sufficient volume of production in a single plant.

Lead cable sheaths have also been generally adopted. Recently plastic sheaths and plastic wire insulation have replaced lead and paper for a part of the production. In England we find a mixed solution—paper-insulated wires protected by a plastic sheath wrapped with an aluminum tape [7].

Europe uses very little Stalpeth and Alpeth sheathing. A limited amount of cable is produced with extruded aluminum sheaths, especially in Norway where aluminum costs are low. In Germany cables with a welded corrugated-metal sheath are used fairly extensively.

The toll telephone and telegraph network is also essentially a cable network. The highest percentage of channel-kilometers provided by radio compared with cable is found in Norway, which has 45 percent radio and 55 percent cables. Radio accounts for  $\frac{1}{3}$  in Spain and  $\frac{1}{4}$  in Italy. France and Sweden have the lowest percentages of radio channels to cable channels [8]. Long-distance radio television circuits may or may not be included in these percentages.

The toll cable network is to a large extent a coaxial cable network. Two sizes have been adopted. The size in greater use employs inner and outer diameters of 2.6 and 9.5 millimeters (0.1 and 0.4 inch), sizes very similar to those in the United States. There are minor variations in the coaxial cables but these do not

affect the electrical characteristics, which are uniform.

The other cable is smaller, and we believe it is not yet in use in the United States. It has inner and outer diameters of 1.2 and 4.4 millimeters (0.05 and 0.17 inch) [9].

Most composite cables comprise several coaxial pairs, from 4 coaxials to 12. Several pairs or quads are incorporated in the cable for supervision and control of the repeaters, or for short-haul telephone traffic.

The present specification for the larger cable calls for repeaters spaced 4.5 kilometers (2.8 miles) apart to provide a 12-megahertz bandwidth, which corresponds to a maximum of 2700 telephone channels over a pair of coaxials. An 8-megahertz bandwidth is standard in the United States.

The smaller coaxials have been used so far with a limited number of channels per coaxial pair, for instance 300 in Italy.

Paired long-distance cables in Europe use almost universally 0.9-millimeter (0.04-inch) conductors. The problem of protection against interference from high-voltage power lines, electrified railroads, and lightning justifies a fairly thick envelope of lead and metal tapes. Aluminum sheathing is frequently specified for cables following high-voltage electrified railroads because the higher conductivity of aluminum offers greater protection against interference.

It is well established that 4-wire carrier circuits are superior in transmission performance to 2-wire loaded circuits. In consequence, many star quad cables with paper insulation have been designed in Europe to accommodate from 12 to 120 carrier channels per pair one way. Another cable design specially applicable to 120 carrier channels involves polythene insulation of the conductors. These systems usually employ 2 cables on each route, 1 each way, to solve the crosstalk problem.

One finds in Europe also a fairly extensive use of 12-channel carrier systems on paper-insulated pairs of a single cable, the crosstalk being avoided by frequency separation in opposite directions.

One can apply such multiplexing to existing loaded cables by deloading a number of pairs. New cables have been designed to handle 12 or 24 carrier channels with this type of equipment.

These methods differ from the well-known  $N$  family of carrier systems in that the latter derive a significant part of their economy from their ability to use fairly long repeater spacing in almost any unloaded or deloaded cable without special treatment. This comes about principally because of the use of compandors and frequency-frogging repeaters as well as fairly high voltages on the cable pairs to supply power to the repeaters. The 12- and 24-channel carrier systems in Europe do not include these features.

As a very-limited use is made of compressors and expanders, the balance in the cable circuits is improved to the point of rendering these unnecessary. Also in Europe many systems use a single pair with directional filters, whereas in the United States it is more common to use 2 pairs without filters for the same purpose.

In carrier, Europe lags considerably behind the United States. Many economic studies based on European conditions fail to justify the application of carrier to the shorter distances that are considered economical in the United States. This is of course partly a question of relative first cost and cost of maintenance of carrier systems, compared with the same elements for physical circuits. Here again, as in the case of cables, a large number of separate firms produce carrier systems in a variety of types. This may have an influence on the field of application of these systems, but the differences in technical concepts undoubtedly play an appreciable role in the large discrepancy between the use of carrier systems in Europe and the United States.

### 8. Tropospheric Forward-Scatter Transmission Systems

The possibility of successful transmission of very-high-frequency radio waves beyond the horizon was known many years back; in particular, tests established such possibility when a telephone network linking Barcelona to Majorca and the other Balearic Islands was established in 1934 [10].

Another early tropospheric link was placed in service between Sardinia and Minorca in September 1957, joining the Spanish and Italian telephone networks [11, 12].

An impressive recent achievement in this field is the cutover of a military network using principally tropospheric forward scatter and also line-of-sight transmission.

The backbone is made up of a series of tropospheric links from the north of Norway to Paris over 2 routes, one via Denmark and Germany, and the other via the Shetlands and Great Britain. An extension reaches also the Faroes Islands. The link continues from Paris to Turkey via Italy and Greece. Extensions reach Malta, Crete, and Cyprus.

The total length of tropospheric links is 12 000 kilometers (7500 miles) with 45 repeaters or terminal stations. The network involves also a number of line-of-sight radio links covering a total distance of 2000 kilometers (1250 miles) with 64 terminals or repeaters [13].

A recent project involves a direct circuit between France and Portugal.

### 9. Telegraph

Except in a very-few countries where the telegraph network and telegraph service are separate from telephone, the telegraph network is incorporated in the telephone cable or open-wire network.

The annual telegraph traffic is almost static in volume, but the telex service is increasing everywhere at a rate far in excess of that of telephone traffic [6]. The telex traffic requires

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switching facilities that, contrary to United States practice, are in exchanges apart from the telephone exchanges.

The terminal printers are of a variety of types that are of the mechanical class as in America and use codes permitting them to interwork. Some steps have been taken in France to introduce printers of the so-called semielectronic type [14].

### 10. Sound Broadcasting and Television

Point-to-point transmission of sound programs is handled almost everywhere via the telephone network. The operation of sound broadcast transmitters is a function of the telecommunication company or department in Sweden, Switzerland, The Netherlands, and Denmark.

In Great Britain, Germany, Italy, France, and Belgium, sound broadcasting is handled by a government-owned corporation. In all cases such corporations are responsible for the programs.

It is notable that Switzerland also has a sound broadcasting service over the subscriber tele-

phone wires. The program is distributed either by carrier or directly at voice frequency. In the latter case it is of course interrupted when the telephone is in use.

Sound broadcasting over telephone wires is also extensively used in Sweden. The programs are not interrupted when the telephone is used as the transmission uses a high-frequency carrier.

Television in Europe employs a number of different transmission standards. There are 6 very-high-frequency standards, the main characteristics of which are listed in Table 1. There have been later developments on ultra-high frequency with 625 lines and with several variations in the other parameters involved.

One result of this lack of standardization is not only that television sets differ from country to country, but also that in regions close to one or more borders the user must purchase sets capable of shifting from one standard to another. Sets used in the regions close to France, Belgium, and The Netherlands, or France, Switzerland, and Germany, are designed to receive up to 4 different standards. It goes without say-

TABLE 1  
EUROPEAN TELEVISION STANDARDS

Area of Coverage	Number of Lines	Video Modulation	Sound Modulation	Video Bandwidth in Megahertz
United Kingdom	405	positive	amplitude modulation	3
Western Europe except France and United Kingdom	625	negative	frequency modulation	5
Belgium	625	positive	amplitude modulation	5
Eastern Europe	625	negative	frequency modulation	6
France	819	positive	amplitude modulation	10
Belgium	819	positive	amplitude modulation	5

ing that their cost is appreciably higher than sets designed for a single standard.

The average density of television sets in Europe is of the order of one third the United States figure, Great Britain having the highest density with 26 sets per 100 inhabitants [15].

Despite the operating difficulties resulting from this complex situation, there is a network in Europe, called Eurovision [16], that broadcasts events of general interest. Equipments have been designed for translating from one standard to another without undue loss of quality.

The point-to-point television circuits are usually radio links carrying only television programs. These also may be operated either by the telecommunications administration or by the broadcasting corporation.

Television broadcast transmitters are operated in each country by the same authorities as for sound.

### 11. Central-Office Switching Systems

Discounting the short-lived switching systems, one may classify systems presently in use (at least for extensions of existing offices) that are manufactured in Europe into approximately 20 families, some large, some more modest. Each family divides in turn into several principal systems that differ in concept and field of application. One can certainly list 50 coded switching systems in all. It is recognized that several systems may use the same apparatus. However, even based on apparatus alone, more than 20 different systems are given in the following list.

Rotary *7A1, 7A2, 7B, 7D, 7E, 7EN*  
*R6* with and without register  
 Pentaconta crossbar  
*HKS* crossbar  
*HE-60 L*  
*CX 100* crossbar  
*RX 20* crossbar  
*UAX 5* to *UAX 14*  
*PRE 2000* with and without register

*2000* with and without register  
 Siemens Brothers Numbers *16* and *17*  
*SXS 22, SXS 40, SXS 50*  
*EMD 55* (motor switch)  
*FWS 62* (toll system)  
*F6*  
*KM* motor switch  
*ESK*  
*48, 48 M, 48 HK*  
*AWZA 42, AWZA 49, AWZA 52*  
*HS 25, HS 31, HS 52*  
 Standard *41* crossbar  
*A204* crossbar  
*AGF* 500-point selector  
*ARF* crossbar  
*ARK* crossbar  
*ARM* crossbar (toll system)  
*CP 400* crossbar  
*UR 49A*

One may start by a broad division of these systems into two classes, which are usually called direct and indirect systems.

Direct switching systems operate on the principle that each dialed digit directly actuates one switching stage, which in turn selects a free outlet to the next selector stage, the last two digits corresponding to a single switching stage. The time between dialing successive digits is used to find the free outlet. The number of stages of selection corresponds to the number of digits dialed, except that digits not needed for some paths are absorbed. Direct systems are consequently stage-by-stage selection systems.

The greatest majority of direct switching systems are of the step-by-step class, characterized by the up-and-around step-by-step switch. Crossbar switches with associated controls are sometimes used in direct switching systems, each crossbar selector corresponding to one stage of selection [17].

In other words, in direct switching systems the subscriber, when operating his dial, controls directly, and so to speak personally, the operation of the successive stages of selection in the network. If for any reason there were more



digits in the dialed number than stages of selection, these extra digits are unnecessary and must be absorbed.

There is a direct relation between the code being dialed by the subscriber and the design of the selectors used; in particular the speed of the selectors controls the speed at which the dial or sender can operate, and the time necessary for selection of a free outlet controls the interdigital time in most cases.

In these direct systems, as dialing starts, selection starts also, and the progress of the call over the junctions takes place in response to dial impulses.

Indirect operation is based to some extent on the characteristics of manual operation, in that the identification of the station dialed by the calling subscriber and the series of steps that follow are not one single process, but two independent operations. This is done by introducing—between the request delivered by the subscriber in the form of a code characteristic of the called party and what is done about it—elements of logic, of decision, and of adaptation to conditions and circumstances totally lacking in the direct system.

This indirect method means that when a subscriber is calling, receipt of the dial tone indicates that he is connected temporarily to a common equipment. This equipment is capable of receiving the code transmitted by the calling subscriber, translating such code into a sequence of orders that depend on conditions, and establishing the connection through the switching network. Orders are then transmitted, usually by fast signaling, over the junctions to operate the remote exchanges.

These two methods of switching control approximately equal numbers of automatic lines in the United States. They are found principally in the step-by-step offices for the direct method and in the panel and crossbar offices for the indirect method; however, no new panel offices have been installed for many years.

We assume that the advantages and limitations

of both methods are well understood and do not intend to review them in detail [18].

The choice of method affects the numbering of subscribers. In all cases one can distinguish local and toll networks. (By local we mean the network where dialing is in accordance with the subscriber directory number. By toll we mean the network interconnecting these local networks.)

The choice of system influences the size of the local zone. In the direct switching area the local zone is restricted in importance because the numbering and routing are closely linked. This is not the case in indirect systems and it permits extension of the local zone to cover a large number of exchanges, the routing between these exchanges being determined by a register-translator.

One practical result of these differences is that in countries with direct switching, the number of digits in the local network is usually less than in the larger zones with indirect systems. However, to dial over the whole country, the number of prefixes in the first case is larger, and finally the maximum number of digits to be dialed is higher for complete networks with small local networks.

In Europe we find three approaches in the design of local switching networks; they apply to countries equipped principally with direct switching systems, those where direct and indirect systems are mixed in the same network, and those operating with indirect switching.

The major representatives of the first group are Great Britain and Germany, where the 2-motion step-by-step switch has been extensively used since the end of the first world war. Recently single-motion motor switches have been largely substituted for the 2-motion switch in Germany, and a similar switch is used also in Great Britain for toll exchanges [19]. In both cases, one of the advantages is that access is provided to a larger number of trunks than is possible with a 10-by-10 step-by-step switch.

In the large multioffice areas it has been found advantageous to introduce a register-translator to facilitate the routing of calls. This is the case in the principal towns of England. For a similar reason the interconnection between local areas frequently involves a register-translator. This solution is found both in England and in Germany.

Austria, Portugal, and Greece have step-by-step offices. Recently Austria has also adopted a crossbar system; Greece has done likewise but in this latter instance uses stage-by-stage direct selection.

Norway, Denmark, Belgium, France, and Spain are, for all practical purposes, overwhelmingly on indirect switching. In these countries, except Denmark, the majority of lines are equipped with the rotary switching system. This system was originally conceived by Western Electric Company at the same time as the panel system. As is often the case, it was difficult to choose between the two solutions and both survived, panel inside and rotary outside the United States. The rotary system was manufactured by several International Telephone and Telegraph Corporation divisions or licensees and exported to a large number of countries. Incidentally there are a few rotary exchanges in the United States.

The rotary, as its name indicates, employs a rotary motion of brushes, whereas the panel uses a vertical motion [20]. Both systems have many characteristics in common, including the use of a common drive and of register-translators. This has the advantage of permitting access at each stage to a large number of trunks.

The rotary switching system is being progressively superseded, as is the panel system, at least in most new offices, by crossbar systems. A design called Pentaconta [21] differs in concept from the Number 5 Western Electric, principally in that Pentaconta may be scaled down to serve small offices economically while being capable also of application to large offices.

Norway has used rotary and recently intro-

duced our crossbar versions coded *8A* and *8B*, which are characterized by partial use of electronic controls [22]. Belgium uses almost exclusively the rotary system in various versions, recently with partial electronic control. Denmark is equipped with rotary and with other indirect systems, an Ericsson crossbar, and the Pentaconta system. The Ericsson system has points in common with the Western Electric Company crossbar, but these are more in the apparatus design than in circuits. This situation is not surprising, as the introduction of crossbar systems took place in Sweden first and then in the United States. Later both sides made a number of contributions to the present apparatus designs [23].

France selected two indirect systems. The rotary was applied to the Paris area and to some of the larger French towns. The other system, coded *R6*, used a single-motion step-by-step switch with registers [24]. It served the rest of France and also North Africa. Both systems have been superseded by Pentaconta crossbar in the larger areas including Paris, and by Ericsson crossbar coded *CP 400* in the other regions [25].

All offices of the Spanish telephone company were of the rotary type. Recently, however, the first cutover of a Pentaconta crossbar exchange took place in Madrid, followed shortly afterward by a similar cutover in Barcelona. This system will be used in new offices and will progressively replace rotary.

We now meet the more-complicated cases of mixed direct and indirect switching systems. These are found in Sweden, The Netherlands, and Switzerland. Sweden originally adopted the Ericsson 500-point system [26]. The switch is very characteristic: It is motor driven and performs two successive motions in the same plane, first rotating, then radial in depth. The contacts are made over a bare-wire multiple, and each inlet has access to 500 outlets. As in panel or rotary, the system uses registers and translators.

All Stockholm offices are equipped with the Ericsson 500-point system, which has also been exported to many countries, principally outside Europe.

Sweden has also extensively used crossbar systems designed by the Swedish administration [27]. The original systems were used in small rural exchanges and followed the principle of direct stage-by-stage selection. Later on, register- and marker-controlled crossbar systems were introduced for central offices and for rural and toll exchanges. One Swedish town with an exchange of 3000 lines has been equipped with push-button digit senders to gain experience with this method.

The Netherlands has found it convenient, and sometimes necessary because of war destruction, to employ many systems simultaneously. Before the war, Siemens step-by-step (*F* system), *7A* and *7D* rotary, and Ericsson 500-point systems were used. After the war, *7E* rotary, Philips, and *ATE* step-by-step were introduced. Ericsson crossbar was also adopted in one district [28].

It must be noted that in The Netherlands the direct and indirect systems are grouped in the northern and southern parts, respectively, to simplify interworking problems that are necessarily complex in such cases.

Switzerland also has several systems. They originate from two groups already mentioned (International Telephone and Telegraph Corporation and Siemens Brothers), but there are also designs originating from the Swiss Hassler Company [29]. The administration has adopted several designs from each source, as follows.

(A) Hassler Company: Three systems with registers; the *HS 25* and the *HS 52*, both with rotating selectors, and the *HS 31* with a rotating and radial motion.

(B) International Telephone and Telegraph Corporation: Rotary *7A*, *7D*, *7E*, and Pentaconta crossbar.

(C) Siemens Brothers: Step-by-step *A42* up-and-around selector, *A49* motor switch, *A52*

register system with motor switch, and *ESK* semielectronic relay system.

These systems are located in different cantons of Switzerland. Full interworking is provided over the whole country.

Although uniform equipment and signaling methods greatly facilitate full interworking within one country, interworking between several different automatic systems can be carried out quite successfully with proper planning, as shown by these latter examples.

## 12. Signaling

Signaling methods applied within the national boundaries are clearly a matter for local decision. In consequence a number of unrelated solutions have been adopted in Europe that can be analyzed as follows.

Besides the short-range direct-current and 50-cycle signaling, the great majority of circuits use signaling in the voice band. The frequencies and the codes differ. Five systems operate with single frequencies between 2000 and 3000 hertz or out of band at 3825 hertz. Five other systems use combinations of 2 frequencies between 600 and 2400 hertz.

Two systems have been recommended by the Comité Consultatif International Télégraphique et Téléphonique for international circuits [30]. One uses a single frequency and one uses two simultaneous frequencies. They are included in the 10 systems referred to above.

Recently multifrequency signaling systems have been favored to speed up signaling. One version, usually called the European system, uses 12 frequencies 120 cycles apart, 6 in each direction, in groups of 2. Signals are exchanged both ways, digit by digit. This is already in use in Belgium, The Netherlands, and Denmark, and is expected shortly in several other countries. The intention was to standardize this system as much as possible, both for national and international circuits [31].

Recommendations have also been submitted to

the Comité Consultatif International Télégraphique et Téléphonique that are expected to be approved shortly, for an international signaling system compatible with submarine cable circuits equipped with time-assignment-speech-interpolation, as well as landlines including microwave circuits.

Another system is known as the Socotel system; this is standard for new offices in France. It is a version involving 6 frequencies in groups of 2. It transmits digits in a first group of 4, then the balance when called for. A seventh frequency is used, if required, in the so-called "compelled" system.

Denmark uses a forward multifrequency pulsing system. Routing in the toll network is done by sending a cyclic toll code from the originating exchange until acknowledged by the terminating exchange.

There is little doubt that the trend is toward greater application of multifrequency signaling.

Besides the signals involved in the switching process, the user is exposed to a number of tones. The ringing tones are fairly varied. The frequency of 450 hertz is the most usual, with or without modulation and in several codes. Busy tones and codes vary also. The inexperienced traveller in Europe may misunderstand them [32].

Recorded voice information is also provided within several national networks, in particular to help the subscriber dial correctly. Of course, it fails to help those unfamiliar with the language.

### 13. Private Branch Exchanges

The proportion of telephones connected as extensions or via a private branch exchange to the total number of telephones in European countries averages the same as in the United States: slightly more than one-third, with the exception of France, Germany, and Great Britain, which are as high as 48, 45, and 45 percent, respectively.

Appreciably fewer companies manufacture central offices than private branch exchanges, as several companies produce only the latter and practically all central-office manufacturers produce both.

The variety of equipment types is correspondingly large. We find in the majority of cases, however, that the apparatus used for central offices is also applied to private branch exchanges. One major exception is Germany, where no crossbar systems have been used in central offices, although they have been widely used in the latter.

The private branch exchanges are sold or rented to the user, who can choose from several approved models produced by different manufacturers. This applies to all countries except Sweden, Switzerland, Spain, and The Netherlands, where these exchanges are the property of the telephone operating departments. In Belgium only the large ones are the property of the operating agency. In Germany about 30 percent belong to the Bundespost.

Where outright purchase is permitted, direct competition among manufacturers often leads to offers of a large variety of extra facilities. These are not standard and sometimes create a problem for the casual user of a private-branch-exchange extension telephone. A limited number of such telephones now use push-button operation to save time; however, the process involved is not directly applicable to main exchanges.

Direct inward dialing to, and identified outward dialing from, private branch exchanges are services that may or may not be provided depending on the conditions of the network. These services are provided principally in step-by-step areas where no special problem is created (Germany, and parts of Switzerland and Austria, in particular). They are not generally provided in register areas with fixed number lengths, as an end-of-selection signal is involved that is not yet available in the existing systems. In consequence, a present tendency

is to provide such a signal in all new signaling and switching systems to facilitate the widespread introduction of such services. Inward dialing to large private branch exchanges, using the called subscriber's extension number, is provided in many instances (for example, at the Radio and Television Center in Paris).

### 14. Recent Achievements

#### 14.1 TRANSMISSION SYSTEMS

A definite trend in coaxial cable systems is toward an increase in bandwidth, with a corresponding increase in the number of telephone channels transmitted. The 2.6-to-9.5-millimeter (0.1-to-0.4-inch) coaxial system was equipped with repeaters for a 4-megahertz band, and later on for a 12-megahertz band. A further increase in bandwidth to 50 or 60 megahertz is now under preliminary consideration, although no definite standards have been established.

The 1.2-to-4.4-millimeter (0.05-to-0.17-inch) coaxial cable system originally equipped with repeaters for 1.3 megahertz is now under study to handle a wider band. The objective is either 3.6 or 4.8 megahertz and both standards may be adopted. In The Netherlands an objective of 6 megahertz is being considered.

#### 14.2 SATELLITES

The future impact of satellite communication is fully appreciated in Europe, and satellites Relay and Telstar have been followed with great interest.

Three ground stations have already been installed in Europe: at Pleumeur-Bodou [33] in France, at Goonhilly Downs [34] in England, and at Raisting [35] in Germany. The French station is similar to the United States installation at Andover (horn reflector antenna), the English station is equipped with a steerable dish, and the portable German station uses a paraboloidal reflector.

The satellite ground stations differ markedly from those used in conventional radio relay

systems; they include high-power ultra-high- or super-high-frequency transmitters, low-noise amplifiers (maser in most cases), and extensive antennas for receiving the very-small signal power retransmitted by the relay. Moreover, asynchronous satellites such as Relay and Telstar must be tracked by a steerable antenna.

Many tests involving both telephone and television have been performed between the American, French, and English stations via Telstar. An experimental telephone connection has been made between the American and German stations via Relay.

Ground stations for satellite communication have been installed in Italy and Spain.

Satellite telecommunications apply to telegraphy, telephony, television, and even coordination of sea and air traffic [36].

It is recognized that satellite development calls for resources that exceed those of any individual country in Europe. As a result, 16 European countries have created the European Conference on Satellite Communication, with the object of being represented by this common association in dealings with the United States Comsat Corporation. Agreements reached at these discussions would involve the installation of a number of ground stations, which in Europe will likely be the property of the existing telecommunication agencies and be operated by them.

Several other European organizations are active in space research and will influence the development of satellite communication.

#### 14.3 COLOR TELEVISION

It is acknowledged that there should be a single color television standard in Europe. Hopefully the formal agreement will be reached at an international meeting in the spring of 1965.

Three systems are under consideration.

(A) United States National Television System Committee (N.T.S.C.)

**(B)** French Sequential with Memory (S.E.C.A.M.) [37], in which a single sub-carrier alternately transmits for each line one of the two necessary chromatic components. The component not transmitted is stored for the interval corresponding to one line by means of a delay line so that both components are simultaneously present at the receiving end. The same chromatic component is consequently applied to two successive lines. The receiver has no color adjustment.

**(C)** German Phase Alternation Line (P.A.L.) [38], which is similar to **(A)**. Both color components are transmitted entirely and simultaneously. The difference is, that to reduce loss of quality because of phase distortion, the phase of one of the two components is switched by 180 degrees from one line to the next. The signals at the receiving end are combined for two successive lines by means of a delay line, one of the components being reproduced by addition and the other by subtraction. The receiver has no color adjustment.

#### 14.4 SWITCHING SYSTEMS

In recent years, techniques developed for computers have been introduced in telecommunications, and particularly in switching. Such techniques are directly applied to telegraph exchange systems of the "store-and-forward" type, which takes advantage of the large capacity of electronic memories and the flexibility of electronic switching.

Many laboratories are working on the problems in semi- or fully electronic switching. By semi-electronic we mean systems in which the speech path is established through metallic contacts by the action of electronic controls. Fully electronic applies to systems with electronic devices in the speech path and electronic controls.

The British Post Office, in cooperation with the 5 British telephone manufacturers, has established development programs that resulted by the end of 1962 in the installation and cut-over of a public exchange serving 800 sub-

scribers. The exchange operates on the principle of time-division-multiplex switching, using pulse-amplitude modulation [39].

A similar interest of the French Telecommunication Administration in research led to the creation of Socotel. Among its aims is the study of semi- and fully electronic switching systems [40, 41].

Furthermore, two semielectronic telephone switching systems ordered by the German Post Office are now in experimental use at Munich and Stuttgart [42, 43]. A telephone exchange with central electronic control equipped originally for 2000 lines but designed for 10 000-line capacity will be installed in Madrid in 1966.

Development of fully electronic telephone switching systems is underway in most telephone laboratories. Several experimental models have already been designed, and one, a private automatic branch exchange using gas tubes as crosspoints and centralized control, has been serving 240 lines in Paris for more than 4 years [44].

The invention of pulse-code modulation 25 years ago [45] was a far-reaching event from a system viewpoint. This method is particularly well adapted to electronic multiplex switching, and allows consideration of an integrated system in which the voice is coded in digital form and the resulting signals pass through both the transmission and switching systems without decoding. A number of systems based on this principle are being studied by national laboratories and private companies [46]. They have already been the object of military orders.

The trends appear to be toward semielectronic systems for the near future, partly because they are compatible with existing telephone instruments, and partly because they may be more economical than fully electronic systems, at least until the full merits of integrated pulse-code switching and transmission systems are established. In either case the trend is clearly toward central electronic control systems, to

save on apparatus and derive full advantage of the capabilities of electronic circuits.

In a different application we find that the techniques of automatic computation have already helped the telecommunications industry through automated design engineering and manufacturing processes, which are likely to develop further in coming years.

### 15. Summary

This rapid survey of telecommunications in Europe shows that political conditions have influenced the development of national networks, each of which has its own individuality. This variety of equipments, systems, and methods has been harmonized to a degree by action of consultative committees, by contacts between agencies, and by liaison between suppliers.

This multiplicity of conditions is in itself a source of valuable experience, and supplies a wealth of information for planning.

The trend is toward a greater interchange of knowledge and experience between the entities involved, leading undoubtedly to more-uniform concepts and practices. This is all the more timely as the European network will progressively operate on a fully automatic basis, subscribers reaching all parties by direct dialing.

### 16. Acknowledgments

The author expresses his thanks to Messrs. F. Babin, J. Déjean, and C. Grandjean of the Laboratoire Central de Télécommunications, to Mr. H. Pech of the Lignes Télégraphiques et Téléphoniques, and to many of his colleagues in the associated companies of the International Telephone and Telegraph Corporation, for their help in preparing this paper.

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- E. M. Deloraine** was born in Paris, France, on 16 May 1898. He received in 1918 the B. S. degree, the Certificat de Mathématiques, and in 1920 the engineering diploma of the École Supérieure de Physique et Chimie, a branch of Paris University. In 1949, he was granted the degree of Docteur-Ingénieur by Paris University.
- In 1917, he joined the French Army Signal Corps and later engaged in research work at the Eiffel Tower. He became a member of the London engineering staff of the International Western Electric Company in 1921, where he worked on radio broadcast transmitters and was responsible for part of the development in

Great Britain of the first radio transatlantic telephone circuit.

In 1928, he organized the International Standard Electric Corporation Paris laboratory that became Laboratoire Central de Télécommunications. He was made European Technical Director of that corporation in 1933. From 1931 to 1937, he contributed importantly to the application of ultra-high frequencies to communication. He was also active in the advancement of high-power broadcasting.

Dr. Deloraine came to the United States in 1941 to establish a laboratory for defense work for Federal Telephone and Radio Corporation. In 1946, he was appointed General Technical Director of International Telephone and Telegraph Corporation, Vice-President and Technical Director of the International Standard Electric Corporation, and Vice-Chairman of Standard Telecommunication Laboratories in Great Britain. In this period, he was personally

active in research and development of switching systems. Later, he was appointed and still serves as Vice-President of International Standard Electric Corporation, President of the Laboratoire Central de Télécommunications, and President of Le Matériel Téléphonique.

Dr. Deloraine was made a Chevalier of the Legion of Honor in 1938 for exceptional services to the Posts and Telegraphs Department of France, and in 1945 was promoted to Officer of the Legion of Honor by the Minister of the Navy. As proposed by the Minister of Posts and Telecommunications, he was made in 1963 an Officer of Postal Merit and in 1964 a Commander of National Merit.

Dr. Deloraine is a Fellow of the Institute of Electrical and Electronics Engineers and a Member of the Institution of Electrical Engineers in Great Britain. He also holds membership in several scientific societies in France.

## Pert Cost

Pert, which is an acronym for Program Evaluation and Review Technique, is a method of estimating the time that will be required for each activity in a complex engineering program and of periodical evaluation to determine if the schedule is being kept. It was described in a programmed learning course called An Introduction to Pert\*. An extension of this system to include not only time management of such engi-

neering programs but cost as well has appeared under the title of Pert Cost. It too is in the form of a programmed learning course.

Pert Cost—A Programed Instruction Manual is on 8.5-by-11-inch (216-by-280-millimeter) pages, 171 of which are held between plastic covers by a plastic comb passing through perforations along one edge of each sheet. It is available from the Special Services Department, Federal Electric Corporation, 621 Industrial Avenue, Paramus, New Jersey, at \$6.50 per copy.

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\* See *Electrical Communication*, volume 38, number 2, page 212; 1963.

# Transistor Carrier Multiplex Equipments

## Part I—Broad Design and Salient Circuit Features

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### 1. Introduction

An essential part of any multichannel carrier telephone link is the multiplex equipment. This accepts the individual audio-frequency speech circuits, modulates them to carrier frequencies, and assembles them into "blocks" for transmission over the wide-band carrier system, be this repeated cable or radio link. The standard blocks recommended by the Comité Consultatif International Télégraphique et Téléphonique for systems of up to 960 channels are group (12 speech channels between 60 and 108 kilohertz) and supergroup (60 speech channels or 5 groups between 312 and 552 kilohertz). In the majority of cases multiplex equipment represents a very-high proportion of the cost of a link, and it must be of economical design as well as of high performance and reliability.

The basic design and salient electrical features of a new family of all-transistor 960-channel

multiplex equipment are described here; two alternative constructions are treated in Parts 2 and 3. This equipment is the result of a co-ordinated development and engineering program that made use of the facilities of ITT Europe companies in England, Germany, Belgium, and The Netherlands as listed in Section 5.

#### 1.1 PREPARATION OF DESIGN SPECIFICATIONS

One objective was a design that would satisfy the needs of many customers with a minimum of modification. To this end, the recommendations of the Comité Consultatif International Télégraphique et Téléphonique and the requirements of a wide range of administrations and other operating organizations were studied, and a set of specifications was prepared from the information obtained.

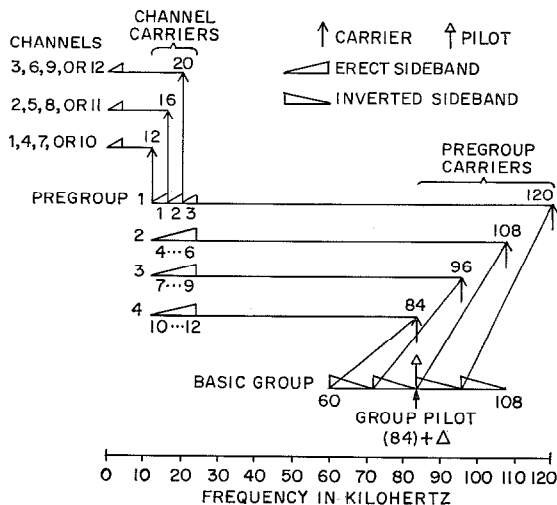


Figure 1—Frequency allocation for the translation of 12 audio-frequency channels into a basic group by double modulation.

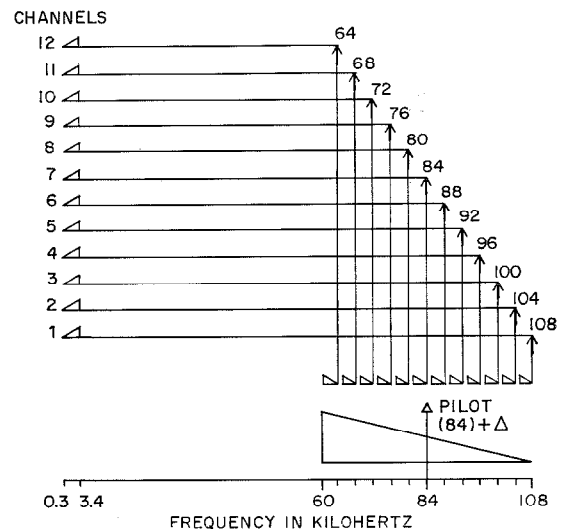


Figure 2—Frequency allocation for the translation of 12 audio-frequency channels into a basic group by single modulation.

1.2 SYSTEM ARRANGEMENT

In accordance with recommendations of the Comité Consultatif International Télégraphique et Téléphonique, the multiplex equipment is divided into channel, group, and supergroup translating equipments and the relevant carrier frequency-generation equipment.

Channel equipment modulates 12 speech channels into the basic group frequency range between 60 and 108 kilohertz, the channels being inverted and spaced at 4-kilohertz intervals. This is the basic group *B* of the Comité Consultatif International Télégraphique et Téléphonique. To satisfy different administrations and also to suit the production facilities of our various manufacturing companies, this equipment has been designed in two forms, double modulation and single modulation. Frequency allocations are shown in Figures 1 and 2, respectively.

Group equipment modulates 5 groups (each of 12 channels) into the basic supergroup frequency range between 312 and 552 kilohertz, the channels being erect. There is one basic design, the difference in the requirements of various administrations being the nominal levels and impedances at the group input and output points. The frequency allocation is shown in Figure 3.

Supergroup equipment modulates 16 supergroups into the frequency range between 60 and 4028 kilohertz, the channels being inverted (except for supergroup 2, which is not modulated). Various other combinations of supergroups are possible, for example, supergroups 1 through 5 for 300-channel cable or radio systems. The frequency allocation is shown in Figure 4.

Carrier generation equipment employs quartz-crystal master oscillators of appropriate stability. It supplies the translating equipments with channel, group, and supergroup carrier frequencies and certain pilot frequencies.

Through-group and through-supergroup filter equipments, as their names imply, are used for the through routing of groups and supergroups

without demodulating them into channels and groups, respectively. They pass the basic 60-to-108-kilohertz or 312-to-552-kilohertz bands and suppress all frequencies from adjacent groups or supergroups.

Group and supergroup automatic-gain-control equipments are used under certain circumstances to compensate for level fluctuations, generally on long systems.

2. Electrical Design

The electrical design of the equipment incorporates the most-modern design techniques, including insertion-loss network synthesis by computer and the most-modern components have been included subject to the dictates of proven reliability.

2.1 CHANNEL TRANSLATING EQUIPMENT

The channel translating equipment is perhaps the most-important part of a multiplex equipment. As one unit is required for every channel, the quantity (and hence space and cost) of this equipment is considerably in excess of that of other multiplex units.

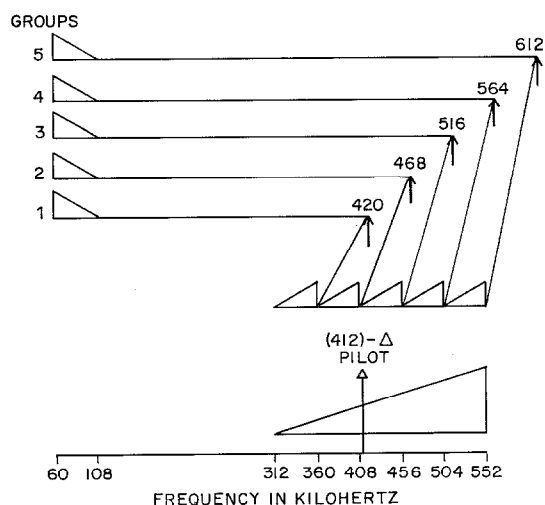


Figure 3—Frequency allocation for the translation of 5 groups into a basic supergroup.

As already explained, it was considered necessary to design double-modulation and single-modulation versions. The relative advantages and disadvantages of these two techniques have been discussed for many years, and it is probably true to say that in general the differences are too small to prove which is better. Doubtless this explains the use of both types throughout the world. Both versions were designed to meet the same specification and certain portions of the circuits are identical.

Although the main aim was for channel equipment with in-built out-band signaling, a single-modulation version without signaling was developed also with particular emphasis on British Post Office requirements.

### 2.1.1 Double Modulation

This design translates 3 channels into the pre-group range between 12 and 24 kilohertz, followed by translation of 4 such pregroups into the basic group *B* range between 60 and 108 kilohertz.

The carrier frequencies used are 12, 16, and 20 kilohertz, and 84, 96, 108, and 120 kilohertz, respectively. These frequency allocations were chosen to permit the use of coils and capacitors in the filters. Each channel has an out-of-band signaling frequency of 3825 hertz, which provides facilities for ringing or dialing, and which may be used for metering pulses during conversation. A functional diagram is shown in Figure 5.

At the 4-wire audio-frequency input, a set of attenuators permits a wide range of input levels to be accepted. This is followed by a diode volume limiter that clips very-high input levels, thus reducing the peak amplitudes from loud talkers or direct-current impulses that might otherwise cause overloading of subsequent equipments or interference with the signaling frequency. A combined low-pass and high-pass filter suppresses input frequencies below 300 and above 3400 hertz, and provides the injection point for the 3825-hertz signaling frequency, which is passed through a band-pass filter to limit the sidebands transmitted. The

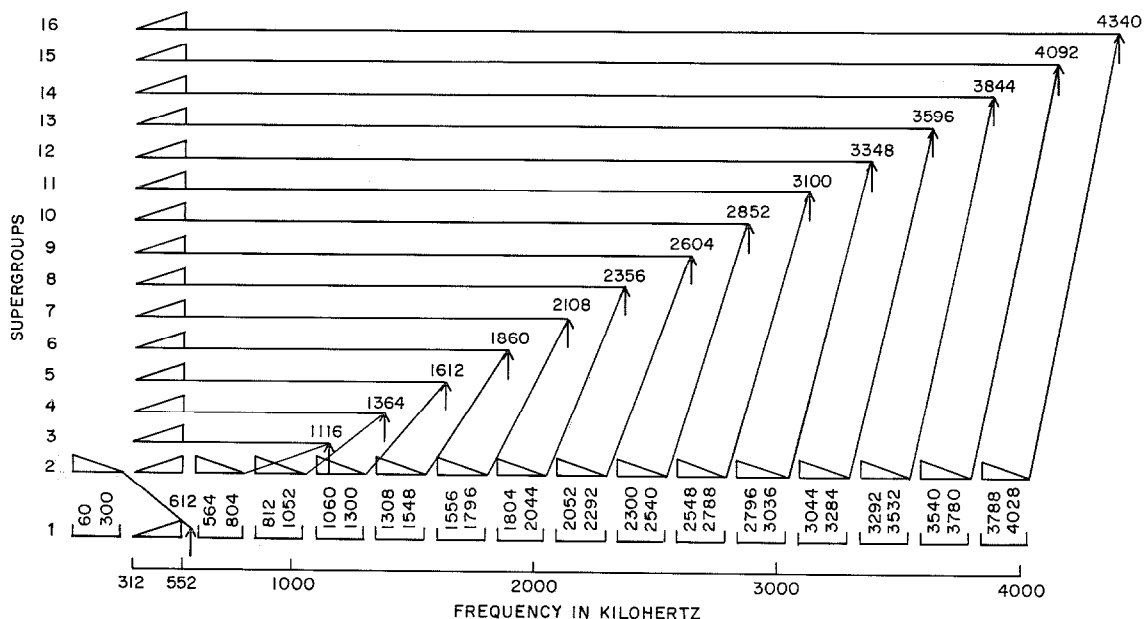


Figure 4—Frequency allocation for the translation of 16 supergroups to give a 960-channel band in the frequency range between 60 and 4028 kilohertz.

combined speech and signaling input is then modulated in a diode ring modulator, using a carrier frequency of 12, 16, or 20 kilohertz.

The following channel band-pass filter selects the upper sideband; the use of ferrite cores and silvered-mica capacitors has led to a filter of small physical size and stable characteristics. A special computer synthesis technique was used to give the optimum design of the combined audio-frequency filter, modulator, and channel filter.\* The 3 channels are combined to form a 12-to-24-kilohertz pregroup and are amplified and then modulated with a carrier frequency of 84, 96, 108, or 120 kilohertz in another diode ring modulator. The lower sideband is selected by a relatively simple band-pass filter. The 4 pregroups are then combined to form the 60-to-108-kilohertz basic group and amplified to provide a range of output levels.

The reverse process is applied in the receive direction, a wide range of input levels being acceptable. Pregroup sideband selection, de-

modulation, and amplification are followed by channel sideband selection, demodulation, further filtering, and amplification. A wide range of audio-frequency output levels is provided, and the amplifier includes a gain control for routine level adjustments. This amplifier is divided into two parts separated by a combined low-pass and high-pass filter; the first part comprises two common-emitter stages and the second part a common-emitter stage plus push-pull output stage operated class-A. The signaling frequency is picked off between the two parts, to obtain a reasonably high level without risk of interference from speech intermodulation products, and passed through a band-pass filter to the signal receiver.

The group reference pilot (84.08 or 84.140 kilohertz) is injected after the 12-channel basic group has been formed; that is, at the input of the final transmit amplifier. Crystal narrow-band-stop filters are inserted in both transmit and receive paths to help suppress input frequencies that might interfere with the pilot and to prevent interference from the pilot into speech or signaling.

The signaling circuits have been designed to operate over a wide range of levels and to

\*C. Kurth, "Analysis of Diode Modulators Having Frequency-Selective Terminations Using Computers," *Electrical Communication*, volume 39, number 3, pages 369-378; 1964.

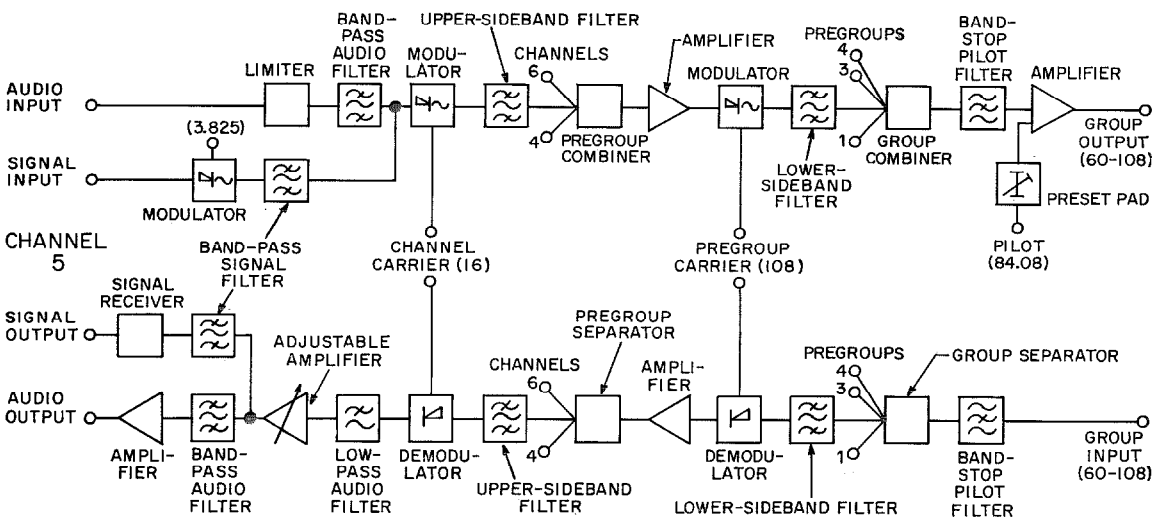


Figure 5—Channel translating equipment using double modulation. Frequencies in kilohertz are shown in parentheses.



## Carrier Multiplex Equipments: Design and Circuits

provide low distortion to signaling pulses. Continuous, tone-on-idle, or tone-on-busy conditions are provided for. Adequate suppression is provided to make the signaling tone or pulses inaudible to adjacent channels or the same channel. The signal receiver comprises a band-pass filter, single-stage amplifier, tuned coil, square-law detector, direct-current amplifier, and relay-driving stage. The input filter and the

tuned coil together provide the required selectivity for immunity from speech interference. The input amplifier includes gain control to allow for different signaling levels, and straps between the detector and the direct-current amplifier provide for variations in the tone condition. The direct-current amplifier and relay-driving stage are stabilized against transistor variations with temperature by the use of compensating diodes. The sealed reed relay provides for extremely reliable operation without maintenance and requires very-little space. The circuit design facilitates the exclusion of the signal receiver when a nonsignaling channel unit is required.

As already mentioned, the pregroup filters are relatively simple and serve only to select well-defined sidebands. On the other hand, the requirements of the channel filters, audio-frequency filters, and signal filters have been evaluated very carefully and apportioned in the optimum manner.

Figure 6 shows a typical attenuation/frequency characteristic for the channel modulation stage.

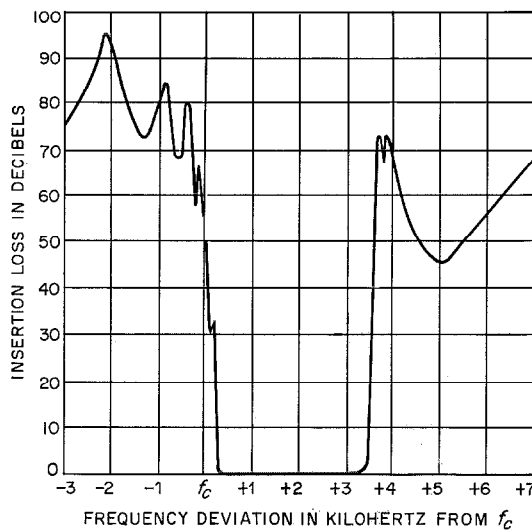


Figure 6—Typical discrimination characteristic of double-modulation channel translating equipment.

### 2.1.2 Single Modulation

Single-modulation design translates 12 channels

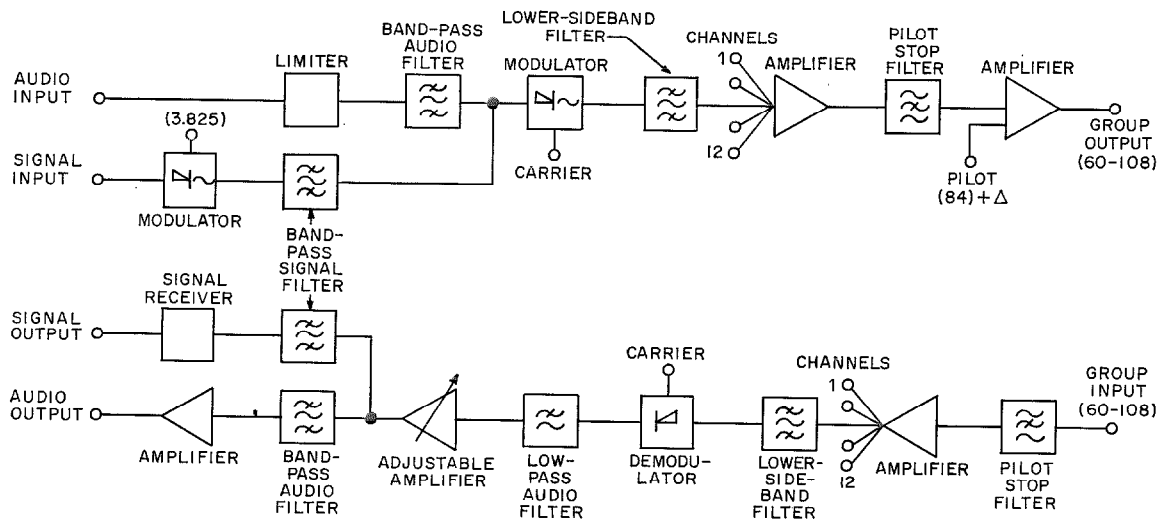


Figure 7—Channel translating equipment using single modulation.

directly into the 60-to-108-kilohertz range. The carrier frequencies used are spaced at 4-kilohertz intervals between 64 and 108 kilohertz. The channel filters employ quartz-crystal resonating elements to give the relatively sharp cutoff characteristics required.

A functional diagram is shown in Figure 7. The input attenuators are followed by a transistor volume limiter, combined low-pass and high-pass filter, and signaling-frequency injection, in a similar way to that described earlier. The modulator uses a symmetrical transistor that affords excellent switching characteristics and a high degree of carrier suppression with very-low carrier power. The channel band-pass filter selects the lower sideband; quartz crystals, ferrite cores, and ceramic capacitors are combined to give a filter of small size, very-sharp cut-off characteristics, and stable performance. The 12 channels are combined via a resistor network and low-input-impedance amplifier circuit, which afford good electrical separation. A second amplifier provides a range of output levels.

The receive direction employs the reverse process with equipment similar to that already described. A wide range of input levels is acceptable.

As with the double-modulation equipment, the

requirements of the various filters have been evaluated together. The channel crystal filter is a double-lattice design that highly suppresses upper-sideband frequencies and has an excellent pass-band characteristic with good stability. Its characteristic is asymmetrical, the lower-frequency side being aided by the audio low-pass filter. Figure 8 shows a typical characteristic for the combined filters.

The version without signaling is similar in many respects. The audio filters are somewhat

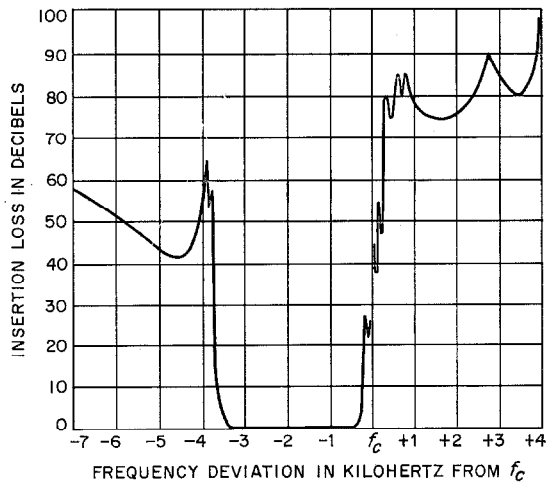


Figure 8—Typical discrimination characteristic of single-modulation channel translating equipment with out-band signaling.

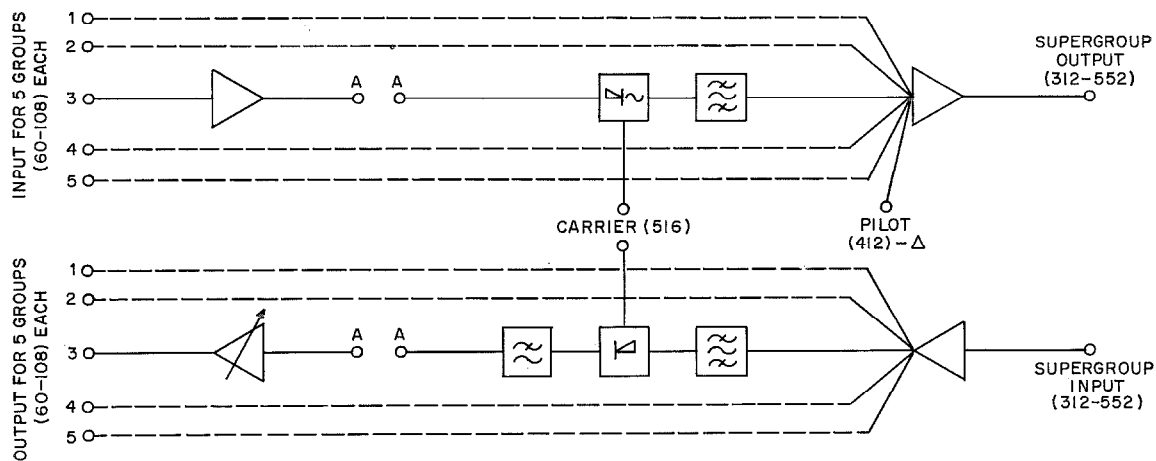


Figure 9—Translation between 5 groups and 1 supergroup.

## Carrier Multiplex Equipments: Design and Circuits

simplified, and the cutoff frequency of the crystal channel filter has been increased slightly to give even-better low-frequency performance and to meet the special requirements of the British Post Office.

### 2.2 GROUP TRANSLATING EQUIPMENT

A functional diagram of the translation between group and supergroup is shown in Figure 9. The equipment is designed to work with a range of input and output levels and impedances

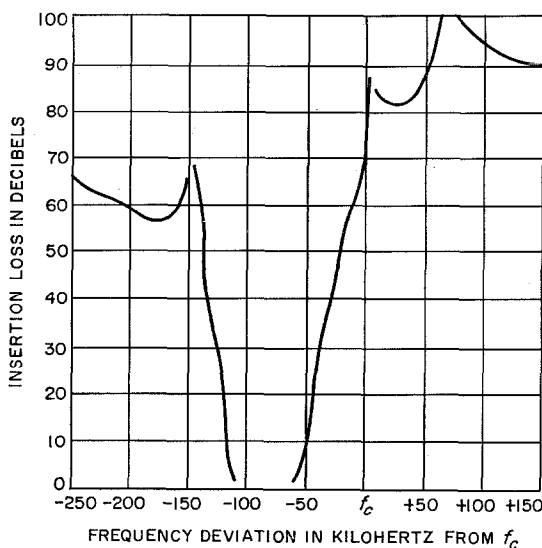


Figure 10—Typical discrimination characteristic of group translating band-pass filter.

for compatibility with the requirements of various administrations, and allowance is made for the attenuation of station cabling.

In the transmit direction, a single-stage input amplifier provides a matching impedance, gives level flexibility, and reduces the carrier leak fed back to preceding equipment. The ring modulator is designed for efficient carrier switching and uses germanium diodes; the intermodulation margins and the stability with changes in applied carrier supply level are of a high order. The band-pass filters, which select the appropriate lower sidebands, are of the insertion-loss type and were designed by computer using a synthesis technique. The use of high-permeability ferrite cores and silvered-mica capacitors has led to a filter of excellent performance and small size; typical stop-band and pass-band characteristics are shown in Figure 10. The transmit supergroup amplifier is a 2-stage common-emitter design and includes an input hybrid coil for combining odd and even groups of filters.

The receive-path circuits in Figure 9 are similar. The receive group amplifier has 4 stages using both common-base and common-emitter circuits; the feedback path includes manual gain control and will accept a thermistor to provide optional automatic gain regulation under the control of a separate group reference pilot receiver with-

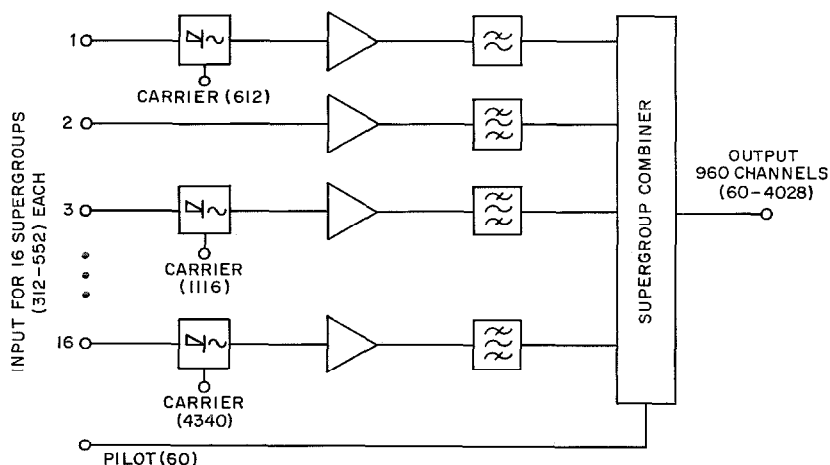


Figure 11—Combining of 16 supergroups to give a 960-channel band (send side).

out needing additional equipment in the through path.

Narrow-band-stop filters are provided as optional items in the transmit and receive paths of group 3 to suppress the supergroup reference pilot frequency. Such filters at this point permit interconnection of any groups without interference between the pilots of adjacent links. They also ease the requirements of individual channel translating filters in preventing interference between the pilot and the speech and signaling frequencies.

### 2.3 SUPERGROUP TRANSLATING EQUIPMENT

A functional diagram of the combination of 16 supergroups into a 960-channel band is shown in Figure 11. As with the group translating equipment, a range of input and output levels has been provided for in the design.

All supergroups except supergroup 2 are modulated and the lower sideband transmitted to line. The carrier frequencies are 612, 1116, 1364, and at 248-kilohertz intervals to 4340 kilohertz. Supergroup 2 is transmitted direct in the basic supergroup band from 312 to 552 kilohertz.

In the transmit direction, each basic supergroup goes to a ring-modulator circuit. The modulator is directly connected to an amplifier, which provides a resistive termination and thus gives minimum attenuation distortion and keeps signal levels well-above noise. A band-pass filter (low-pass for supergroup 1) that follows the amplifier selects the lower sideband of modulation. The filters are combined as odd-numbered and even-numbered supergroups separately to minimize mutual interference. Additional amplification may be provided if necessary.

The receive direction functions similarly. An amplifier between band-pass filter and demodulator provides a good match to the demodulator and reduces noise. The receive supergroup amplifier includes an adjustable gain control.

Facilities are provided to inject 308 kilohertz into the supergroup modulators to provide ad-

ditional frequencies for line measurements, also to inject a line-continuity pilot as well, if necessary. In the receive direction a 60-kilohertz frequency comparison pilot may be picked off, and the receive supergroup amplifier provides pick-off of the 411.92-kilohertz supergroup reference pilot. Separate automatic gain control using this frequency may be provided by additional equipment.

### 2.4 THROUGH-GROUP FILTER

The through-group filter comprises an input impedance-matching transformer, band-pass filter, equalizer, and output transformer. The band-pass filter is an insertion-loss design and has a ladder configuration. Most sections of the filter use coils and capacitors, but crystals are used at the critical edges in view of the very-steep-cutoff attenuation requirements. The pass-band attenuation of the filter is low enough to permit through-group connection in most cases without additional amplification.

A typical discrimination characteristic is shown in Figure 12.

### 2.5 THROUGH-SUPERGROUP FILTER

The permissible attenuation for through connection of supergroups in a large number of territories is nominally 0.5 neper (from  $-3.5$  to  $-4.0$  nepers) or 5 decibels (from  $-30$  to  $-35$  decibels). It is possible to design a filter to have a pass-band loss low enough not to

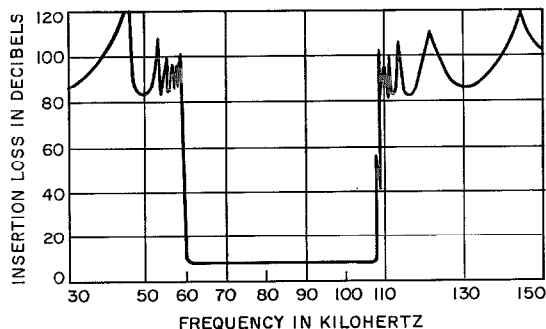


Figure 12—Typical discrimination characteristic of through-group filter.

exceed this value, but very-high- $Q$  components are required and impedance-masking attenuation cannot be included; moreover many customers demand a maximum loss of only 1 or 2 decibels in the filter to allow for station cabling losses. It was decided to incorporate a low-gain amplifier into the filter and to design for high discrimination (including pilot suppression) and good stability.

Adjustable input attenuators are followed by the coil-and-capacitor filter sections and a quartz-crystal section for suppression at 556 kilohertz. Two constant-impedance equalizer sections are used, one for each edge of the pass band. The single-stage amplifier has a gain of 10 decibels. A typical discrimination characteristic is shown in Figure 13.

### 2.6 CARRIER GENERATION EQUIPMENT

Just as standard translating equipments can be added to an installation to increase circuit capacity, so has the carrier generation equipment been designed with standard units that are suitable for systems with low and high circuit capacities, permitting later expansion on site. Compatibility with existing carrier generation equipments was considered important; to achieve this to a considerable extent, channel, group, and supergroup generation are based on

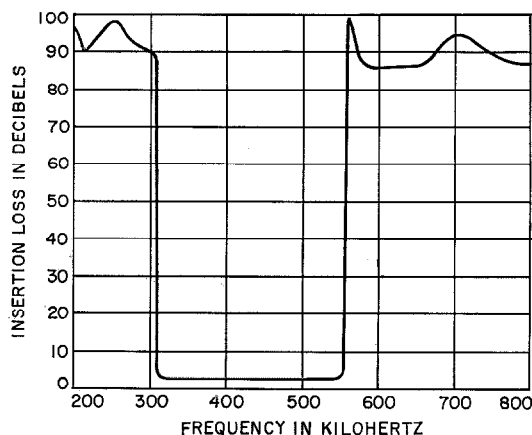


Figure 13—Typical discrimination characteristic of through-supergroup filter.

fundamental frequencies of 4, 12, and 124 kilohertz (the first two being derived from 124 kilohertz) as in many previous arrangements. Also, compatibility with existing translating equipments is achieved so far as practicable by due attention to the purity requirements of the carrier supply. However, the new generation equipment includes features such as digital dividers, transistor pulse-shaping circuits, and circuit techniques that lead to reduced filter discrimination requirements.

#### 2.6.1 Master Oscillator

Although the carrier generation equipment features the use of standard units suitable for systems with low and high capacity, the master oscillator itself has been designed in three alternative forms for systems of different capacity.

(A) Systems having from 16 to 45 supergroups (12 megahertz) use a 2480-kilohertz oscillator employing an *AT*-cut crystal vibrating on its fifth mechanical overtone with a proportional-control oven. This new fifth-overtone technique gives extremely low drift rates without unduly prolonged pre-aging; the chosen frequency of 2480 kilohertz has proved suitable for this type of crystal and is a multiple of 124 kilohertz. The proportional-control system used for the oven employs thermistor temperature sensing. Alarm circuits are provided to detect abnormal temperatures. The oscillator has a stability of a few parts in  $10^8$  per month. A separate divider circuit of the regenerative modulator type, carefully designed to avoid the possibility of non-starting or free-running, converts 2480 kilohertz to 124 kilohertz via 3 divisions of 2, 5, and 2.

(B) Systems having up to 16 supergroups (4 megahertz) use a 124-kilohertz oscillator employing a vacuum-flask oven with a sensitive mercury-contact thermometer. The contact actuates the oven heater via a transistor, achieving a very-stable crystal temperature under normal conditions. Alarm contacts are provided also. The oscillatory circuit is a 2-stage linear amplifier with a Meacham bridge feedback cir-

cuit, in which the frequency of oscillation is determined by the series resonance of the arm containing the crystal and the amplitude of oscillation is controlled by a resistance lamp. The oscillator has a stability of 1 part in  $10^7$  per month.

(C) Systems having up to a few supergroups use a 124-kilohertz oscillator employing a relatively simple vacuum-flask oven with a thermistor-controlled heater-switching circuit.

### 2.6.2 Generation of Basic Frequencies

The frequency of 124 kilohertz, common to all master-oscillator alternatives, is used to derive 4 and 12 kilohertz for carrier generation, plus 60 and 300 kilohertz for frequency-comparison pilots and 308 kilohertz for inter-supergroup pilots.

The first stage is a 124-to-4-kilohertz binary divider. The 124-kilohertz input is converted to square waves and applied through gates to a 5-stage counter; the gates are switched by the last binary stage so that the normal count of 32 is converted to a count of 31. The 4-kilohertz

square wave is filtered and amplified for distribution. Another filter selects the 12-kilohertz component, which also is amplified for distribution.

The pilots are produced by selecting harmonics of square waves or by simple modulation. The 3 frequencies of 60, 300, and 308 kilohertz are amplified for distribution.

### 2.6.3 Channel Carrier Generation

#### 2.6.3.1 Double Modulation

Carrier generation for double-modulation channel equipment is required to provide channel frequencies of 12, 16, and 20 kilohertz, plus pre-group frequencies of 84, 96, 108, and 120 kilohertz. A functional diagram is shown in Figure 14.

The channel carriers are harmonics of 4 kilohertz, the basic frequency. This is amplified, then volume limited so that output levels are largely independent of input level variations, and passed to a toroidal coil using a nickel-iron

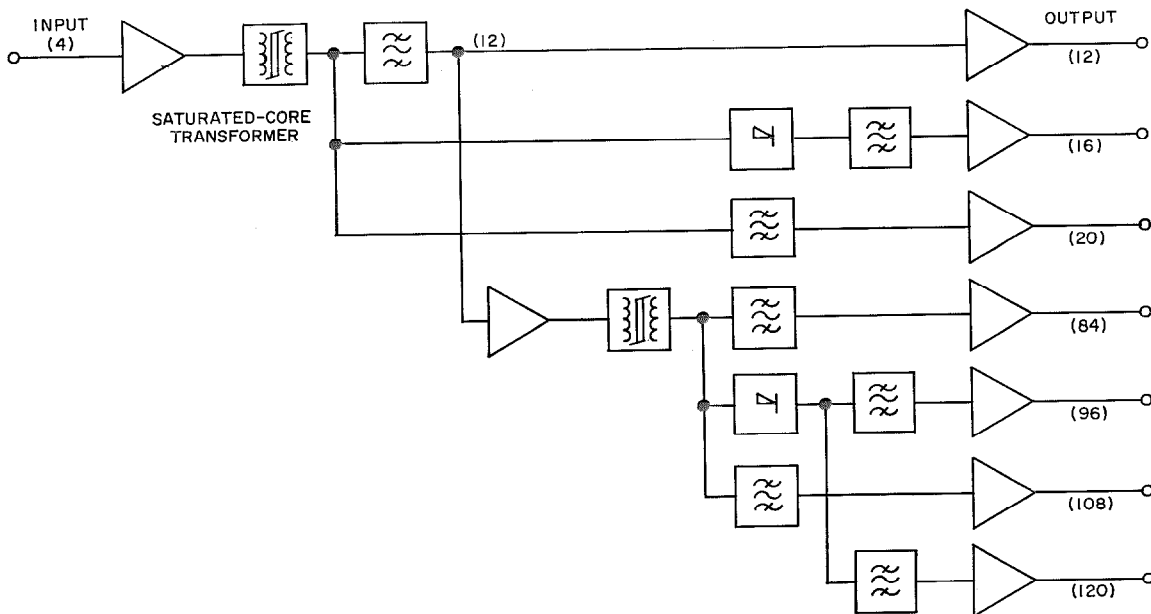


Figure 14—Carrier generation for double-modulation channel translating equipment.

tape core. This core is saturated, giving very-short symmetrical positive and negative pulses that contain all odd harmonics of 4 kilohertz. The core has an almost-ideal rectangular hysteresis loop and is an improvement over earlier saturated-core generators with respect to the small size and relatively low input power required.

Theoretically, symmetrical pulse trains contain odd harmonics but no even harmonics. In this case the pulses are sufficiently symmetrical to give a high degree of suppression of even harmonics of 4 kilohertz, thus easing the requirements of the succeeding filters. Frequencies of 12 and 20 kilohertz are directly filtered, and 16 kilohertz is obtained after rectification of the pulses. Alternative designs of amplifiers provide for the output power requirements of different sizes of installations.

The pregroup carriers are harmonics of 12 kilohertz, which is available as one of the channel carriers. Similar saturated-core and rectifier techniques are used to permit these frequencies to be filtered and amplified as required.

2.6.3.2 Single Modulation

The required frequencies occur at 4-kilohertz intervals from 64 to 108 kilohertz. A functional diagram is shown in Figure 15.

One of the main aims was to reduce the discrimination requirements of the 12 output filters, which in earlier designs had to use quartz crystals. This aim has been achieved by using a transistor pulse-shaping circuit with a base frequency of 8 instead of 4 kilohertz, so that the filters must suppress frequencies 8 kilohertz on either side instead of 4.

The input frequency of 4 kilohertz is doubled, filtered, amplified, squared, and applied to a damped resonant circuit; the resultant half sine wave is then shaped and amplified to give a 5-microsecond rectangular asymmetrical pulse at an 8-kilohertz repetition rate. This pulse width has been chosen so that all the required harmonics have approximately the same amplitude. Those carrier frequencies that are multiples of 8 kilohertz are obtained by direct filtering. The remainder, which are odd multiples of 4 kilohertz, are produced by modulating the rectangular pulse with a carrier of 124 kilohertz, the modulator input frequencies being restricted to 56 kilohertz and below by a low-pass filter. The lower sideband is selected and amplified, and the required carrier frequencies are obtained by direct filtering.

Alternative distribution amplifiers have been designed to suit the output power requirements of small and large stations, and may be equipped

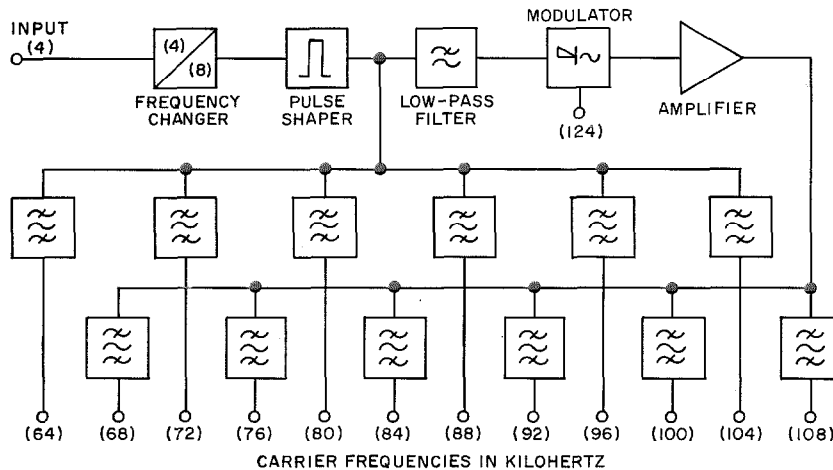


Figure 15—Carrier generation for single-modulation channel translating equipment.

as required. For application to self-contained very-low-capacity systems (for example, 12-to-60-channel systems), no amplifiers are required.

A 120-kilohertz group carrier supply for 12-to-60-channel systems may be filtered directly from the 8-kilohertz rectangular pulse as a harmonic and suitably amplified.

### 2.6.4 Group Carrier Generation

The required frequencies are 420, 468, 516, 564, and 612 kilohertz. A functional diagram is shown in Figure 16. The aim in this case also was to reduce the filter requirements. The base frequency of 12 kilohertz is distorted in a full-wave rectifier and the 48-kilohertz harmonic is selected by a band-pass filter. A transistor pulse generator then produces 5-microsecond rectangular pulses at the 48-kilohertz repetition rate. A low-pass filter provides one output containing 48 and 96 kilohertz, while a band-pass filter provides 144 kilohertz. A ring modulator supplied with a carrier of 124 kilohertz and an input of 144 kilohertz produces a  $3f_e + f_m$  output of 516 kilohertz, which is selected

by a band-pass filter and amplified. The amplifier output is split to give the required carrier frequency output of 516 kilohertz and also to supply another ring modulator, which mixes it with the 48- and 96-kilohertz frequencies. The upper and lower sidebands from this modulator are the required carrier frequency outputs of 420, 468, 564, and 612 kilohertz, which are selected by band-pass filters.

Alternative distribution amplifiers have been designed to suit the output requirements of small and large stations.

### 2.6.5 Supergroup Carrier Generation

The required frequencies are 612, 1116, 1364, and at 248-kilohertz intervals to 4340 kilohertz. The 612-kilohertz carrier is identical to group 5 carrier and is obtained from the group equipment and amplified separately as shown in Figure 16.

Excepting 612 kilohertz, all the required frequencies are odd harmonics of 124 kilohertz. The aim, therefore, was to produce symmetrical pulses at a 124-kilohertz repetition rate.

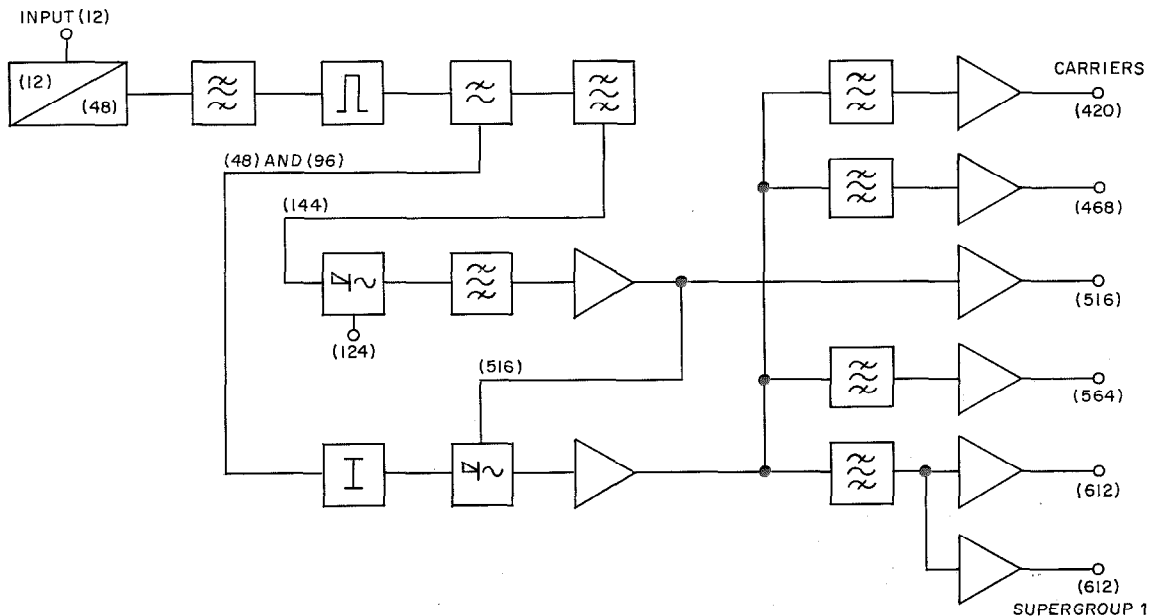


Figure 16—Generation of group carrier and first supergroup carrier.



The pulse generator uses a pulse-shaping circuit similar to that described in Section 2.6.3.2, to produce asymmetrical rectangular pulses at 248 kilohertz. To convert these into highly symmetrical pulses at 124 kilohertz, the pulse train is "modulated" with a carrier frequency of 124 kilohertz via a pair of transistors, which switch alternate pulses to positive and negative positions. At the same time the pulses are amplified to a suitable output power.

The required frequencies are selected by a set of band-pass filters. These are of a coil-and-capacitor design at the lower frequencies and include quartz crystals at the higher frequencies. Each filter is followed by an amplifier that provides sufficient output power for a number of supergroup translating equipments.

### 2.6.6 Group and Supergroup Reference Pilot Generation

The Comité Consultatif International Télégraphique et Téléphonique recommended group pilot frequencies and their tolerances are 84.08 kilohertz  $\pm 1$  hertz and 84.14 kilohertz  $\pm 3$  hertz; the supergroup equivalents are 411.92 kilohertz  $\pm 1$  hertz and 411.86 kilohertz  $\pm 3$  hertz. A *DT*-cut crystal without an oven meets the group reference pilot requirements. This crystal has a relatively shallow frequency-temperature characteristic such that, with a simple temperature-compensating circuit comprising a thermistor-shunted capacitor, no crystal oven is required. The output is level-stabilized.

The supergroup reference pilots are derived by modulating the group reference pilot with a carrier frequency of 496 kilohertz derived from 124 kilohertz.

### 2.6.7 Automatic Changeover

The requirements of different customers for standby carrier supply equipment and automatic changeover vary considerably, consequently the design aim was for monitoring and switching circuits of wide application. The emphasis was

placed on very-high reliability, especially of the actual switching element, and on high-speed operation. The latter requirement was taken into account in the design of certain filters in the carrier generation paths also.

Sealed mercury-wetted reed relays with permanent-magnet latching provide reliable high-speed switching. Prolonged tests have confirmed their speed and reliability. Contact transit times are normally less than 1 millisecond, and the method of latching ensures that through connection is not affected by the failure of a winding or a power supply.

Monitor circuits rectify and amplify the appropriate carrier output, and transistor flip-flop switches are triggered if the carrier level changes by more than a predetermined amount. Besides the changeover relays, auxiliary relays and alarm lamps must also be controlled.

## 3. Electric Components

An important aspect of design was the selection of optimum electric components, taking into account reliability, size, cost, and availability. This selection was based on past experience and on special life tests, components being standardized for use in all equipments including both double-modulation and single-modulation channeling types.

For best use of space many components have been chosen to have uniform height and to be suitable for direct insertion into printed-wiring cards. This permits the space between adjacent cards to be used effectively without stacking components.

Both germanium and silicon transistors are used, the advantages of each type being exploited in different applications.

Apart from a few special cases, inductors use ferrite cores, most being pot cores with diameters ranging from 11 millimeters upward. Full advantage has been taken of coil adjustment by threaded slug to reduce the number of trimmer capacitors required and to facilitate testing.

Silvered-mica capacitors are used for applications requiring very-high stability, and polystyrene types are used if slightly lower stability is permissible; alternatively, ceramic capacitors of known negative temperature coefficient are used in conjunction with certain types of ferrite material. For medium capacitance values and for stability requirements of approximately 5 to 20 percent, miniature paper and synthetic plastic-dielectric types are used. For high values of capacitance, solid tantalum types are considered the most suitable. Care has been taken to use capacitors having highly reliable lead-out wire connections (for example, welded or soldered wires or some other special construction). Working voltages are always considerably below the rated voltages to ensure long life.

#### 4. Operating Conditions

A study of equipment rooms in many parts of the world shows that the temperature range is relatively limited as a rule, although in a few places greater extremes occur occasionally. The

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In 1954 he joined Standard Elektrik Lorenz

equipment has therefore been designed to provide full performance over the ambient temperature range from +10 to +40 degrees centigrade, with humidity up to 95 percent. The equipment is capable of operation, with slightly relaxed performance and with no permanent deterioration, over the temperature range from -20 to +55 degrees centigrade. The conditions that may be encountered during temporary storage have also been taken into account.

#### 5. Acknowledgments

This article primarily has reported the design work undertaken by the line transmission departments of Standard Telephones and Cables, Standard Elektrik Lorenz, Bell Telephone Manufacturing Company, and Nederlandsche Standard Electric Maatschappij. The authors acknowledge the information and assistance given by members of these departments, in particular by Dr. Rabe of Standard Elektrik Lorenz.

as a development engineer. In January 1963 he became chief engineer of carrier systems development.

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# Transistor Carrier Multiplex Equipments

## Part 2—Deep-Rack Construction (Mark 6 Multiplex)

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### 1. Introduction

A preceding article in this issue describes the broad electrical design and salient circuit fea-

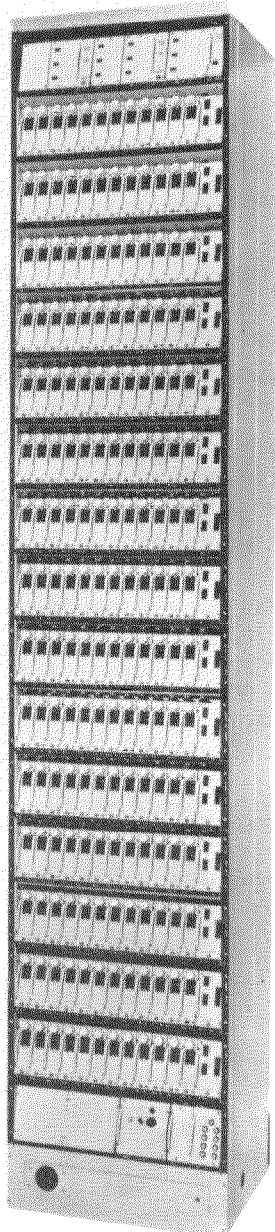


Figure 1—Typical equipped rack (channel translating equipment).

tures of a new range of multiplex equipments that have been produced in two different mechanical forms. The present article describes the equipments as engineered in the so-called deep-rack type of construction, an equipment practice known as the British Post Office 62-type construction. A following article describes the alternative mechanical design featuring the front-leadout construction. The technical data given apply over a temperature range from +10 to +40 degrees centigrade and humidity up to 95 percent, but satisfactory operation is obtained over a temperature range from -20 to +55 degrees centigrade.

### 2. Mechanical Construction

#### 2.1 GENERAL

In developing a new mechanical construction for transistor equipments, subracks (shelves) were adopted as the basic unit instead of full-size racks. It is realized that a full-size rack can mount a very-large amount of equipment, in many cases more than required by initial installations. The investment in station space, rack cabling, et cetera, involved in the use of partially equipped racks is by no means negligible. In some cases the racks would never be fully equipped, normally being designed only for one specific type of equipment. In the sub-rack construction adopted, the rack framework becomes a station fitment that can be used to house shelves of any type of equipment, in effect becoming an extension of the station floor.

The very-high degree of flexibility provided by this method is fully realized only if individual shelves can be readily cabled on site. Experience with an earlier construction using subracks, *STEP-5*, plus much experimental work, demonstrated the practical difficulties that arise from cabling to shelves mounted back-to-back on a single rack framework. Moreover the space actually available for components, after allowing for plugs, sockets, and cabling, became un-

economically small if the back-to-back equipment were to be within the depth of 450 millimeters (17.7 inches) recommended by the Comité Consultatif International Télégraphique et Téléphonique. *STEP-5* exceeded this depth. Consequently it was decided to use the full depth for every shelf, with installation consisting basically of sliding a shelf into the rack framework and running station cabling directly to tags at the back of the shelf.

In the majority of cases, components are mounted on separate plug-in printed-wiring cards. A few large units use chassis-type construction.

Figure 1 shows an equipped rack. The construction has been standardized by the British Post Office as 62-type.

### 2.2 CARD

Each plug-in card comprises a light steel frame mounting one or more boards of synthetic-resin-bonded paper or similar material. The boards have etched-copper printed wiring on one side and components on the other side. Normally one board mounts at least one complete electrical entity (for example, an amplifier circuit). Depending on the component space required, the board may be up to 318 by 127 millimeters (12.5 by 5 inches) in size. Two or more smaller boards may be mounted within the same card frame.

The card frame also mounts the connector plug and the front plate. The latter carries a handle, name of unit, test points, and controls. The frame and fittings are zinc plated and passivated, and the front plate is stove enamelled. The complete card becomes a neat, compact, and rigid unit. A typical card is illustrated in Figure 2.

### 2.3 CHASSIS

A few large units, such as power supplies, use the chassis construction. The chassis consists of

a pair of steel side frames, between which may be mounted bulky components or various types of component board. Some portions of the assembly may be hinged to provide access to all components. A front plate with two handles, plus one or two connector plugs at the rear, are standard fittings. Figure 3 illustrates a typical chassis unit.

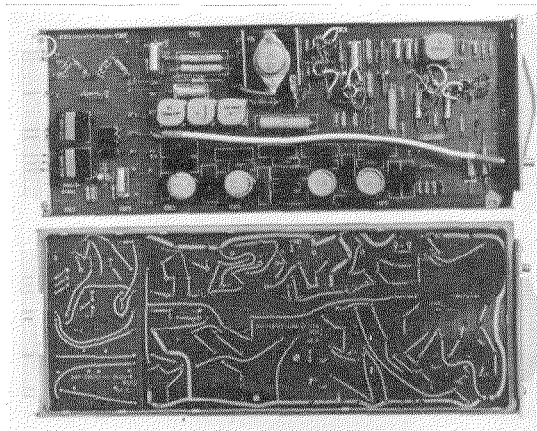


Figure 2—Typical card, showing component and printed-wiring sides.

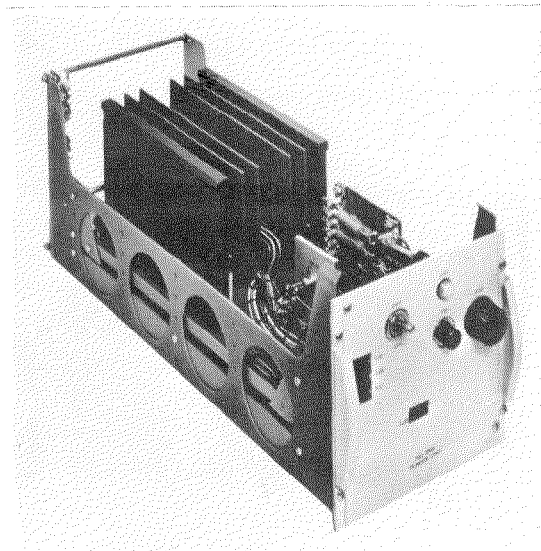


Figure 3—Typical chassis unit (power supply).

## Carrier Multiplex Equipments: Deep-Rack

### 2.4 SHELF

A shelf is a light strong prefabricated steel structure consisting of a corrugated base plate with formed front and rear frames. It is zinc plated and passivated. Card guides are fitted as required, being screwed or bolted to both front and rear frames. These guides may be located at intervals of 5.1 millimeters (0.2 inch), affording considerable flexibility in the spacing of cards or chassis. Connector sockets are mounted at the rear, using the card-guide fixing studs to assure accurate location. A retaining latch fitted to the front frame guards against accidental removal of a card. All wiring between the cards of any one shelf is carried out in the factory, being run as a cable along the back of the shelf or as point-to-point connections.

The dimensions of the standard shelf are approximately  $495 \times 395 \times 152$  millimeters ( $19.5 \times 15.5 \times 6$  inches). Figure 4 illustrates a shelf.

### 2.5 RACK FRAMEWORK

The rack framework is a steel assembly consisting of a base of box section, a top of welded angle and bar, and two side plates. Although it is designed to be shipped piecemeal and assembled on site, it is very rigid.

Shelf support rails are fitted to each side of

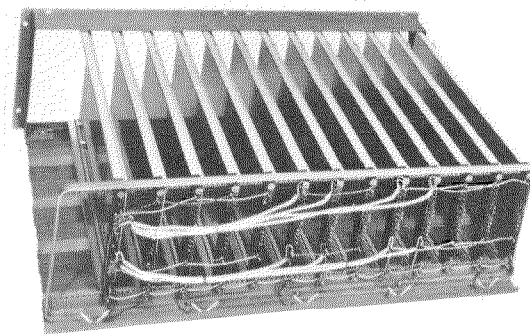


Figure 4—Rear view of unequipped shelf, showing card guides and socket strips.

the rack at normal spacing of 152 millimeters (6 inches), but rail locating points are provided at 51-millimeter (2-inch) intervals for special cases. The rails are inclined at an angle of 15 degrees to the horizontal, an arrangement that reduces the temperature within a shelf by encouraging air circulation from back to front; the card front plates do not normally occupy the full 152-millimeter height so that a small gap is left above them. The 15-degree angle also reduces the unusable space resulting from the bottom shelf being above floor level and provides some space above the top shelf to lead in cables from the station overhead racking. The rack is finished with stoved enamel applied over the phosphatized steel.

The rack dimensions are 511 millimeters (20.5 inches) wide by 450 millimeters (17.7 inches) deep, in accordance with recommendations of the Comité Consultatif International Télégraphique et Téléphonique. Several different heights are available; for example, a 2743-millimeter (9-foot) rack provides space for 17 standard shelves. Adequate space is left between the shelves and the back of the rack for station cabling, which extends the full width and height of the rack. Cable support rails and cable separating fingers are provided. Cabling to the shelf connector tags is simpler than cabling to the congested tag blocks that were all mounted at the top of earlier racks.

Figure 5 illustrates a rack framework.

### 2.6 CONNECTORS

One of the most-important aspects of a plug-in card type of construction is the connector. The contact pressures cannot be as high as those of conventional *U*-links in view of the large number of connectors (up to 40) for any one card, otherwise withdrawal and insertion are unduly difficult. Analog-type circuits call for highly stable and very-low contact resistance, whereas this stringent requirement is eased somewhat in the frequent applications of plug-in cards to computer and other digital-type cir-

cuits. Coaxial connectors demand extremely reliable outer connections to avoid crosstalk.

Our experience with earlier types of connectors, and the considerable research undertaken by the British Post Office, have contributed to a satisfactory design. Special attention is paid to the gold plating.

### 2.7 POWER DISTRIBUTION

Power supply units are shelf mounted. However, to simplify the distribution of alternating-current mains or station battery supplies to the power units, a power-distribution unit may be fitted to the station superstructure, immediately to the rear of the rack framework.

### 2.8 MAINTENANCE

It is not proposed to discuss equipment maintenance in detail. However, a few maintenance aids built into the design of the equipment construction are worthy of mention.

#### 2.8.1 Station Cabling

The ease of access to station cabling terminations facilitates inspection in case of suspected faults. Coaxial-type connectors can be removed from the socket moldings with a simple tool without unsoldering.

#### 2.8.2 Removal of Components

The following aids facilitate the location and removal of faulty components.

(A) Soldered straps to isolate circuit entities within a card, thus locating the part of the card that contains the fault.

(B) Special tools to permit multitagged components, for example coils, to be removed with an ordinary soldering iron.

(C) Composite card drawings showing components and "ghosted" wiring to facilitate location of component terminals.

#### 2.8.3 Test Points

Many test points may be fitted to the card front plate. This permits strategic points (normally main inputs and outputs) to be made accessible through *U*-links or to bridging sockets. The coaxial and noncoaxial sockets accommodate test plugs used with earlier 56-type equipments, thus reducing the number of special test cords required.

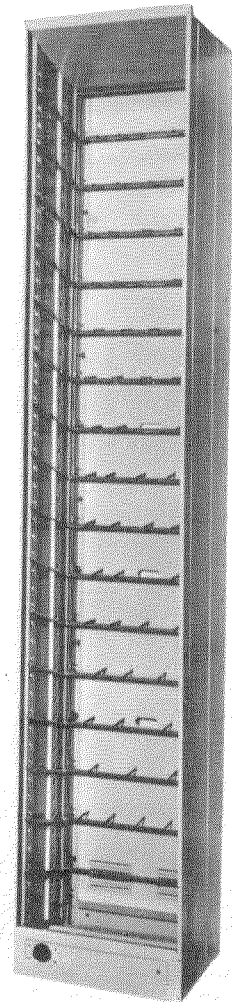


Figure 5—Unequipped rack framework, showing shelf support rails.

## Carrier Multiplex Equipments: Deep-Rack

### 2.8.4 Alarm Lamps and Keys

Alarm lamps and keys are normally fitted to the front plates of the appropriate cards, rather than to a special display unit, and thus facilitate the rapid location of faulty cards.

### 2.8.5 Card Outriggers

To check the performance of a card in detail while it is operating, card outriggers may be used. These extend all connections to a socket at the front of the equipment into which the card is plugged. The outriggers (coaxial and noncoaxial) are hinged to prevent damage if a card is accidentally struck. Figure 6 illustrates the use of an outrigger.

## 3. Channel Equipment

Only the single-modulation version of the channel equipment has so far been engineered in this construction. Both out-band signaling and nonsignaling forms are available. In both cases one complete group of 12 channels is contained within one standard 152-millimeter (6-inch) shelf.

### 3.1 CHANNEL EQUIPMENT WITH OUT-BAND SIGNALING

#### 3.1.1 Description

All the circuits for one channel, except the crystal channel filter, are mounted on one card, the cards for all 12 channels being identical. The channel filters are mounted together, 4 per card on a total of 6 cards. Combining circuits, group reference pilot injection, and narrow-band-stop filters are mounted on another card. Most components, except the crystal filters, are of a standard height. Thus by mounting the filter units separately from the other components, the packing density is improved. Figure 7 shows a channel card, and Figure 8 a complete shelf.

Various arrangements may be made to supply carrier, pilot, and signal frequencies, depending

on local conditions. Normally a single shelf includes carrier-frequency distribution units, a group reference pilot distribution unit, and duplicated 3825-hertz signal oscillators with automatic changeover and distribution. Bay trunk facilities are provided on this shelf.

#### 3.1.2 Controls and Test Facilities

Facilities are provided at the front of each card for all routine measurements and adjustments. Test points with miniature *U*-links provide access to the 4-wire audio input and output points, for both terminated and bridged measurements. Similar access is provided for the high-frequency (group distribution frame) input and output also. The test sockets have been designed to accept standard test plugs used in 56-type construction. Adjustable resistors are also provided to control gain of the audio receive amplifier, signal bias, and sensitivity.

Adjustments normally made only at the initial installation (for example, audio input and output levels, signal levels, and type of signal) may be made by soldered straps with the card removed from the shelf. In special circumstances, for example fault finding, outriggers may be used.

The sealed dry-reed signal relay requires no maintenance and thus does not have to be sited at the front of the card.

#### 3.1.3 Technical Data

##### (A) Audio Levels and Impedances

4-wire input	-17 to +14 decibels referred to the level at the 2-wire point of origin, 600 ohms balanced
4-wire output	-4 to +10 decibels referred to the level at the 2-wire point of origin, 600 ohms balanced. Adjustable in steps of 1 decibel with

continuous gain control of at least  $\pm 3$  decibels in receive direction

**(B) High-Frequency Levels and Impedances**  
 Transmit output —44 to —33 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

Receive input —10 to —5 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced.

Alternative impedance of 135 ohms or 150 ohms balanced, with receive level down to —31 decibels referred to the level at the 2-wire point of origin, can be provided.

**(C) Carrier Supply (Per Frequency)**  
 Level to each channel card (modulator plus demodulator) 0.775 volt root-mean-square into approximately 1500 ohms ( $\approx 0.4$  milliwatt)

Level to distribution shelf to supply up to 25 groups +11 decibels referred to 1 milliwatt into 140 ohms

**(D) Amplitude-Frequency Response \***  
 Looped equipment transmit-plus-receive +3.5, —0.9 decibels at 300–400 hertz and audio-frequency loss at 3000–3400 hertz; relative to 800 hertz, +1.75, —0.9 decibels at 400–600 hertz and at 2400–3000 hertz; not worse than— +0.9, —0.9 decibel at 600–2400 hertz

\* These figures correspond to  $\frac{2}{3}$  of the maximum variations permitted by the recommendations of the Comité Consultatif International Télégraphique et Téléphonique (Figure 7 of Red Book, volume 3).

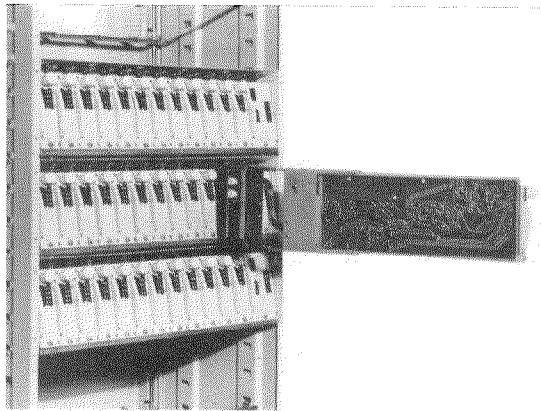


Figure 6—Outrigger in use.

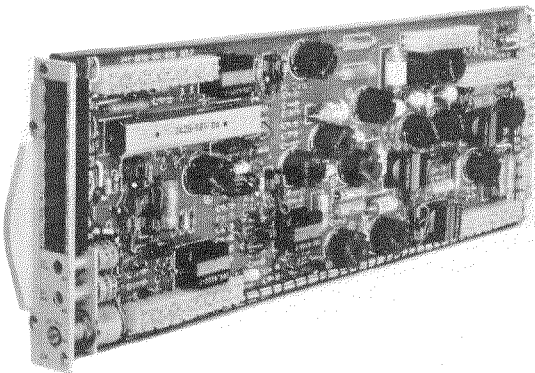


Figure 7—Channel translating card with out-band signaling.

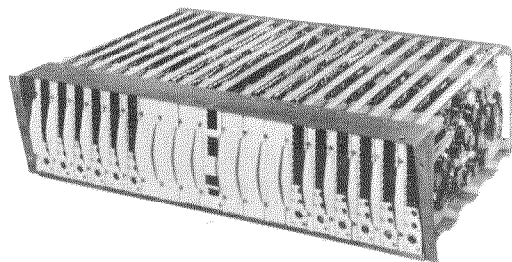


Figure 8—Fully equipped shelf for 12 channels of translating equipment with out-band signaling.



## Carrier Multiplex Equipments: Deep-Rack

Average response for a group of 12 channels, not worse than—

one-half of above figures

### (E) Linearity

Change in equivalent loss if input is changed from 0 to +4 decibels

$\geq 0.3$  decibel

Output level for input level of +20 decibels

$\geq +10$  decibels

### (F) Noise and Crosstalk

Basic noise in the absence of pilot or signal frequencies but including carrier leak

$\geq -74$  decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted (40 picowatts, psophometrically weighted)

Noise due to 84.08-kilohertz group reference pilot at a level of -20 decibels relative 1 milliwatt referred to a point of zero relative level

$\geq -75$  decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted (30 picowatts, psophometrically weighted)

Adjacent-channel interference margin with white-noise input

$\leq 63$  decibels (psophometrically weighted)

Adjacent-channel interference margin with

$\leq 63$  decibels (psophometrically weighted)

simulated typical speech input as defined by the Comité Consultatif International Télégraphique et Téléphonique (Figure 14 of Red Book, volume 3)

Channel-to-channel crosstalk ratio (looped equipment transmit-plus-receive)

$> 70$  decibels

Near-end crosstalk ratio on same channel (side-tone)

$> 60$  decibels

### (G) Carrier Leak

Carrier leak of each channel, transmit direction

$< -25$  decibels

### (H) Phase Distortion

Typical group delay

kilohertz-milliseconds

(looped equipment

0.3 - 5.5

transmit-plus-receive)

0.4 - 3.0

0.6 - 2.1

0.8 - 1.5

1.0 - 1.2

2.0 - 1.1

2.5 - 1.2

3.0 - 1.4

3.2 - 1.9

3.4 - 3.5

### (I) Signaling (3825 Hertz)

Alternative levels available

-4 to -8 and -18 to -20 decibels

Signaling distortion,

$\geq \pm 5$  milliseconds

for maximum pulse speeds equivalent to 30 milliseconds each for tone on and tone off, and for overall level variations of  $\pm 5$  decibels

(Typical figure in normal operation)

$\pm 3$  milliseconds

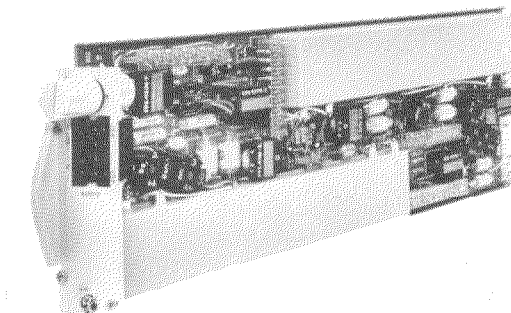


Figure 9—Channel translating card without signaling.

Ground to transmit optional strapping  
tone or ground to sup-  
press tone

Noise due to signaling  $\geq -70$  decibels rela-  
at low level on same tive 1 milliwatt re-  
channel or on adjacent ferred to a point of  
channel zero reference level,  
psophometrically  
weighted (100 pico-  
watts, psophometri-  
cally weighted)

**(J) Power Consumption**

Maximum under 500 milliamperes di-  
worst condition, per rect current at 20 volts  
shelf of 12 channels

**3.2 CHANNEL EQUIPMENT WITHOUT SIGNAL-  
ING**

**3.2.1 Description**

This equipment is similar in many respects to that described in Section 3.1.1. However, the card space vacated by the signaling circuits has been used to mount the crystal channel filter, which is therefore contained in a different size of can. This arrangement slightly reduced the effective volume, but no advantage was gained from containing between 12 and 24 channels in one shelf; hence the most-economical layout was adopted. In addition to the 12 channel cards, a 13th card mounts the combining circuit, pilot injection, and narrow-band-stop filters. Figure 9 shows a channel card and Figure 6 complete shelves.

Controls and test facilities are provided similar to those described in Section 3.1.2.

A carrier-frequency and pilot-frequency distribution shelf is available and is normally mounted on the same rack.

**3.2.2 Technical Data**

All data are the same as in Section 3.1.3, except for the following.

**(A) High-Frequency Levels and Impedances**

Transmit output -37 to -34 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

Receive input -10 to -6 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

Alternative impedances of 135 ohms or 150 ohms balanced, with receive level down to -31 decibels referred to the level at the 2-wire point of origin, can be provided

**(B) Amplitude-Frequency Response**

Looped equipment transmit-plus-receive audio-frequency response is within the figures given in Section 3.1.3. Additionally, the low-frequency response is improved and the loss relative to 800 hertz does not exceed—

- +4.0, -0.9 decibels at 250-300 hertz
- +1.0, -0.9 decibel at 300-2400 hertz
- +1.75, -0.9 decibels at 2400-3000 hertz
- +3.5, -0.9 decibels at 3000-3400 hertz

**(C) Phase Distortion**

Typical group delay	kilohertz-milliseconds
(looped equipment	0.3 - 2.6
transmit-plus-receive)	0.4 - 2.1
	0.6 - 1.7
	0.8 - 1.5
	1.0 - 1.3
	2.0 - 1.1
	2.5 - 1.2
	3.0 - 1.5
	3.2 - 2.0
	3.4 - 3.3

**(D) Power Consumption**

Per shelf of 12 channels 135 milliamperes direct current at 20 volts

#### 4. Group Translating Equipment

##### 4.1 DESCRIPTION

One complete basic supergroup of group translating equipment (5 groups) is contained within one standard 152-millimeter (6-inch) shelf. The modulator, demodulator, and associated filters for one group are mounted on one card. The group-frequency transmit and receive amplifiers for one group are mounted on one card; identical cards are used for all sizes of groups, hence a single spare amplifier card may be used as a replacement for any group.

The basic-supergroup amplifiers, combining circuit, supergroup reference pilot injection, and narrow-band-stop filters are mounted on a pair of cards. Figure 10 shows a complete shelf of group translating equipment. A functional diagram is shown in Figure 11.

##### 4.2 CONTROLS AND TEST FACILITIES

Facilities are provided at the fronts of cards for all routine measurements and adjustments. Test points with *U*-links provide access at group input and output, and at basic-supergroup input and output, the latter two being coaxial. In addition, test points are provided for in-traffic measurement of the group reference pilot at the receive output and of test tones at the transmit output, using hybrid coils to prevent interference with traffic. An adjustable resistor provides continuous control of the gain of the group receive output level.

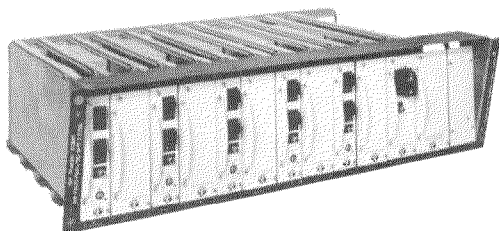


Figure 10—Fully equipped shelf for 5 groups of translating equipment.

##### 4.3 TECHNICAL DATA

###### (A) Basic-Group Levels and Impedances

Transmit input —42 to —27 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

Receive output —11 to —5 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

###### (B) Basic-Supergroup Levels and Impedances

Transmit output —47 to —33 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

Receive input —33 to —20 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

###### (C) Carrier Supply (Per Frequency)

Level to each group modulator or demodulator +10 decibels referred to 1 milliwatt into 75 ohms

Level to distribution unit to supply up to 16 modulators and demodulators +26 decibels referred to 1 milliwatt into 75 ohms

###### (D) Amplitude-Frequency Response

Each direction of transmission separately 0.5-decibel maximum spread per group, with 0.25-decibel maximum spread per 4-kilohertz channel band

###### (E) Noise for Looped Equipment

Basic noise <—74 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted (40 picowatts, psophometrically weighted)

Total noise when fully loaded with white noise at equivalent channel level as specified by the Comité Consultatif International Télégraphique et Téléphonique

< -72 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted (60 picowatts, psophometrically weighted)

(F) Crosstalk

Any single path, between groups, between transmit and receive directions, or between channels within a group, crosstalk ratio not worse than—

80 decibels

(G) Upper-Sideband Interference

Margin

< 75 decibels

(H) Carrier Leak

Per group

> -25 decibels

(I) Modulator Compression Ratio

For carrier levels within ±2 decibels of nominal

< 10:1

(J) Power Consumption

Per shelf of 5 groups 250 milliamperes direct current at 20 volts

5. Supergroup Translating Equipment

5.1 DESCRIPTION

The supergroup translating equipment has been designed with the need in mind for flexibility in the number of supergroups installed and for adding to existing installations. A total of 7 shelves are required for a complete 16-supergroup installation. The topmost of these shelves mounts combining circuits and line-frequency amplifiers for all supergroups. Cards for unneeded supergroups may be omitted. The second-highest shelf mounts modems and amplifiers for supergroup 1, plus filters and amplifiers for supergroup 2. The remaining shelves mount modems and amplifiers for supergroups 3 through 16, and are so arranged that any one shelf can accommodate any three supergroups. Each supergroup occupies 4 cards, a transmit filter card, a receive filter card, a modulator

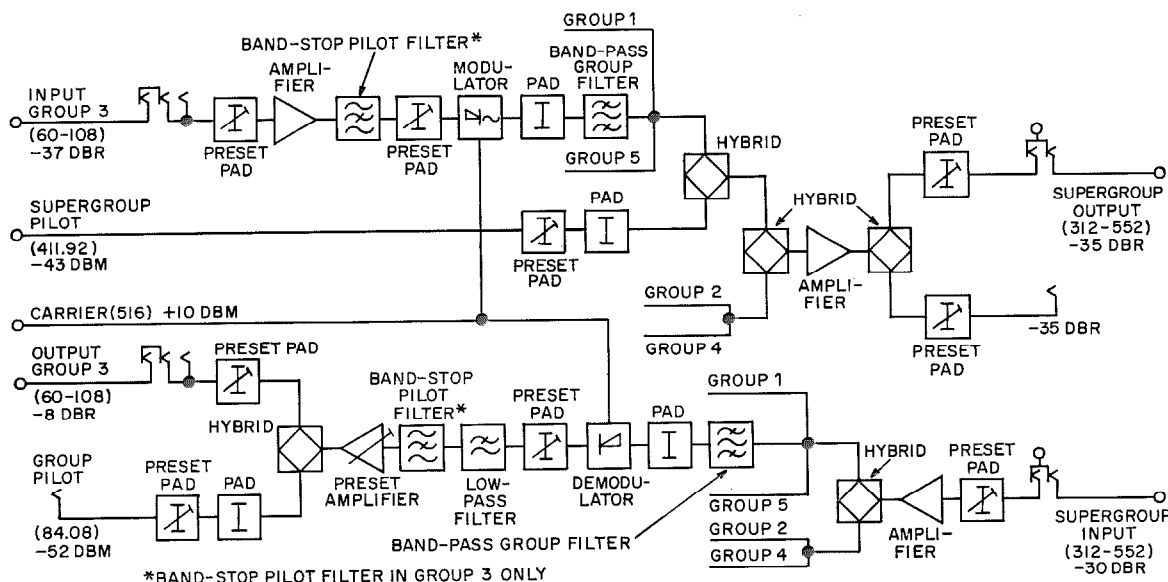


Figure 11—Translation of 5 groups into one supergroup. Frequencies in kilohertz are shown in parentheses. Input, output, pilot, and carrier circuits are of 75 ohms impedance. DBM = decibels referred to 1 milliwatt and DBR = decibels referred to the level at the 2-wire point of origin.

## Carrier Multiplex Equipments: Deep-Rack

and amplifier card, and a demodulator and amplifier card. The latter two cards are interchangeable for all supergroups above super-

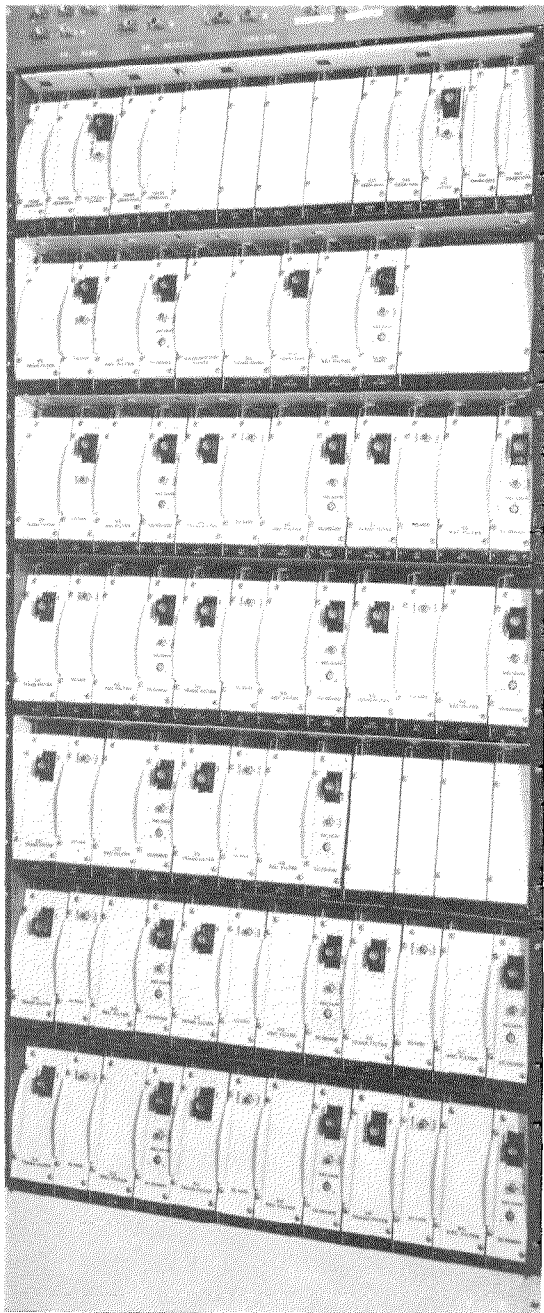


Figure 12—Supergroup translating equipment; equipped shelves for supergroups 1 through 16.

group 3. Figure 12 shows a set of equipped shelves. Figures 13 and 14 are functional diagrams of the transmit and receive sides, respectively.

The slope attenuation of long runs of station cabling can become important at the line frequencies of 60 to 4028 kilohertz. Station cabling equalizer units are available.

### 5.2 CONTROLS AND TEST FACILITIES

Coaxial *U*-links are provided at basic-supergroup input and output. In addition, special hybrid-coil test points are provided at the receive output and at the transmit output. An adjustable resistor provides continuous control of the supergroup receive output level.

### 5.3 TECHNICAL DATA

#### (A) Basic-Supergroup Levels and Impedances

Transmit input	−37 to −35 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced
Receive output	−30 to −28 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

#### (B) Line-Frequency Levels and Impedances

Transmit output	−50 to −40 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced
Receive input	−28 to −15 decibels referred to the level at the 2-wire point of origin, 75 ohms unbalanced

#### (C) Carrier Supply (Per Frequency)

Level to each supergroup (modulator plus demodulator)

+13 decibels referred to 1 milliwatt, 75 ohms unbalanced

(D) Amplitude-Frequency Response

Each direction of transmission separately

0.8-decibel maximum spread per supergroup, with 0.25-decibel maximum spread per 4-kilohertz channel band for most channels

(E) Noise for Looped Equipment

Total noise when fully

< -70 decibels rela-

loaded with white noise at equivalent channel level as specified by the Comité Consultatif International Télégraphique et Téléphonique

(F) Crosstalk

Any single path, between supergroups, between transmit and receive directions, or between channels

tive 1 milliwatt referred to a point of zero relative level, psophometrically weighted (100 picowatts, psophometrically weighted)

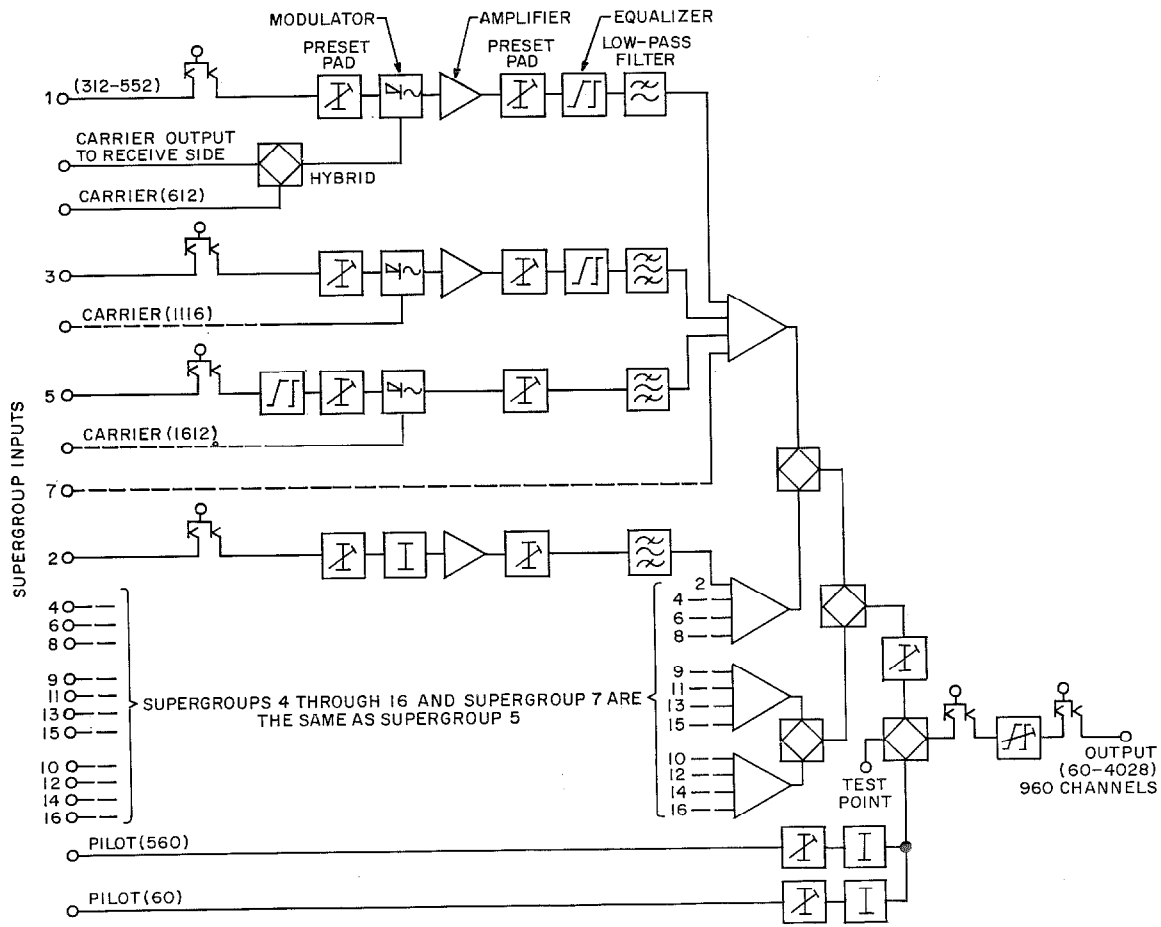


Figure 13—Supergroup translation on transmit side. Frequencies in kilohertz are in parentheses. Input, output, pilot, and carrier circuits are of 75 ohms impedance.

## Carrier Multiplex Equipments: Deep-Rack

within a supergroup, 80 decibels  
crosstalk ratio not  
worse than—

(G) Upper-Sideband Interference  
Margin  $\leq 80$  decibels

(H) Carrier Leak  
Per supergroup  $\geq -30$  decibels

(I) Modulator Compression Ratio  
for carrier levels  $\leq 10:1$   
within  $\pm 2$  decibels of  
nominal

(J) Power Consumption

Per set of shelves for 16 supergroups 1.5 amperes direct current at 20 volts

### 6. Through-Group Filter

#### 6.1 DESCRIPTION

The through-group filter has been designed as a separate self-contained unit. It may be added to any installation in which through-routing of complete 60-to-108-kilohertz basic groups is

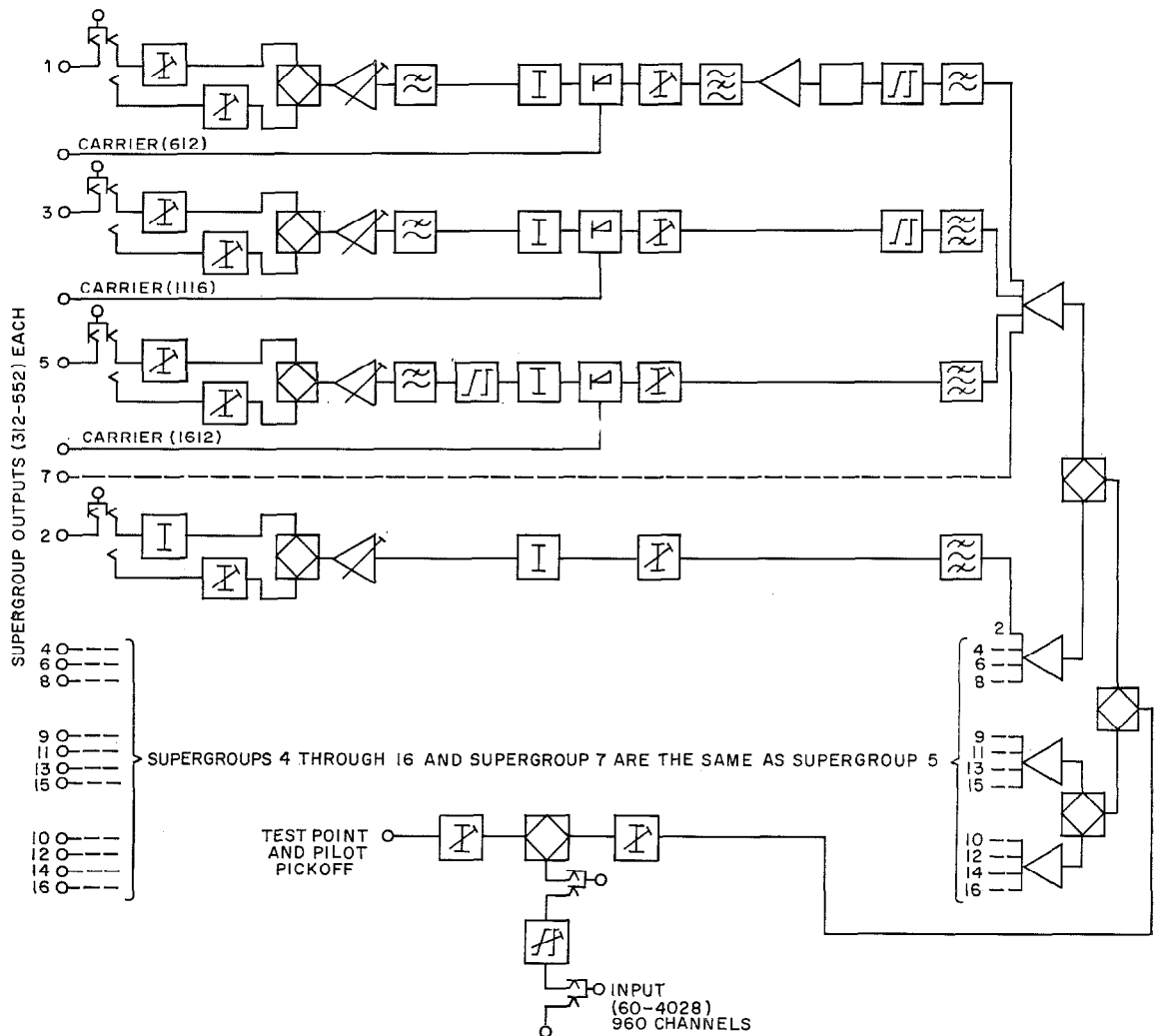


Figure 14—Supergroup translation on receive side. Frequencies in kilohertz are in parentheses. Circuits are of 75 ohms impedance.

required. It uses the chassis type of construction, up to 3 separate chassis being contained within one standard 152-millimeter (6-inch) shelf.

Input and output test points are provided on the front plate.

6.2 TECHNICAL DATA

- (A) Insertion Loss  
At 84 kilohertz, range 6 to 30 decibels of adjustment
- (B) Impedance  
Input and output 75 ohms unbalanced
- (C) Amplitude-Frequency Response  
Spread over basic-group band from 60.6 to 107.7 kilohertz  $\geq 0.8$  decibel  
Spread over any 4-kilohertz channel band  $\geq 0.25$  decibel, except edge channels  $\geq 0.5$  decibel  
Attenuation at 60.175 kilohertz relative to that at 63.2 kilohertz 1.5 decibels, maximum
- (D) Suppression of Crosstalk  
Group-to-group crosstalk  $\leq 70$  decibels  
Within carrier music channel bands of 36 to 48 and 132 to 144 kilohertz  $\leq 80$  decibels  
Signal frequency of 108.175 kilohertz  $\leq 35$  decibels

7. Through-Supergroup Filter

7.1 GENERAL DESCRIPTION

The through-supergroup filter uses chassis construction. It comprises 4 sealed units containing the coil-and-capacitor sections and one unit containing the pilot-stop crystal sections. The 5 sealed units are of identical size. Four are mounted as pairs on two cards with the fifth unit sharing a card containing equalizer cir-

cuits and the single-stage amplifier. A photograph of a complete chassis is shown in Figure 15. Two such chassis are normally located on one shelf.

Input and output coaxial test points are provided on the front plate.

7.2 TECHNICAL DATA

- (A) Insertion Loss  
At 412 kilohertz, range 0 to 10 decibels of adjustment
- (B) Impedance  
Input and output 75 ohms unbalanced
- (C) Amplitude-Frequency Response  
Spread over basic-supergroup band from 312 to 552 kilohertz  $\geq 1.0$  decibel  
Spread over any 4-kilohertz channel band  $\geq 0.25$  decibel, except edge channels  $\geq 0.5$  decibel
- (D) Suppression of Crosstalk  
Supergroup-to-supergroup crosstalk  $\leq 70$  decibels  
Within carrier music channel bands of 268 to 288 and 572 to 590 kilohertz  $\leq 80$  decibels  
Pilot frequencies of 308 and 556 kilohertz :  
for bandwidth of

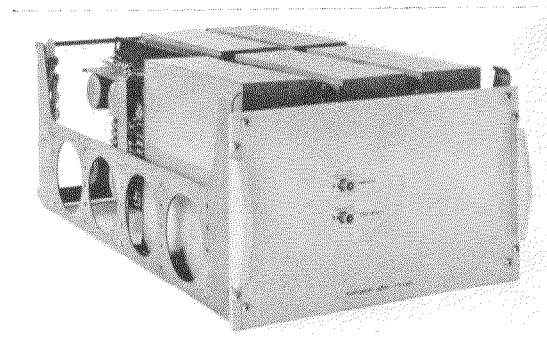


Figure 15—Through-supergroup filter.



## Carrier Multiplex Equipments: Deep-Rack

$\pm 8$  hertz  
for bandwidth of  
 $\pm 40$  hertz

$\leq 40$  decibels  
 $\leq 20$  decibels

### (F) Power Consumption

Per filter 10 milliamperes direct current at 20 volts

### (E) Noise

Total noise when fully loaded with white noise at equivalent channel level specified by the Comité Consultatif International Télégraphique et Téléphonique and when operating at nominal input and output levels of  $-30$  and  $-35$  decibels referred to the level at the 2-wire point of origin

$< -83$  decibels relative 1 milliwatt referred to a point at zero relative level, psophometrically weighted (5 picowatts, psophometrically weighted)

## 8. Carrier Supply Equipment

### 8.1 DESCRIPTION

The carrier supply requirements for individual stations vary widely. This equipment has been arranged to fit into a number of standard shelves, which may be installed in different combinations to suit station equipments ranging from a single 60-channel system to a number of 960-channel systems, either together as a conventional centralized carrier supply, or individually on the appropriate translating-equipment racks. Moreover, the capacity of small

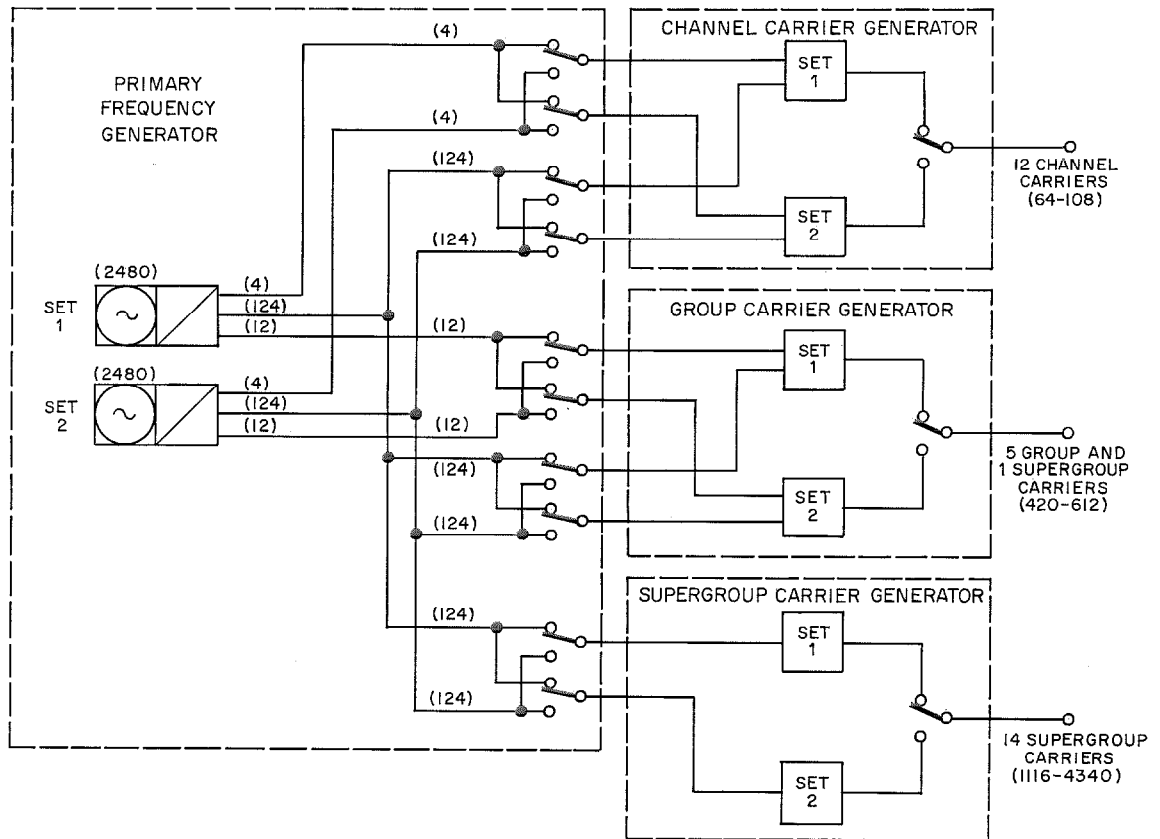


Figure 16—Carrier generators and changeover switching for a large station.

stations may be expanded with a minimum of difficulty and redundancy. In addition to the normal channel, group, and supergroup carriers, pilot frequencies recommended by the Comité Consultatif International Télégraphique et Téléphonique are provided.

The following equipment is arranged in separate sets of shelves for flexibility of installation.

(A) Master oscillator plus central generation of pilot frequencies and primary frequencies of 4, 12, and 124 kilohertz.

(B) Generation of channel carrier frequencies.

(C) Generation of group carrier frequencies.

(D) Generation of supergroup carrier frequencies.

In a very-large station a set of shelves for (A) would be used to supply a number of sets of shelves for (B), (C), and (D). Each set (which in some cases comprises one shelf only) is de-

scribed fully below. These descriptions are given in terms of typical large stations and small stations, with complete duplication of all units in the former and duplication only of common units in the latter. Shelves are wired so that each basic type of shelf can be converted from one alternative to another by selecting the appropriate cards and by strapping shelf terminals. Figure 16 is a simplified diagram of the overall arrangement. Figures 17 through 20

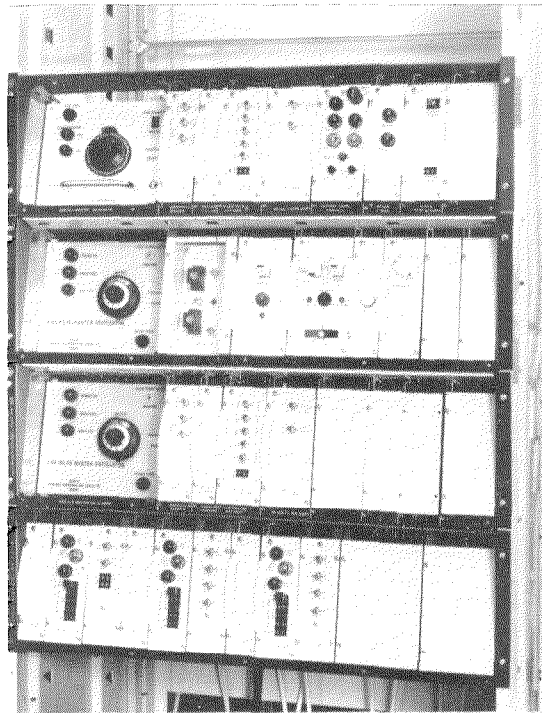


Figure 17—Shelves mounting master oscillators plus sources of pilot frequencies and primary frequencies.

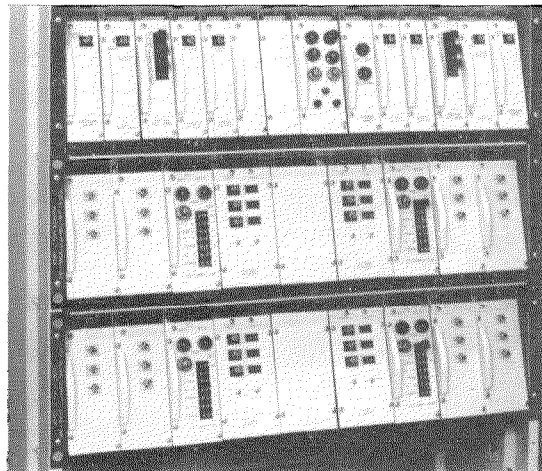


Figure 18—Shelves mounting channel carriers.

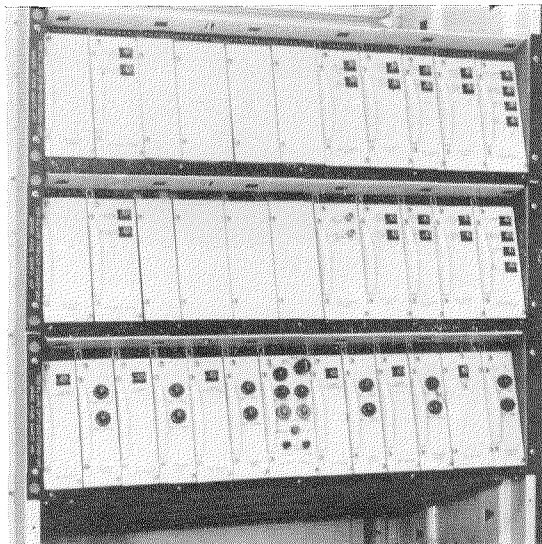


Figure 19—Shelves mounting group carriers.

## Carrier Multiplex Equipments: Deep-Rack

illustrate typical rack assemblies of centralized carrier supply equipment.

### 8.2 MASTER-OSCILLATOR AND PRIMARY-FREQUENCY GENERATION

The master oscillator is available in 3 forms.

(A) A 2.48-megahertz extremely stable unit recommended for major stations and suitable for use with 12-megahertz systems or 1800-channel radio-link systems. The stability (approximately  $\pm 3$  parts in  $10^8$  per month) minimizes routine adjustments without the complication of automatic synchronization. This oscillator is shown in Figure 21. Precise continuous frequency adjustment, narrow-range temperature alarms for the oven, and high-temperature cutout are features of the design. A card-mounted divider from 2.48 megahertz to 124 kilohertz is provided with the oscillator.

(B) A 4.96-megahertz highly stable unit (better

than  $\pm 1$  part in  $10^7$  per month) is suitable for line frequencies of up to 4 megahertz (960 channels). Continuous frequency adjustment and oven temperature alarms are included.

(C) A 124-kilohertz moderately stable unit (better than  $\pm 1$  part in  $10^6$  per month) is suitable for systems up to 120 channels. Continuous frequency adjustment and oven temperature alarms are included.

In each case a master oscillator is associated with cards to derive, amplify, and distribute frequencies of 124, 12, and 4 kilohertz. Other cards providing frequency comparison pilots of 60 or 300 kilohertz, intersupergroup pilot base frequency of 308 kilohertz, and group and

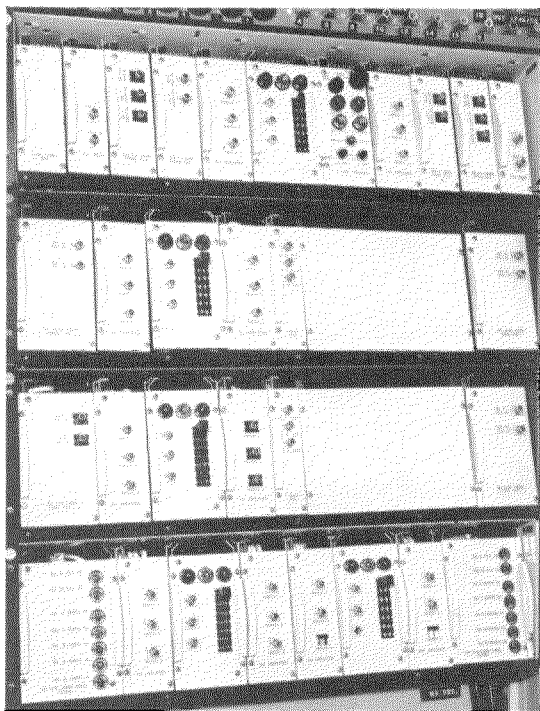


Figure 20—Shelves mounting supergroup carriers.

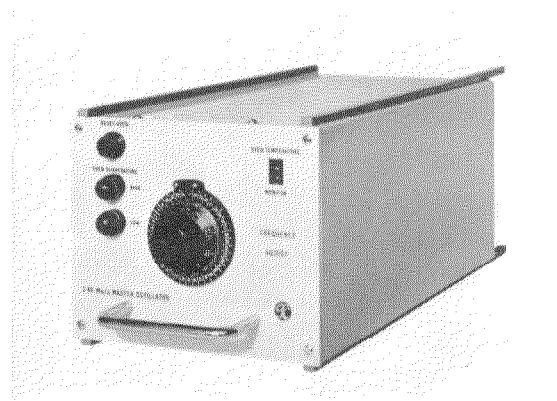


Figure 21—2.48-megahertz master oscillator.

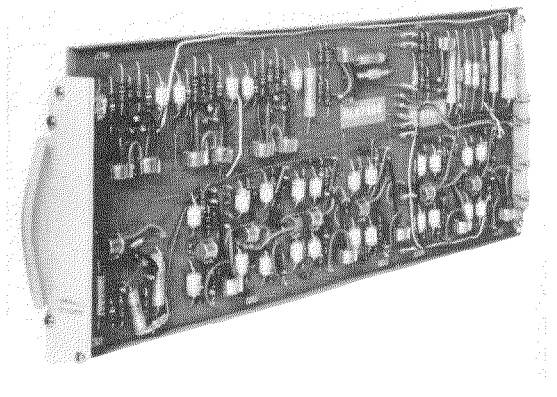


Figure 22—124-to-4-kilohertz digital divider card.

supergroup reference pilots are optional. A further optional unit is a frequency comparator for end-to-end and local comparison of the frequencies of working and standby oscillators. An off-frequency alarm is provided for the 2.48-megahertz comparator. Automatic change-over units are available for the primary frequencies and pilot frequencies. Figure 22 shows the 124-to-4-kilohertz digital divider card.

The following shelf arrangements are standard but can be changed.

### 8.2.1 Large Station

Two identical shelves, each containing a highly stable oscillator and cards to produce 124, 12, and 4 kilohertz.

One shelf containing changeover and distribution units.

One shelf containing frequency-comparator unit, plus a third manually switched oscillator if required.

One shelf containing duplicated group and supergroup reference pilot supplies plus change-over.

The first two shelves may be equipped for 60-, 300-, or 308-kilohertz supplies. These shelves will supply several sets of channel, group, and supergroup carrier generators. Self-contained changeover ensures that all equipments are supplied from the same oscillator, and that the standby oscillator is brought into use only if equipment within these shelves should fail.

### 8.2.2 Small Station

The arrangement described in Section 8.2.1 may be used or alternatively an arrangement using the 124-kilohertz medium-stability oscillator. This requires only one shelf to mount duplicate oscillators and cards to produce 12 and 4 kilohertz plus the 60-kilohertz pilot with a simplified frequency comparator. Nonduplicated group reference pilot supply may be provided also from this shelf.

### 8.3 CHANNEL-CARRIER GENERATION

These shelves mount pulse generators, filters, modulators, amplifiers, et cetera, to derive and distribute the 12 channel carriers from 64 through 108 kilohertz, with 120 kilohertz

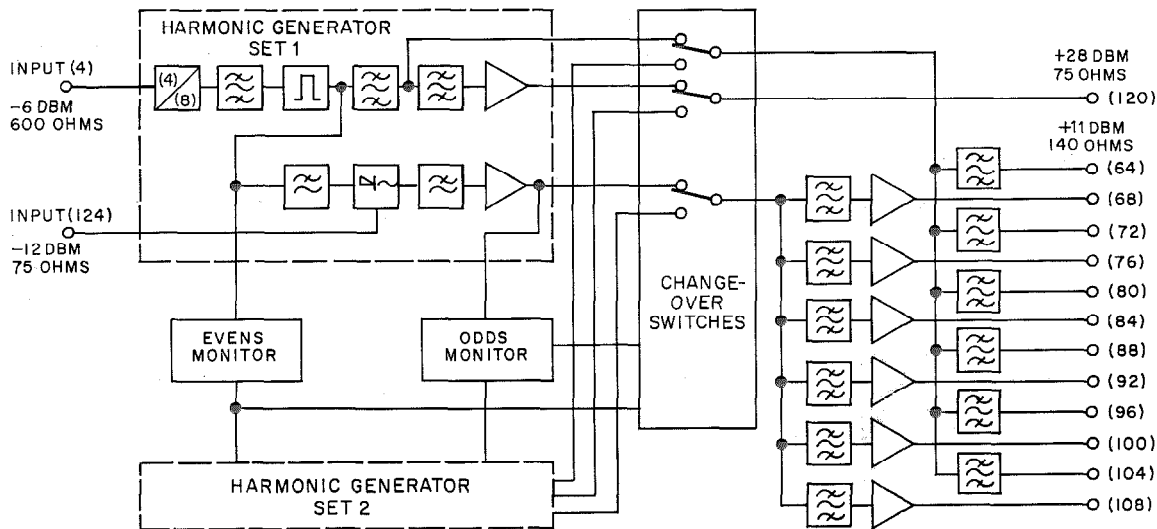


Figure 23—Channel carrier supply equipment. The optional 120-kilohertz supply is shown. Changeover may alternatively be fitted after the carrier pickoff filters. DBM = decibels referred to 1 milliwatt.

## Carrier Multiplex Equipments: Deep-Rack

(group carrier for 12-channel systems) optional. They receive 4 and 124 kilohertz from the primary-frequency generators. A functional diagram is shown in Figure 23 and a card mounting 6 channel filters is shown in Figure 24.

The following shelf arrangements are standard.

### 8.3.1 *Large Station*

One shelf contains two identical sets of cards (working and standby) to derive the channel carriers at low level, plus optional cards for 120 kilohertz including amplification and automatic changeover.

One shelf contains two sets of 6 high-power distribution amplifiers for even-numbered channels (working and standby) with individual automatic changeover for each frequency.

Another identical shelf provides for odd-numbered channels.

These shelves provide an output power per channel carrier of +24 decibels referred to 1 milliwatt and will supply up to 240 groups of 12 channels each. The primary-distribution units included on the shelves provide 16 outlets per frequency at +11 decibels referred to 1 milliwatt, each suitable to supply a secondary-distribution unit mounted on a channel translating rack.

### 8.3.2 *Small Station*

One shelf contains two identical sets of common equipment cards plus one set of 12 filters and

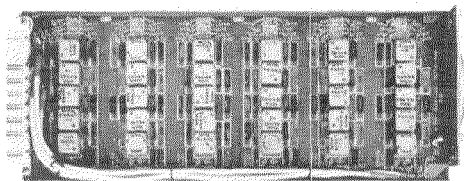


Figure 24—Channel carrier supply filter card.

automatic changeover; cards for 120 kilohertz are optional.

This shelf provides an output power of +11 decibels referred to 1 milliwatt per channel carrier and will supply up to 25 groups of 12 channels via a secondary-distribution unit. The shelf itself is identical to that for large-station use, so that additional cards may be plugged into it and the amplifier shelves added to convert to large-station practice. It may be used in conjunction with the high-power distribution amplifiers if necessary, in which use output-level monitors are available as optional items.

## 8.4 GROUP-CARRIER GENERATION

These shelves mount pulse generators, filters, modulators, amplifiers, et cetera, to derive and distribute the 5 group and supergroup-1 carriers of 420, 468, 516, 564, and 612 kilohertz. They receive 12 and 124 kilohertz from the primary-frequency generators. A functional diagram is shown in Figure 25.

The following shelf arrangements are standard.

### 8.4.1 *Large Station*

One shelf contains one set of pulse generators, filters, and amplifiers. Normally two identical shelves are installed.

One shelf contains changeover units.

These shelves provide an output power per group carrier of +26 decibels referred to 1 milliwatt and will supply up to 32 supergroups of 60 channels each. The two outlets provided on the shelf will each supply a secondary-distribution unit normally mounted on a group-translating rack.

### 8.4.2 *Small Station*

One shelf contains duplicate common-equipment cards, changeover, and level-monitor units.

One shelf contains filters and amplifiers.

These shelves provide the same output power as in Section 8.4.1. An alternative arrangement requires one shelf only and has distribution amplifiers suitable for supplying up to 16 supergroups of 60 channels each; in this case no level-monitor units are included. The shelves themselves are identical with those for large-station use to facilitate conversion from one type of installation to another.

### 8.5 SUPERGROUP-CARRIER GENERATION

These shelves mount pulse generators, filters, amplifiers, et cetera, to derive and distribute the carriers (1116, 1464, . . . , 4340 kilohertz) for supergroups 3 through 16. They receive 124 kilohertz from the primary-frequency generators.

The following shelf arrangements are standard.

#### 8.5.1 Large Station

One shelf contains duplicate pulse generators as well as filter and amplifier cards for supergroups 3 through 5, including changeover.

Three shelves contain duplicate filter and amplifier cards for supergroups 6 through 10, 11 through 13, and 14 through 16, with changeover.

These shelves provide an output power of +20 decibels referred to 1 milliwatt and will supply up to 4 systems of 16 supergroups each. The distribution units provide four outlets per frequency at +13 decibels referred to 1 milliwatt each.

#### 8.5.2 Small Station

Four shelves as above are needed, with only one set of filters and amplifiers and with level-monitor units.

### 8.6 CHANGEOVER AND ALARM ARRANGEMENTS

Three main principles of the automatic-changeover arrangements have been adopted.

(A) The equipment is completely symmetrical, so that either *A* or *B* units may be used as the working or the standby set; thus it is not necessary to return to the original set after a changeover has occurred.

(B) All carriers are always derived from the same master oscillator; thus all frequencies within a station are synchronous.

(C) Each set of generator shelves (for example, channel, group, et cetera) has its own self-contained changeover; this leads to maximum protection and simplifies fault location.

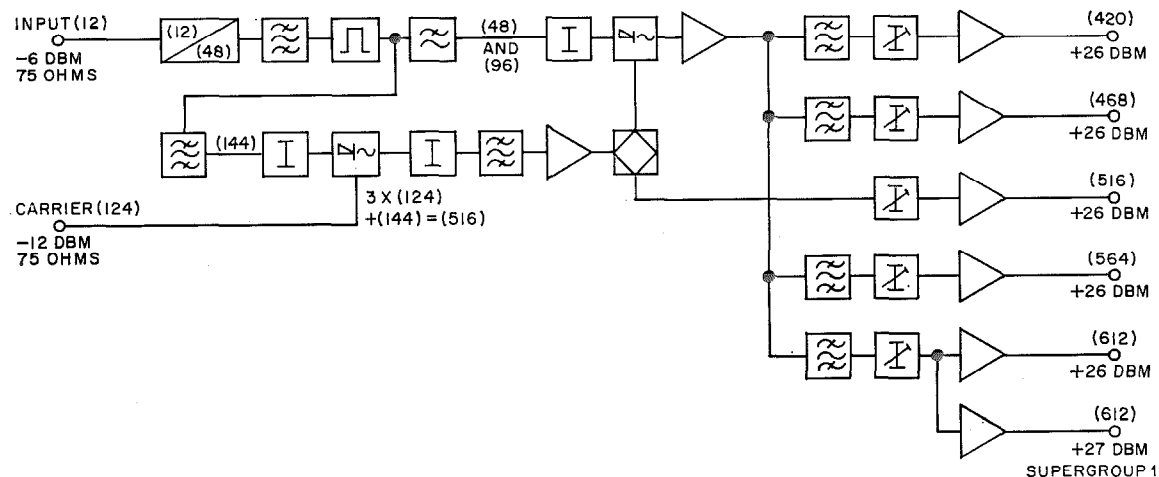


Figure 25—Group-carrier and first-supergroup-carrier generation. *DBM* = decibels referred to 1 milliwatt.

## Carrier Multiplex Equipments: Deep-Rack

Highly reliable mercury-wetted reed relays are used for switching the carrier frequencies. Permanent-magnet latching ensures against accidental changeover or contact floating because of power or control-circuit failure. The relays are driven by transistor amplifiers and bistable circuits to ensure operation at the correct drop in carrier level. Changeover times are very short. Supervisory relays operating in parallel with the mercury-wetted reed relays provide alarm indications.

Two basic types of card are used, a changeover card mounting the mercury-wetted reed relays and drive circuits, and a control card mounting supervisory circuits.

The following additional facilities are provided.

(A) Visual indication of whether the *A* or *B* set is operating.

(B) Visual indication, and extended loop to station alarm, of changeover and of a fault, including facilities for location of the faulty unit. Alternative arrangements for urgent and nonurgent alarms can be provided by strapping.

(C) Full "alarm-receiving-attention" facilities, with safeguards against accidental inhibition of alarms.

(D) Synchronization of primary frequency with changeover of channel, group, and supergroup carriers, if necessary, by strapping.

### 8.7 DISTRIBUTION ARRANGEMENTS

Earlier carrier generators have normally employed centralized distribution frames from which carrier supplies were cabled to all translating equipments. In a large station this led to a considerable amount of interrack cabling, a condition that was aggravated as more translating equipments were mounted on one rack. As mentioned, the present equipment is arranged in shelves that may be mounted on the same rack as the appropriate translating equipment or on central racks. In the former case inter-rack cabling is reduced to a minimum, as nor-

mally one carrier supply equipment connects to only the translating equipment on the same rack. In the latter case each carrier supply equipment includes primary-distribution facilities, each outlet being cabled to a secondary-distribution shelf mounted on the appropriate translating rack. This reduces considerably the interrack cabling.

### 8.8 TECHNICAL DATA

#### (A) Frequency Stability

Master oscillator refer to Section 8.2

Group reference pilot  $\pm 1$  hertz (assuming temperature range of +10 to +40 degrees centigrade)  
(84.08 kilohertz) and  
supergroup reference pilot (411.92 kilohertz)

#### (B) Level Stability

Typical value for  $\pm 0.5$  decibel  
channel, group, and  
supergroup carriers,  
assuming temperature  
range of +10 to +40  
degrees centigrade and  
a period of at least one  
month

Group reference pilot  $\pm 0.2$  decibel  
and supergroup refer-  
ence pilot

Level variation due to  $\pm 0.25$  decibel  
changeover from work-  
ing to standby equip-  
ments can be adjusted  
to—

#### (C) Spurious Frequencies

Suppression of spurious frequencies is adequate to meet the noise and crosstalk figures given for the various translating equipments.

#### (D) Power Consumption

The following figures are for a fully duplicated large-station centralized type of installation, and allow for the worst conditions of alarms and changeover. In all cases the voltage is 20 volts direct current.

Shelves for master oscillator, primary frequencies, and reference pilots	6.5 amperes
Channel carrier shelves	6 amperes
Group carrier shelves	6 amperes
Supergroup carrier shelves	6 amperes

## 9. Group Automatic Gain Control

### 9.1 DESCRIPTION

The group automatic gain control is self-contained and operates with the group reference pilot. Each automatic-gain-control unit provides continuous smooth level control and alarm indications without the need for any form of switched sampling of group levels. Thus these units may readily be incorporated in installations of any size and may be added to existing installations at any time.

A functional diagram is shown in Figure 26. The through-path amplifier, thermistor-controlled attenuator network, 84.08-kilohertz pilot pickoff crystal filter, regulator circuit, and alarm circuit are mounted on one card. Up to 6 units may be contained within a standard shelf, which has space also for an optional alarm indicator card.

The gain-control circuit is designed to be fairly slow acting, to avoid unnecessary changes in gain caused by very-short spurious variations in pilot level or short bursts of noise.

### 9.2 ALARM AND TEST FACILITIES

Each automatic-gain-control unit incorporates a transistor-operated alarm relay, which operates if the output pilot level deviates beyond certain limits. This relay extends a ground to the common alarm indicator card, lighting an alarm lamp and closing a station alarm loop after a short delay. A nondelayed alarm loop is extended directly from the automatic-gain-control unit and may be used for group-busy alarm purposes if required. One alarm indicator card can serve a large number of automatic-gain-control units, each unit having its own alarm lamp. Full alarm-receiving-attention facilities are incorporated.

*U*-links and level-measuring test points are provided at the input and output of each automatic-gain-control unit. Also, a protected output test point is provided for in-traffic measurement of pilot level.

### 9.3 TECHNICAL DATA

#### (A) Levels and Impedances

Input	-10 to -6 decibels referred to the level at the 2-wire point of origin (nominal), 75 ohms unbalanced
Output	-8 to -6 decibels referred to the level at the 2-wire point of origin (nominal), 75 ohms unbalanced

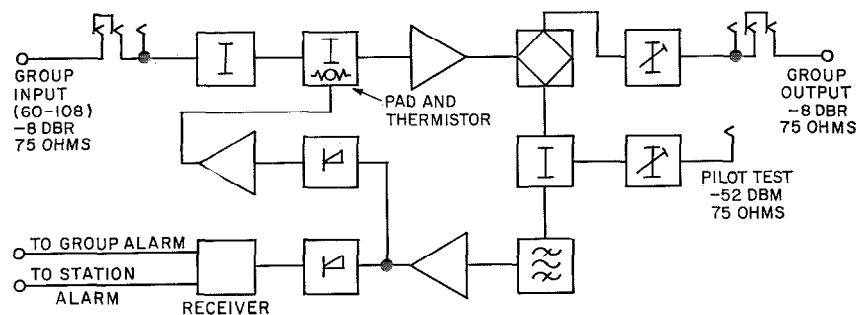


Figure 26—Group automatic gain control. *DBM* = decibels referred to 1 milliwatt. *DBR* = decibels referred to the level at the 2-wire point of origin.



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(B) Amplitude-Frequency Response Over 60-to-108-kilo- hertz-group band	0.2-decibel maximum spread
(C) Pilot Frequency and Level 84.08 kilohertz	$\pm 5$ hertz at $-20$ decibels
(D) Gain-Control Range For a control ratio of at least 10:1 Maximum range	$\pm 3$ decibels minimum $\approx \pm 4.5$ decibels
(E) Noise and Intermodulation Basic noise Intermodulation products with two test tones, each at 0 decibels relative 1 milliwatt referred to a point of zero reference level	negligible for each product, better than $-80$ decibels relative 1 milliwatt referred to a point of zero reference level
(F) Alarm Range Output pilot level variation to initiate an alarm	$\approx \pm 2$ decibels from nominal
(G) Gain-Control Delay Delay time for a step level change of 4 decibels to be restored to within 0.2 decibel of final value	$\approx 60$ seconds
(H) Gain Stability With nominal pilot frequency, gain changes for a variation in ambient temperature of 10 degrees centigrade plus normal voltage variations	$\geq 0.2$ decibel
(I) Power Consumption For minimum to maximum gain correction range for 1 automatic-gain-control unit Alarm lamps and relays under alarm conditions, for 1 automatic-gain-control unit	55 to 85 milliamperes direct current at 20 volts 50 milliamperes direct current at 24 volts (nominal)

## 10. Supergroup Automatic Gain Control

### 10.1 DESCRIPTION

The automatic gain control of the supergroup is very similar to that of the group. The through-path amplifier and thermistor-controlled attenuator network are designed of course to transmit a 312-to-552-kilohertz basic-supergroup band. The 411.92-kilohertz supergroup reference pilot is picked off through a relatively wide-band coil-and-capacitor filter, demodulated with a carrier frequency of 496 kilohertz, and the resultant 84.08-kilohertz pilot is passed to a crystal filter and regulator circuit identical to that used for group automatic gain control. Continuous smooth level control and alarm indications are provided. Apart from a supply of 496 kilohertz obtainable from the associated carrier generator, each automatic-gain-control unit is self-contained and may be added to installations at any time. Up to 6 units may be contained within a standard shelf.

### 10.2 ALARM AND TEST FACILITIES

These are very similar to those described in Section 9.2.

### 10.3 TECHNICAL DATA

#### (A) Levels and Impedances

Input	$-37$ to $-33$ decibels referred to the level at the 2-wire point of origin (nominal), 75 ohms unbalanced
Output	$-35$ to $-33$ decibels referred to the level at the 2-wire point of origin (nominal), 75 ohms unbalanced

(B) Amplitude-Frequency Response  
Over 312-to-552-kilo-  
hertz-supergroup band

(C) Pilot Frequency and Level  
411.92 kilohertz  $\pm 5$  hertz, at  $-20$  decibels

- (D) Gain Control Same as in Section 9.3  
Range, Noise and Intermodulation, Alarm Range, Delay, and Stability
- (E) Carrier Supply  
496 kilohertz +10 decibels referred to 1 milliwatt
- (F) Power Consumption  
For minimum to maximum gain correction range for 1 automatic-gain-control unit 65 to 95 milliamperes direct current at 20 volts  
For alarm lamps and relays under alarm conditions, for 1 automatic-gain-control unit 50 milliamperes direct current at 24 volts (nominal)

## 11. Power Supplies

### 11.1 POWER UNITS

All the equipments are designed to operate from a stabilized supply of 20 volts direct current, with positive to ground. A variety of power units are available that provide a suitable output when supplied from alternating-current mains or station batteries. These supplies need not be regulated and wide variations in voltage may be accepted. The standard power units are rated at 2.5 amperes regulated output; nonregulated outputs for lamps, relays, et cetera, are provided also. The transistor stabilizer circuits provide a high degree of stabilization and smoothing and incorporate overvoltage and overload protection. Figure 3 illustrates a 24-volt battery-type power unit.

### 11.2 FUSES

The regulated supplies pass through distribution fuses, normally one fuse per shelf, but the arrangement is flexible and in some cases individual cards warrant separate fusing. These fuses are of the grasshopper type; they initiate

an alarm and provide a visual indication on failure. Conventional cartridge fuses are used within the power units.

### 11.3 POWER SHELF AND ALARMS

The standard power supply shelf is always equipped with a fuse card, the fuses being wired through a flexible swan-neck cableform (to permit card withdrawal without breaking circuits) and an alarm unit. Up to 3 power units may be mounted on the shelf. The alarm unit provides a station alarm loop and visual indication of the failure of any regulated or nonregulated output and of the failure of any fuse. Location of the individual fuse involves only a partial withdrawal of the fuse card. A rectifier card can be equipped optionally to permit a standby power unit to be connected in parallel. Figure 27 illustrates a typical power shelf.

### 11.4 TECHNICAL DATA

- (A) Supply Voltage 24-volt battery (21.8 to 28 volts)  
50-volt battery (43 to 56 volts)  
90 to 130 or 200 to 250 volts, 45 to 55 hertz
- (B) Output Voltage 20  $\pm$ 0.3 volts direct current for any load

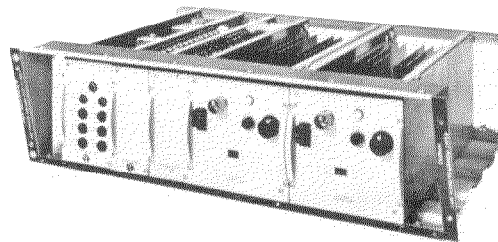


Figure 27—Typical equipped power shelf, showing voltage stabilizer, fuse card, and alarm unit.

## Carrier Multiplex Equipments: Deep-Rack

(C) Maximum Output 23 volts  
Voltage Under Fault  
Conditions

(D) Smoothing Ratio, >100:1  
Input to Output

### 12. Station Planning

The mechanical construction has been designed to permit the utmost flexibility in station plan-

ning. Shelves may be rack mounted and cabled on site, permitting a wide variety of arrangements to suit the requirements of any installation. In many respects the shelf may be considered as an old-type rack, and the rack as a suite. In some installations it may be preferable to keep separate the channel, group, and supergroup translating equipments, with separate centralized carrier generators. In other cases the optimum arrangement may be to

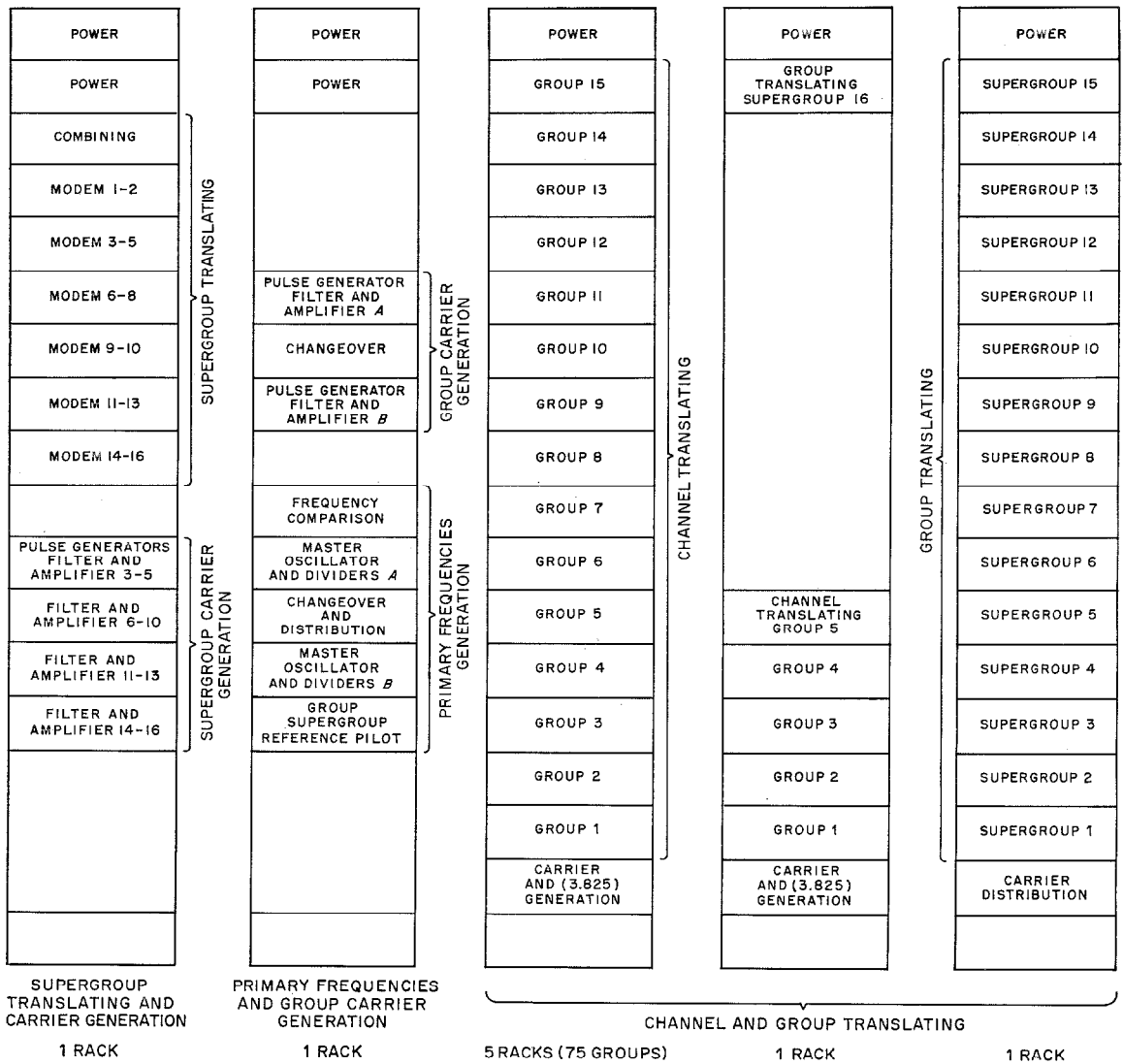


Figure 28—Typical rack layouts for a complete 960-channel system.

mount a channel carrier-generator shelf on each rack of channel translating shelves, or to combine channel and group translating shelves on one rack. There is a trend toward combination arrangements of this type to reduce the vast amount of station cabling usually required; the provision of secondary-carrier-supply distribution, at least on channel and group translating racks, is considered an important contribution to this.

The following examples indicate typical equipment combinations that may be mounted on a single rack framework 2743 millimeters (9 feet) high. In all cases power supply units are included.

### 12.1 CHANNEL EQUIPMENT

Sixteen groups (192 channels) without signaling.

Fifteen groups (180 channels) without signaling, plus carrier distribution or duplicated carrier supplies and distribution.

Fifteen groups (180 channels) with out-band signaling, plus duplicated 3825-hertz supply and carrier distribution.

### 12.2 GROUP EQUIPMENT

Sixteen supergroups (80 groups).

Fifteen supergroups (75 groups), plus carrier distribution or duplicated carrier supplies and distribution.

### 12.3 SUPERGROUP EQUIPMENT

Two 16-supergroup systems.

One 16-supergroup system together with carrier supplies (which will serve up to four 16-supergroup systems).

### 12.4 CARRIER SUPPLY EQUIPMENT

Channel plus group carrier supplies, fully duplicated, to serve at least two 960-channel systems.

Master oscillator and primary frequencies plus supergroup carrier supplies, to serve at least four 16-supergroup systems. The limitation in this case is power dissipation rather than rack space.

### 12.5 COMBINED EQUIPMENTS

Two self-contained 60-channel supergroups, including channel and group translating with duplicated carrier supplies.

Two 60-channel supergroups with carrier distribution, 3825-hertz supply, and group automatic gain control.

Figure 28 illustrates a possible arrangement for one complete 960-channel terminal equipment, excluding automatic gain control or through-connection filters. A total of 9 racks are required in this example for a first-in system; a second-in system would require 8 racks and a third-in system only 7 racks.

## 13. Acknowledgments

The author wishes to acknowledge the information and assistance given him by his colleagues in the Land Line Systems Division of Standard Telephones and Cables.

**Maurice Edwin Collier.** Biography appears on page 47.

# Transistor Carrier Multiplex Equipments

## Part 3—Front-Leadout Construction

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The multiplex equipment described in Part 1 of this series of articles has been constructed in two versions. They are similar in performance and electrical design, the principal difference being in mechanical design. One version, designated as the deep-rack construction and having single-stage-modulation modems in racks 450 millimeters (17.8 inches) deep with access from the front and cabling in the back, has been described in Part 2.

The present article deals with the other version. It is characterized by 2-stage channel modems and single-sided racks 225 millimeters (8.85 inches) deep. Front leadout of the rack cabling virtually eliminates all the disadvantages of back-to-back or wall mounting, for which this version is designed. All mechanical parts are in agreement with the standard equipment practice for ITT Europe [1].

### 1. Construction

#### 1.1 GENERAL CONSIDERATIONS

It is always the progress in the state of the art that creates the need for a new equipment practice for telephone transmission equipment. This progress may reflect the advancing development of conventional components or the introduction of novel components. A design that is to use a new equipment practice must take advantage not only of the latest and most-suitable components, but should also outdo the design to be superseded. The accommodation of lately developed transistor carrier multiplex equipments in racks and subracks of a new equipment practice has been motivated by the availability of reliable transistors, substantially reduced dimensions of conventional components, and automated wiring of equipment units with the aid of printed circuits.

Certain structural members and components

that meet the requirements of the standard equipment practice for ITT Europe have been modified so that the single-sided rack 225 millimeters (8.85 inches) deep is suitable for back-to-back and wall mounting, at the same time virtually eliminating the need for access to the back or cabling side of the rack. This variety has been designated type *ISEP-T*.

The building-block principle, time-tried in the construction of rack and base, has also been retained in type *ISEP-F*. Here, however, a special structural entity has been introduced, the so-called subrack. This subrack accommodates numerous plug-in units, the smallest structural entities in this equipment practice. The subrack is prewired, the wires being led out to a terminal strip accessible from the front side. This newly created subrack has taken the place of the previous rack framework that was prewired for full equipment. This measure serves to adapt type *ISEP-T* to the substantial reduction in volume of the smallest building block, the plug-in unit that evolved from the general application of transistors and printed circuits. The rack framework in type *ISEP-F* consists of sectional steel members that can be assembled on site; its only purpose is to permit subracks to be stacked. All work required for such installation has been greatly simplified and can be done from the front side. When the rack framework has been assembled in its proper place, the subracks are installed in the rack in any desired order, the wiring is ducted to the terminal strips of the subracks, all connections are made, and the subracks are interconnected by cables with plug-type connectors. Additional subracks may be added later without disabling subracks already in operation.

The naked rack framework on which only the subracks are wired has a number of economic and technical advantages. One is that the rack need no longer be equipped with the complete

wiring for future extensions and with the mechanical supports for plug-in units. In other words, the user need not invest for rack components he is not going to use immediately. Another advantage is the adaptability to accept subracks having any electrical function.

The module or  $M$  is the basis of all dimensions, divisions for the grid of the printed circuits, and the contact spacing of the connector. One  $M$  equals 2.54 millimeters (0.1 inch).

### 1.2 PLUG-IN UNIT

In type *ISEP-T*, the plug-in unit is the smallest functional electrical assembly. One of the newest components of this unit is the insulating board 1.5 millimeters (0.06 inch) thick on which the wiring is printed. These printed boards are used for all assemblies except the power supply, which has a conventional chassis and wiring.

A plug-in unit may consist of one or more printed boards of identical height and depth. The printed circuit is on one side of the board; the other side mounts the electrical components, including operating controls and the male connector. The controls are mounted close to the front edge of the board, while the connector is mounted along the rear edge and permits the unit to be plugged in. The printed wiring is obtained by cladding the board with a copper foil, which is then etched away so that only the printed conductors, which were coated to prevent etching, remain. Board and conductors are perforated to accept the connecting leads of the components mounted on the other side of the board; these leads are then dip-soldered to the printed wiring. Dip-soldering is also used to join the tinned tags of the male connector to the printed-wiring connectors of the same width, approximately 1 millimeter (0.04 inch). As stated earlier, the spacing of these tags and the conductors are controlled by the predetermined modules or  $M$ .

If the area of one printed board is sufficient to accommodate all electrical components re-

quired, a single-board plug-in unit will be used. Otherwise 2-board or 3-board units can be provided; the board side with the wiring will then face the component-mounting side of another board.

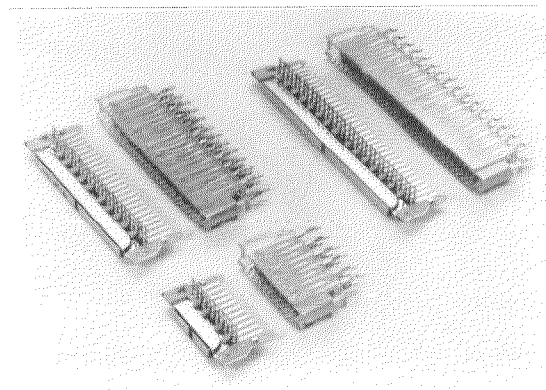
Each unit has an enameled front panel. A slot is provided in the center of the front panel for an extraction tool to pull the unit out of a sub-rack. The front panel has appropriate cutouts for access to test points and operating controls. Printed symbols present all necessary identification for adjusting a plug-in unit.

Metal plates may be inserted to shield boards in a multiboard unit from each other. A single-board unit can be satisfactorily shielded with a *U*-shaped metal plate that encloses all components and protects them mechanically.

Figure 1 shows a high-quality connector developed to meet the standard practice. Only those having 11 or 25 contacts are employed in type *ISEP-T* units. The connector has been described elsewhere [2].

Type *ISEP-T* plug-in units are all the same height and depth; only their width can be varied to accommodate components and assemblies of various sizes. The nominal dimensions of these units (Figures 2 and 3), excluding the

Figure 1—These three sizes of connectors have 11, 25, and 33 contacts, developed to meet the standard equipment practice for ITT Europe.



## Carrier Multiplex Equipments: Front-Leadout

connector and the front panel, are 100 millimeters (3.9 inches) in height and 160 millimeters (6.2 inches) in depth. The width may vary between 10.2 millimeters (0.4 inch) +  $n \times 5.08$  millimeters (0.2 inch), or  $= 4M + n2M$ , where  $n = 1, 2, 3, 4$ .

### 1.3 SUBRACK

The subrack essentially consists of a framework that accommodates several plug-in units. Four equal horizontal steel *I*-bars are welded to two equal side members of steel 1.5 millimeters (0.06 inch) thick. When this empty subrack is mounted in the rack, it is open at front, rear, top, and bottom. When fully equipped it is still open in the vertical direction to provide air circulation. The surfaces of all parts of this subrack are galvanized and chromated.

In accordance with type *ISEP-T*, the height and depth of the subrack shown in Figure 4

have constant dimensions; the width can be chosen to fit the standard rack widths. For a rack 600 millimeters (23.6 inches) wide and 225 millimeters (8.85 inches) deep, the subrack has a height of 119.4 millimeters (4.7 inches), a depth of 194.1 millimeters (7.6 inches), and a width of 538 millimeters (21.2 inches).

This subrack is strong enough to accommodate plug-in units with a total weight of 25 kilograms (55 pounds).

Threaded holes spaced by  $2M$  are provided in all four horizontal bars of the subrack. They are used to insert the upper and lower guides for the units. The holes in the rear bars also serve to attach the supports of the female connectors.

The threaded holes are exactly aligned in horizontal and vertical directions. A guide rail is manually fitted into the subrack without us-

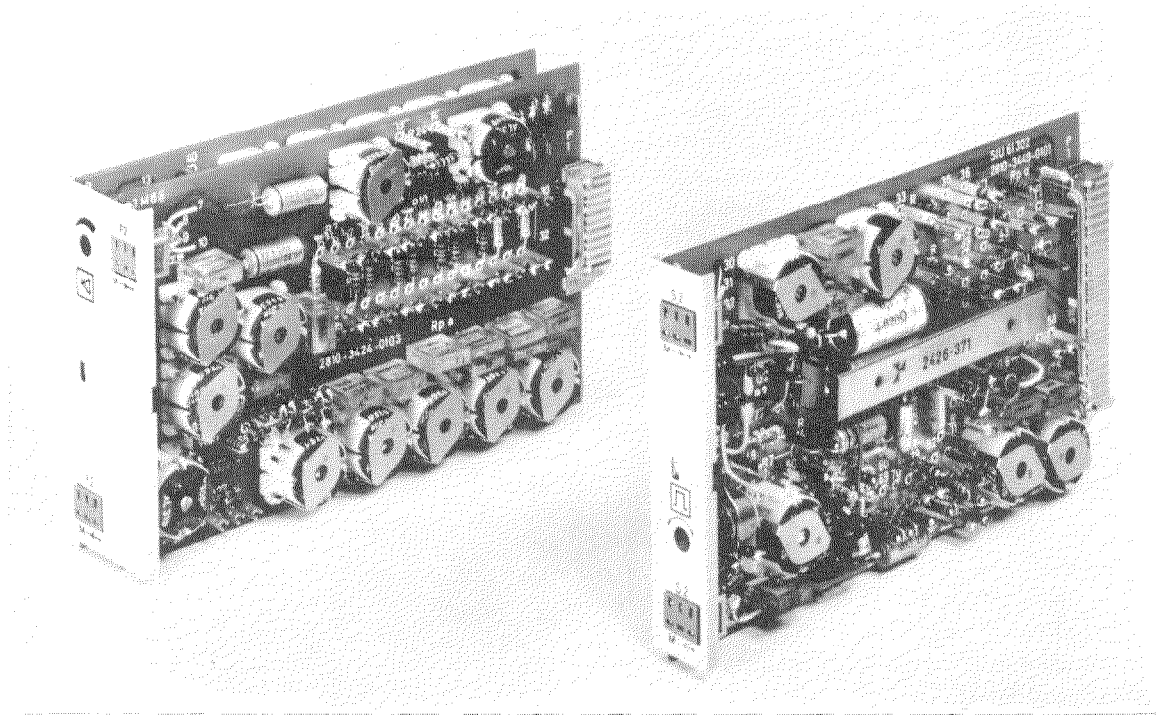


Figure 2—Single-board and 2-board plug-in units of type *ISEP-T*. At left is a speech-channel modem and at right is a signal modem.

ing a tool. It is simply placed over the extended head of the special screw in the rear bar (Figure 5) and then snapped over the head of another special screw in the front bar (Figure 6). It will be noted that the same screw is also used in the rear bar to mount a female-connector support. The guide rails can be removed just as simply.

The grooves of the upper and lower guide rails guide the plug-in units along their whole depth, thus preventing any damage during insertion and removal. The guide rails are made of

plastic and their grooves are dimensioned for a board thickness of 1.5 millimeters (0.06 inch).

The subrack structure is equipped with a locking bar that prevents all units from being pulled out accidentally. This spring-loaded locking bar is located in front of the lower *I*-bar and must be depressed before a unit can be removed.

To insure proper plugging of units into the subrack, designation strips covered with transparent plastic are provided on the lower horizontal and locking bars. Detachable paper strips bearing the identification markings can be slipped behind the transparent plastic foil.

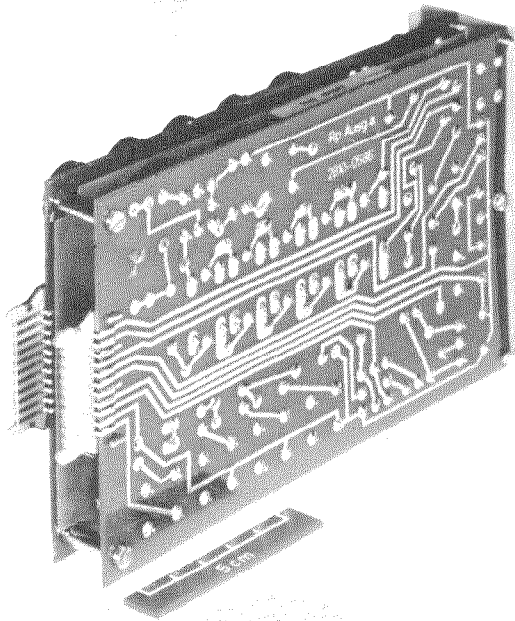


Figure 3—Wiring side of a 2-board unit.

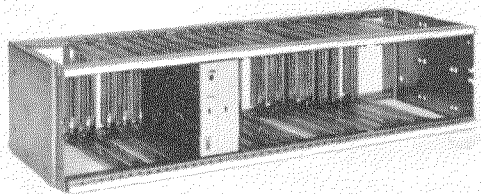


Figure 4—Single-row subrack equipped with female connectors, guide rails, and 2 plug-in units. This subrack is not wired.

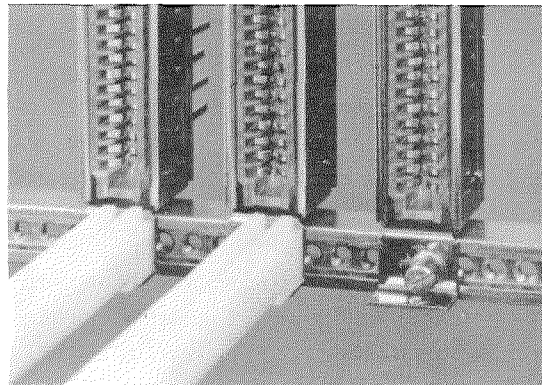


Figure 5—Snap-in mounting of polyethylene lower guide rails to heads of screws in rear horizontal bar.

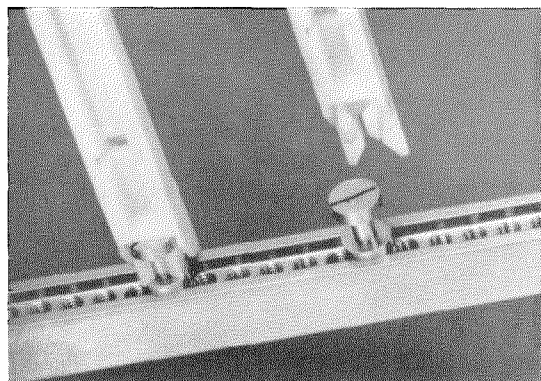


Figure 6—Snap-in mounting of lower guide rails to heads of screws in front horizontal bar (viewed from underneath).



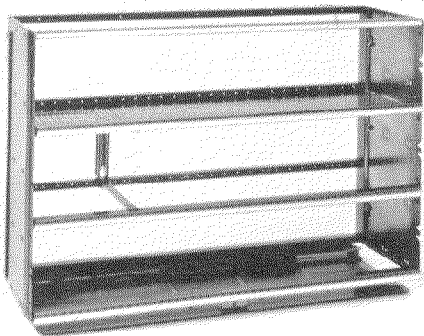
## Carrier Multiplex Equipments: Front-Leadout

Two or three subracks can be combined into a multirow subrack as shown in Figure 7. For an assembly of this type, special rails of 1.5-millimeter-thick sheet steel and appropriate length are fixed to the side members of the subracks. The overall height of a multirow subrack can be reduced when common side members are used.

A 33-contact male connector can be provided for each single-row or multirow subrack. It is mounted to the bottom member between the two horizontal bars. Its height is  $8M$ . At the sides of this connector, 50-point terminal strips for soldered or wrapped connections can be provided. The space in front of the connector is occupied by the mating female connector or soldering elements for coaxial connections.

The complete subrack thus comprises the horizontal bars, side members, female connectors, guide rails, male connector and terminal strip, and cabling, assembled according to the production plan. Such a single-row or multirow subrack is then designated in accordance with its electrical functions (for instance, channel modem subrack).

Figure 7—Triple-row subrack. A male connector and terminal strip are centered at bottom rear.



### 1.4 POWER SUPPLY

The power supply differs in that the printed-circuit board (the major building block described in Section 1.2) is not employed here for two reasons. First, the power supply is a self-contained functional electrical entity; it would hardly make sense to subdivide it into discrete units. Second, many of the components in a power supply could not be mounted on printed-circuit boards.

The power supply therefore constitutes a chassis that fits the width of the subrack described in Section 1.3. The dimensions of the power supply chassis are given in Section 1.6.

The output from the power supply is available from a 25-contact female connector. A cable with a male connector may be plugged in here for the distribution of the operating voltages. A second 25-contact female connector is parallel-connected to the first and to a standby power supply subrack (Section 1.7).

### 1.5 RACK FRAMEWORK

As with the subrack, the rack meeting the standard equipment practice consists of vertical and horizontal steel bars that can be assembled on site into a skeleton or framework. These bars are of angle steel 5 millimeters (0.2 inch) thick, the two legs of the angle being 30 and 60 millimeters (1.2 and 2.4 inches) long. Threaded holes spaced by  $8M$  are provided in the wider leg of each vertical member. These holes serve to attach the subracks to the insides of the rack framework. A bus bar of copper extends along the vertical member close to the threaded holes for good electrical connection between subrack and rack and for protection against electric shock.

Assembly of the rack starts with bolting a base of sheet steel 600 millimeters (23.6 inches) wide and 30 millimeters (1.2 inches) high to the horizontal rack member. This base can be adjusted to level the rack if the floor is not even. When the rack members are assembled, a

## Carrier Multiplex Equipments: Front-Leadout

sheet-metal cover is screwed to the entire rear. Special mounting bars are provided for back-to-back or side-to-side mounting of complete racks so that the rack can be held in the vertical position by its uppermost horizontal member. All parts of the rack are enameled.

### 1.6 DIMENSIONS

The whole system thus comprises racks, sub-racks, units, and power supply chassis. Their dimensions are as follows.

#### 1.6.1 Rack

Width, outer	600 millimeters (23.6 inches)
Width, inner	540 millimeters (21.3 inches)
Depth (fully equipped)	225 millimeters (8.85 inches)
Height	2600 millimeters (8 feet 3.5 inches) maximum
Mounting-hole spacing	20.32 millimeters = 8M (0.8 inch)
Number of mounting holes in 2600-millimeter-high rack	123
Spacing between floor and lower edge of power supply chassis	70 millimeters (2.75 inches)

#### 1.6.2 Subrack with Terminal Strip

Width	538 millimeters (21.3 inches)
Depth	194 millimeters (7.6 inches)
Height:	
single-row	142.2 millimeters = 7 mounting holes (5.6 inches)
double-row	264.2 millimeters = 13 mounting holes (10.4 inches)

triple-row	365.8 millimeters = 18 mounting holes (14.4 inches)
Row height	99.1 millimeters (3.92 inches)
Horizontal mounting-hole spacing	2M = 5.08 millimeters (0.2 inch)
Minimum spacing of guide rails	6M = 15.24 millimeters (0.6 inch)

#### 1.6.3 Plug-in Unit (Less Connector and Front Panel)

Height	39M = 99 millimeters (3.9 inches)
Depth	62.5M = 159 millimeters (6.25 inches)
Thickness	1.5 millimeters (0.060 inch)
Grid	1M = 2.54 millimeters (0.1 inch)

#### 1.6.4 Power Supply Plug-in Chassis

Height	121.9 millimeters (4.8 inches)
Width	538 millimeters (21.3 inches)
Depth	194 millimeters (7.6 inches)

#### 1.6.5 Rows of Plug-in Units in 2600-Millimeter-High Rack

A rack can be equipped with 14 rows of plug-in units in single-row subracks, with 16 rows if eight 2-row subracks are used, and with 18 rows if six 3-row subracks are used.

### 1.7 EQUIPPING THE RACK ON SITE

After the rack has been assembled on site and possibly mounted to the rack group frame, it is equipped from the front in several steps.

The first step is to run cables to the rack from the central power supply (alternating-current and/or battery) and from the other office

## Carrier Multiplex Equipments: Front-Leadout

equipment. These cables are dropped from above the top of the rack as shown in Figure 8 and thence to cable channels consisting of holders screwed along the left and right vertical rack members. This channel is later covered by side members attached to the subracks. Retaining angles can be adjusted for proper positioning of the cables in the cable channel.

The next step calls for mounting the power supply directly above the rack base; it is screwed from the inside to the vertical rack members of angle steel. Power cable is placed into the terminal strip and connected. If a standby power supply is desired, it is mounted in the next-higher position in the same way.

In the third step, the central subrack is inserted into the rack at a prescribed height of about 1100 millimeters (3 feet 7 inches) from the floor. The installation operations are the same as for the power supply chassis. This subrack may be a single-row, double-row, or triple-row type and accommodates units that perform central functions within a rack. These functions may be, for instance: distribution, protection,

monitoring of the operating voltages, control of rack and office alarms, control of carrier, signal, and pilot frequencies, and auxiliary equipment such as order-channel telephone, pilot transmitter, and receiver. For this reason the terminal strip of the central subrack comprises up to eight 33-contact female connectors for the distribution of operating, carrier, signal, and pilot-frequency voltages to the subracks within the rack over flexible plug-in cables. For safety reasons this distribution has a star-shaped configuration.

The other subracks are then mounted. The office cables are connected to the terminal strips of the individual subracks in any sequence desired.

In a final step, the male connectors on the cables are plugged into the corresponding female connectors in the subracks; first the cable connecting the power supply to the central subrack and then the cables connecting the central subrack to all other subracks.

If a standby power supply is provided, the outputs of both power supplies must be connected in parallel. This is again done with the aid of plug-in connecting cables. An additional female connector is provided for this purpose in the terminal strip of each power supply chassis.

All these connecting cables are then laid into the cable channels of the rack, in front of the office cables, and fixed in place by adjustment of the mounting angles.

These steps are all that is necessary to convert the framework of a rack into a fully equipped rack in the conventional sense. This rack is ready for operation after the plug-in units are installed and the power is turned on.

In the first stage of construction, the racks are rarely fully equipped and unneeded subracks are not mounted. They can be inserted later without interrupting operation. The steps necessary to mount additional subracks are the same as described previously. Figures 8 and 9 illustrate the front-leadout cabling of a rack, that is, cabling installed from the front.

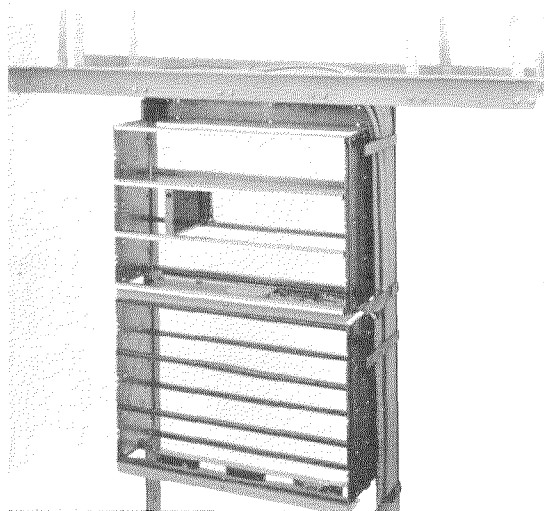


Figure 8—Rack cabling. The office cables shown are ducted from the cable shelf through the rack header into the right-hand cable channel. These cables are for 120 voice-frequency leadouts plus signal wires.

### 1.8 MAINTENANCE MEASURES

Type *ISEP-T* complies with two important requirements for maintenance; simple trouble location and good accessibility for trouble elimination. All important test points and the controls required for adjustments are accessible on the plug-in units. For this purpose the unit front plates feature the jacks for *U*-links and test points as well as the necessary controls. If troubleshooting is to be accomplished on an operating unit, an outrigger can be inserted in place of the unit to be tested; the latter is then plugged into the front of the outrigger. Faults in cabling and in the female connectors of the subracks are easily located and corrected. All that is necessary in most cases is to pull the affected unit from the subrack and replace it.

## 2. Channel Modem Subrack

The channel modem is mounted in a 3-row subrack into which can be plugged the channel, pregroup, and signal modems for the modulation and demodulation of two basic groups. Figure 10 shows the channel and pregroup translators for a basic group. These functions are performed by 29 plug-in units; 12 channel modems, 4 pregroup modems, 12 signal modems, and 1 receiver for the 84.08-kilohertz pilot.

These 29 units occupy 1.5 rows in the subrack. They are so arranged that the channel and pregroup modems of a basic group occupy the first or third row while the associated 12 signal modems and one pilot receiver occupy half of the central row. Figure 11 shows a fully equipped channel modem subrack.

### 2.1 CHANNEL MODEM

The channel modem comprises two printed-circuit boards as shown on the left in Figure 2. The partially hidden board is for receiving and the fully visible board is for transmitting. The front panel gives access to *U*-links and test points for the voice-frequency input and output,

and to the control for adjustment of the voice-frequency output level. The input level is adjusted with the aid of attenuators that are accessible on the visible printed board after the unit has been pulled. To produce 3-channel pregroups, the channel modems must modulate voice-frequency signals with carriers of 12, 16, or 20 kilohertz. Therefore, 3 types of channel modem are available, differing only in the channel filters. The channel modem is 36.1 millimeters (1.4 inches) wide.

### 2.2 PREGROUP MODEM

The basic group comprises the four pregroups converted in frequency to have carriers of 84, 96, 108, and 120 kilohertz. The pregroup modem equipment (Figure 10) is divided into four

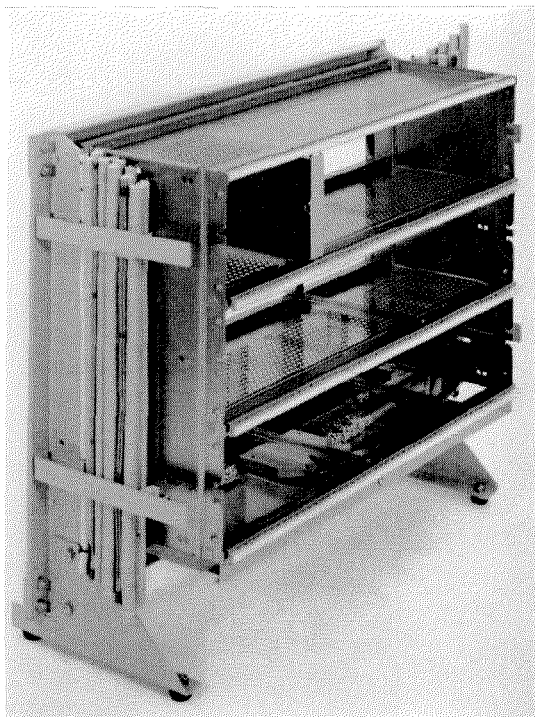


Figure 9—Another view of rack cabling. The cables from the right-hand channel are ducted to the terminal board at the bottom of a 3-row subrack. The cable holders at the left show how the cables are secured.

# Carrier Multiplex Equipments: Front-Leadout

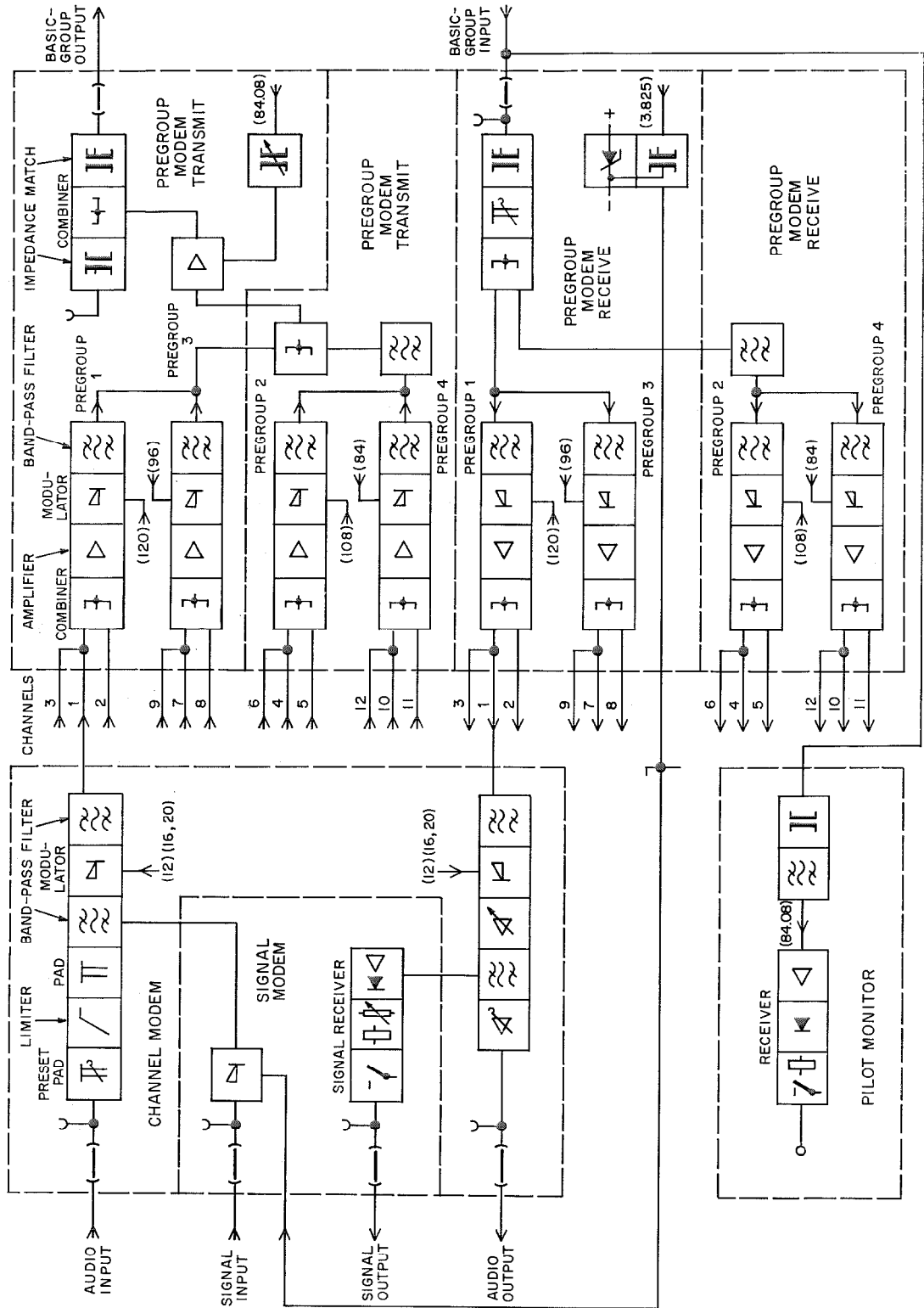


Figure 10—Channel modem. Frequencies in kilohertz are shown in parentheses.

different single-board units of identical dimensions, each 19 millimeters (0.75 inch) wide.

The first type of unit comprises the pregroup 1 and 3 transmitter modems, the transmitter amplifier for the basic group including the adjustable coupling for the group pilot of 84.08 kilohertz, a decoupled test point to check the transfer level of the basic group in the transmitting direction to the *U*-link, and an output transformer for matching to 135 or 150 ohms balanced or 75 ohms unbalanced. The matching adjustment is made before the unit is plugged in. The test point, *U*-link, and the group pilot control are provided on the front panel.

The second type of unit comprises the pregroup 2 and 4 modems in the transmit direction, the band-elimination filter for 84.08 kilohertz, and the decoupler for the combination of the four pregroups translated into the frequency position of the basic group. Similarly the pregroup modems at the receive end resolving a basic group are subdivided among the pregroup modems of the third and fourth types.

### 2.3 SIGNAL MODEM

The single-board unit for the translation of the 3825-hertz signal is 20 millimeters (0.8 inch) wide. It is the right-hand unit in Figure 2. As may be seen from Figure 10, the signal modem comprises the modulator, demodulator, receiving relays, and hermetically sealed reed relays that feature good contact properties, long life, and fast operation. The incoming and outgoing direct-current signal wires  $S_2$  can be opened and their currents monitored from test points. A control is provided to minimize the distortion of the pulses supplied to  $S_2$  outgoing. The *U*-links, test points, and the control are accessible from the front of the unit.

The signal modem can be adjusted at 3825 hertz to the high or low signal level and is therefore useful for all out-band signal transmission methods. The adjustment must be carried out before the unit is plugged in.

If in-band signal transmission is desired, the 3825-hertz signal modem can be replaced by a unit of the same size operated with a signal carrier of 2280 or 3000 hertz.

### 2.4 PILOT MONITOR

It is often desirable to monitor the receive level of the basic-group pilot (84.08 kilohertz) at the end of a basic-group link that is not pilot controlled. For this purpose, the 84.08-kilohertz monitoring receiver is available in a single-board unit 20 millimeters (0.8 inch) wide. The front panel of this unit mounts an alarm indicator lamp and a test point to check the level of the pilot. An alarm is generated if the pilot level falls short by about 1 neper for a period exceeding 0.5 second. The alarm is cancelled when the pilot level approaches its rated value.

### 2.5 RATINGS

#### (A) Voice-Frequency End

Frequency band of one speech channel  
300 to 3400 hertz

Four-wire input:

Level -17 to +4 decibels referred to the level at the 2-wire point of origin, adjustable in 1-decibel steps

Impedance 600 ohms, balanced

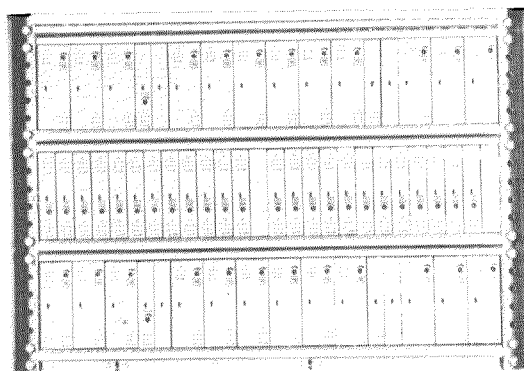


Figure 11—Channel-modem subrack fully equipped for 24 channels including signaling.

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### Four-wire output:

Level	-4 to +10 decibels referred to the level at the 2-wire point of origin, adjustable in 1-decibel steps, plus 5 decibels continuously adjustable
Impedance	600 ohms, balanced

### (B) Basic-Group End

#### Output (transmit end):

Level	-43 to -36 decibels referred to the level at the 2-wire point of origin, adjustable in 0.5-decibel steps
Impedance, adjustable	75 ohms unbalanced, or 135 or 150 ohms balanced
Carrier leak of each channel	<-26 decibels

#### Input (receive end):

Level	-31 to -5 decibels referred to the level at the 2-wire point of origin, adjustable in 0.5-decibel steps
Impedance, adjustable	75 ohms unbalanced, or 135 or 150 ohms balanced

### (C) Linearity of the Speech Channel

Deviation of the output level from linear for an input level of +4 decibels, maximum	<0.3 decibel
Limiting of the output level for an input level of >+20 decibels	+10 decibels
Attenuation of harmonic distortion for an output level of +10	>40 decibels

decibels referred to the level at the 2-wire point of origin

### (D) Amplitude Distortion of the Speech Channel (Referred to 800 Hertz)

Transmit end only	<1/5 *
Receive end only	<1/5 *
Transmit and receive ends in loop connection	<2/5 *

Mean value from 12 channels of a basic group (transmit and receive ends in loop connection) <1/5 \*

### (E) Group Delay and Distortion

Group delay in mid-band 1.1 milliseconds

#### Group delay distortion:

at 800 and 3150 hertz	0.6 millisecond
at 550 and 3300 hertz	1.0 millisecond
at 350 and 3400 hertz	2.0 milliseconds
at 300 hertz	2.7 milliseconds

### (F) Noise and Crosstalk

Background noise in a channel in loop connection (pilot and signal frequencies excluded) <-74 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted

Noise due to 3825-hertz signaling in the same or adjacent channels for a signal level of -18 decibels relative 1 milliwatt re-

\*. . . of the maximum distortion permitted by the recommendations of the Comité Consultatif International Télégraphique et Téléphonique (see Figure 7 in the Red Book, volume III).

ferred to a point of zero relative level

Noise due to 84.08-kilohertz pilot at -20 decibels relative 1 milliwatt referred to a point of zero relative level

Attenuation of intelligible crosstalk >70 decibels

Echo attenuation >70 decibels

Attenuation of unintelligible crosstalk (measured with language equivalent of the Comité Consultatif International Télégraphique et Téléphonique) >65 decibels, weighted

**(G) Signal Channel (3825 Hertz)**

Signal level -4 to -8 or -18 to -20 decibels, adjustable in 1-decibel steps

Signal-level leak (difference between tone and no tone) ≥30 decibels

Signal delay 15 milliseconds

Signal distortion for alternate 30-millisecond pulses and spaces for deviation of ±5 decibels from rated signal level ±5 milliseconds maximum

**(H) Signal Wire**

Transmit end (signal wire grounded) adjustable to "tone" or "no tone"

Receive end (signal wire grounded) switchable to closed-circuit or open-circuit operation

**(I) Carrier Supply (1 Carrier Frequency)**

Channel carrier:

Voltage level 0 decibels

Modem power consumption 1.6 milliwatts

Pregroup carrier:

Voltage level +5 decibels

Modem power consumption 4.6 milliwatts

Signal carrier (3825 hertz):

Voltage level 0 decibels

Power consumption, 12 channels 0.4 milliwatt

**(J) Power Supply**

Operating voltage 20 volts ±2 percent direct current

Power consumption by 12 channels:

Without signal modem 150 milliamperes

With signal modem, low level, tone busy 440 milliamperes

**3. Basic-Group Modem Subrack**

The number of rows for this subrack, prewired and equipped with a terminal board, is not fixed. Normally a 2-row subrack will be required and in special cases a 1-row subrack.

There are two versions, *V* and *N*, of the basic-group modem; both are described below.

**3.1 TYPE *V* BASIC-GROUP MODEM**

Type *V* is provided if it is not necessary to jumper basic groups (no group distribution frame is needed). In this case it is permissible to change the rated levels and impedances across the input and output of the basic-group modem at the basic-group end; therefore, the electrical design permits savings in cost and volume.

Figure 12 shows the arrangement of the plug-in units. The basic-group modem type *V* comprises 13 single-board units of equal dimensions, each 20 millimeters (0.8 inch) wide. One row of the subrack can thus be equipped with basic-group modems for the modulation and demodulation of two basic supergroups. Accessible from the front panels of the units are



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the output and input at the basic-supergroup end and the output for each basic group. The output level of each basic group can be exactly adjusted to the rated value with a front-panel control.

### 3.1.1 Ratings

#### (A) Basic-Group End

Input:

Level                    -42 to -27 decibels referred to the level at the 2-wire point of origin, adjustable in 0.1-decibel steps

Impedance                150 ohms balanced

Output:

Level                    -31 ±2 decibels referred to the level at the 2-wire point of origin, continuously adjustable

Impedance                150 ohms balanced

#### (B) Basic-Supergroup End

Output:

Level                    -47 to -33 decibels referred to the level at the 2-wire point of origin, adjustable in 0.1-decibel steps

Impedance                75 ohms unbalanced

Input:

Level                    -33 to -24 decibels referred to the level at the 2-wire point of origin, adjustable in 0.1-decibel steps

Impedance                75 ohms unbalanced

#### (C) Amplitude Distortion

Maximum width of the attenuation distortion for transmit or receive circuits        0.25 decibel per basic group, referred to 84 kilohertz

#### (D) Noise and Crosstalk (Transmit and Receive Sections Looped)

Background noise        < -74 decibels relative

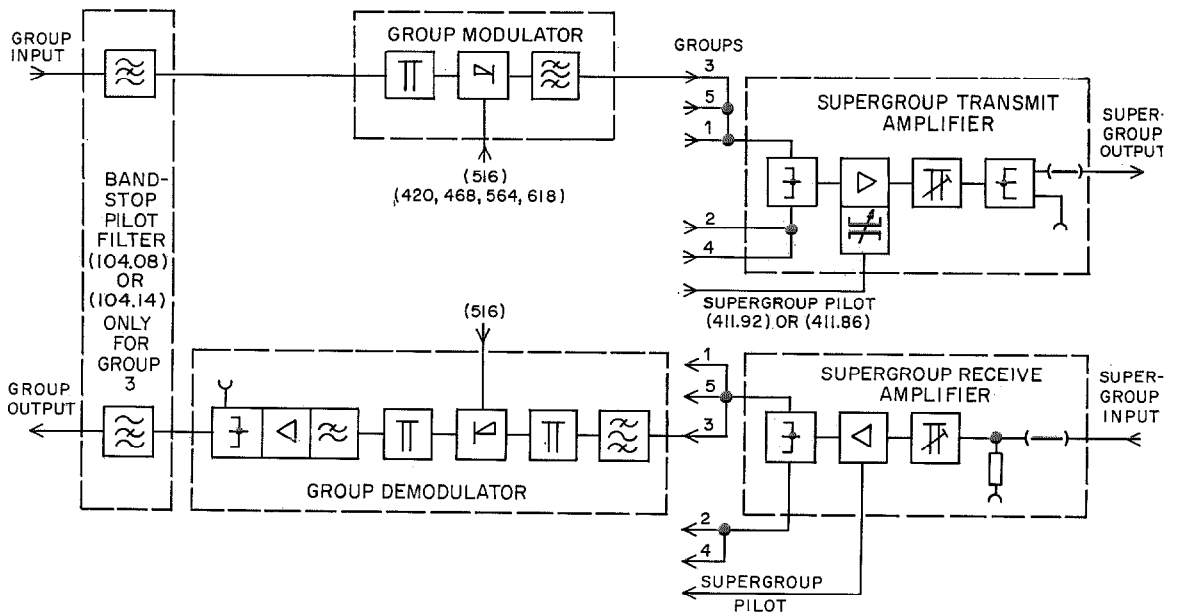


Figure 12—Type V basic-group modem. Frequencies in kilohertz are shown in parentheses.

(without pilot)

1 milliwatt referred to a point of zero relative level, psophometrically weighted (40 picowatts, psophometrically weighted)

(E) Carrier Leaks < -28 decibels per carrier frequency

(F) Dependence of Attenuation on Carrier Level

Transmit or receive within  $\pm 0.2$  decibel section for excursion of  $\pm 2$  decibels from rated carrier level

(G) Carrier Supply Carrier level

0 decibels

Power consumption per modem

20 milliwatts

(H) Power Supply Operating voltage

20 volts  $\pm 2$  percent direct current

Current drain of 5 basic groups 30 milliamperes

Total noise when loaded with Comité Consultatif International Télégraphique et Téléphonique channel level equivalent to white noise

< -72 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted (60 picowatts, psophometrically weighted)

Attenuation of intelligible crosstalk between basic groups, between transmit and receive sections, or between channels within one basic group

> 80 decibels

Suppression of upper sideband in transmit or receive section

> 80 decibels

3.2 TYPE N BASIC-GROUP MODEM

Type N is provided for the normal case in which the basic groups are to be connected with the usual transfer values for level and

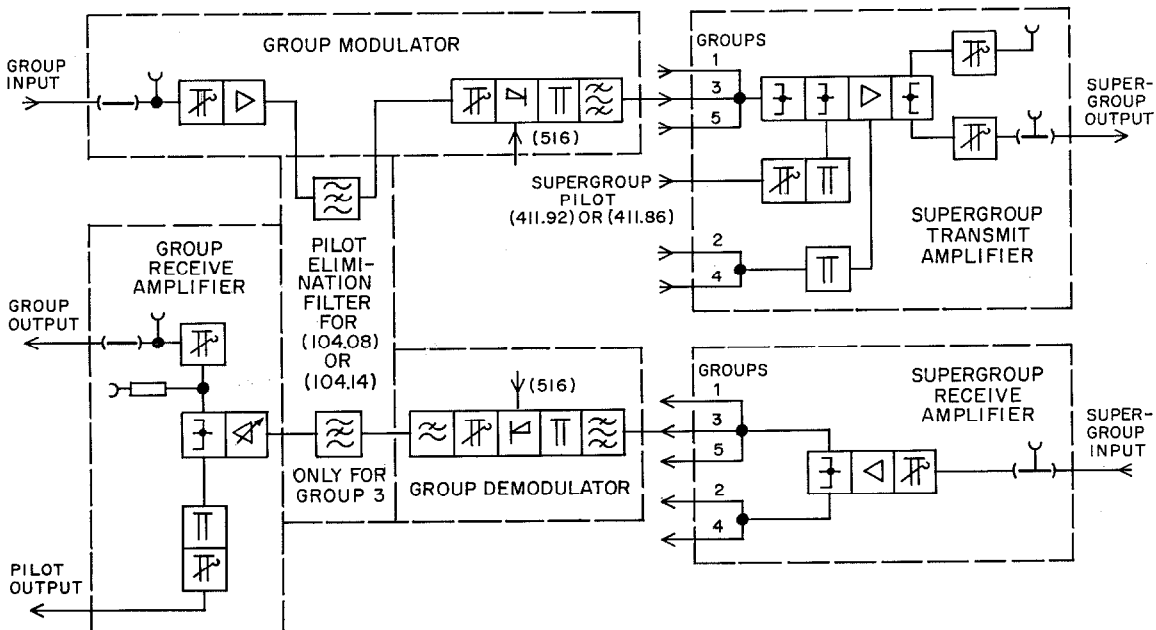


Figure 13—Type N basic-group modem. Frequencies in kilohertz are shown in parentheses.

## Carrier Multiplex Equipments: Front-Leadout

impedance to a group distribution frame for jumpering. It is electrically identical with the type *V* modem, except that the basic-group transmit amplifier in the receive direction has greater gain and power output.

Figure 13 shows the basic-group modem *N* with its 18 units. Four units have identical dimensions and are 25.4 millimeters (1.0 inch) wide. The basic-group modem units therefore occupy 85 percent of a row in the subrack.

The front panels of the units mount the *U*-links, test points, controls, as well as the gain control of the basic-group transmit amplifier.

### 3.2.1 Ratings

All ratings are identical with those in Section 3.1.1 except for the following.

#### (A) Basic-Group End

Input:

Level	-44 to -35 decibels referred to the level at the 2-wire point of origin, adjustable in 0.1-decibel steps
-------	--

Impedance, adjustable	75 ohms unbalanced, or 135 or 150 ohms balanced
-----------------------	---

Output:

Level	-30.5 to -27.5 or -8 to -5 decibels referred to the level at the 2-wire point of origin, adjustable in 0.1-decibel steps, plus $\pm 4$ decibels continuously adjustable
-------	---

Impedance, adjustable	75 ohms unbalanced, or 135 or 150 ohms balanced
-----------------------	---

#### (B) Amplitude Distortion

Maximum width of the attenuation distortion for transmit or receive circuits	$\pm 0.3$ decibel, referred to 84 kilohertz; $< 0.3$ decibel in bandwidth of 4 kilohertz
--	--

(C) Carrier Leaks	-30 decibels per carrier frequency
-------------------	------------------------------------

#### (D) Carrier Supply

Carrier level	+1 decibel
Power consumption per modem	20 milliwatts

#### (E) Power Supply

Current drain of basic groups	5 200 milliamperes
-------------------------------	--------------------

## 4. Supergroup Modem Subrack

Ordinarily, a 3-row subrack with terminal board is used for the supergroup modem subrack. This subrack can be equipped either with (A) the transmit-end modem units for supergroups 1 through 16 and a hybrid unit for their combination or (B) the receive-end modem units for supergroups 1 through 16 and a hybrid unit for their combination. The carrier multiplex equipment thus requires two subracks if no automatic control of the supergroups with the supergroup pilot frequency of 411.86 kilohertz is needed.

If such automatic control is desired, cabling considerations suggest the provision of a pilot-frequency receiver associated with each supergroup. This receiver, which is a separate plug-in unit, can be mounted in the subrack close to the automatically controllable basic-supergroup transmit amplifier (in the receive path of the supergroup). For this case, a 4-row subrack can accommodate the transmit and receive end modems of 5 supergroups, including the 5 pilot-frequency receivers.

The coaxial office cables are directly connected to female connectors vertically mounted in rows on the subrack.

### 4.1 SUPERGROUP MODEM

The circuits were developed and the units organized more with a view to uniformity than to minimum size. Therefore, the basic functional circuits of the supergroup modem for the two

directions of transmission, the modulator or demodulator, transmit or receive amplifier, and the supergroup filters, have been designed as plug-in units. Apart from the supergroup filter, which is in a hermetically sealed, soldered, removable can, the said functional circuits are single-board units of the type described in Section 1.2.

Supergroup modems 3 through 16 differ only in their filters; all other units are electrically and mechanically identical in these modems. The width of the filter units is uniformly 30.5 millimeters (1.2 inches) and of all other plug-in units 25.4 millimeters (1.0 inch).

Supergroup modem 1 for the transmit or receive direction comprises three units. Their functions correspond to those of supergroup modems 3 through 16 for the transmit or receive direction.

Supergroup modem 2 for the transmit or receive direction contains neither a modulator nor a demodulator because its function is to couple only the basic supergroup as supergroup 2. It therefore comprises only the amplifier and filter plug-in units per direction of transmission. These units are 25.4 millimeters (1.0 inch) and 35.5 millimeters (1.4 inches) wide, respectively.

#### 4.1.1 Ratings

##### (A) Basic-Supergroup Modem

Input:

Level -36 to -34 decibels referred to the level at the 2-wire point of origin

Impedance 75 ohms unbalanced

Output:

Level -31 to -25 decibels referred to the level at the 2-wire point of origin

Impedance 75 ohms unbalanced

##### (B) Far End (60 to 4028 Kilohertz)

Output:

Level -45 to -40 or -36 to -30 decibels referred to the level at the 2-wire point of origin

Impedance 75 ohms unbalanced

Input:

Level -36 to -15 decibels referred to the level at the 2-wire point of origin

Impedance 75 ohms unbalanced

##### (C) Amplitude Distortion

Maximum width of attenuation distortion for transmit or receive circuits  $\pm 0.3$  decibel, referred to 412 kilohertz; <0.3 decibel in bandwidth of 48 kilohertz

##### (D) Noise and Crosstalk (Transmit and Receive Sections Looped)

Total noise when loaded with Comité Consultatif International Télégraphique et Téléphonique channel level equivalent to white noise < -70 decibels relative to 1 milliwatt referred to a point of zero relative level, psophometrically weighted (100 picowatts, psophometrically weighted)

Attenuation of intelligible crosstalk between any supergroups, between channels in one supergroup, or between transmit and receive sections >80 decibels

##### (E) Carrier Leaks

Carrier leak per supergroup < -30 decibels

##### (F) Dependence of Attenuation on Carrier Level

Transmit or receive section for excursions of  $\pm 2$  decibels from rated carrier level within  $\pm 2$  decibels

## Carrier Multiplex Equipments: Front-Leadout

### (G) Carrier Supply

Carrier level	+1 decibel
Power consumption per modem	20 milliwatts

### (H) Power Supply

Operating voltage	20 volts $\pm 2$ percent direct current
Current drain per group modem, transmit and receive sections	52 milliamperes

### Output:

Level	-44 to -35 decibels referred to the level at the 2-wire point of origin
Impedance	75 ohms unbalanced, or 135 or 150 ohms balanced

### (B) Pass-Band Range (60.6 to 107.7 Kilohertz)

Attenuation in pass-band range	<6.1 decibels
Attenuation distortion in pass-band range	$\pm 0.5$ decibel, referred to 84 kilohertz
Attenuation distortion in 4-kilohertz bandwidth for channels 1 and 12	<0.5 decibel
Attenuation distortion for other channels	<0.25 decibel

### (C) Band-Stop Range

Attenuation in the ranges from 36 to 48 and from 132 to 144 kilohertz	>80 decibels, referred to 84 kilohertz
Attenuation in the vicinity of signaling frequencies:	
108.15 and 108.175 kilohertz	>39 decibels, referred to 84 kilohertz
108.15 kilohertz $\pm 20$ hertz and 108.175 kilohertz $\pm 20$ hertz	>28 decibels, referred to 84 kilohertz

### (D) Intelligible Crosstalk

Between the filters of one subrack	>80 decibels
------------------------------------	--------------

## 5. Basic-Group Through-Switching Filter

The through-switching filter is 255 millimeters (10 inches) wide, and 4 of them can be fitted into the 2-row subrack with terminal board. The filter has one *U*-link and one test point in both the input and the output, all accessible from the front (see Figure 14).

### 5.1 RATINGS

#### (A) Filter Requirements

##### Input:

Level	-31 to -5 decibels referred to the level at the 2-wire point of origin
Impedance (adjustable)	75 ohms unbalanced, or 135 or 150 ohms balanced

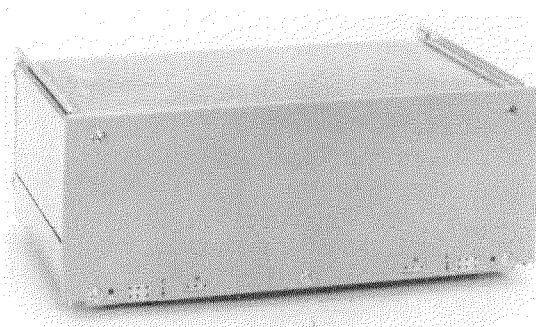


Figure 14—Basic-group through-switching filter. Its dimensions are 100 by 160 by 255 millimeters (4 by 6 by 10 inches).

## 6. Supergroup Through-Switching Filter

The dimensions of this plug-in unit are identical with those described under Section 5 so that the same subrack may be used.

The supergroup through-switching filter is passive and meets the following specifications.

**(A) Filter Requirements**

Input:	
Level	-30 to -24 decibels referred to the level at the 2-wire point of origin
Impedance	75 ohms unbalanced
Output:	
Level	-47 to -35 decibels referred to the level at the 2-wire point of origin
Impedance	75 ohms unbalanced

**(B) Pass-Band Range (312.3 to 551.85 Kilo-hertz)**

Attenuation at 412 kilohertz	≤5 decibels
Attenuation distortion in pass-band range	±0.5 decibel, referred to 412 kilohertz
Attenuation distortion in 4-kilohertz bandwidth for lower and upper corner channels	≤0.5 decibel
Attenuation distortion for other channels	≤0.25 decibel

**(C) Band-Stop Ranges**

Attenuation in the ranges from 268 to 288 and from 572 to 590 kilohertz	>80 decibels, referred to 412 kilohertz
Attenuation in the vicinity of signaling frequencies:	
308 and 556 kilohertz ±8 hertz	>40 decibels, referred to 412 kilohertz
308 and 556 kilohertz ±40 hertz	>20 decibels, referred to 412 kilohertz

**(D) Intelligible Crosstalk**

Between the filters of one subrack	>80 decibels
------------------------------------	--------------

**7. Carrier Supplies**

The carrier supplies, subdivided into plug-in units, can be combined into numerous subracks

to meet the specifications of individual terminal stations in various countries. Thus, for instance, the individual carrier supply subracks can be concentrated in one rack for central distribution; on the other hand, they can be mounted into the racks of the associated frequency modems. The carrier supply power can be increased on site in steps and can thus be adapted to prevailing local conditions at minimum cost.

Plug-in units have also been provided for the pilot frequencies for the basic groups and supergroups (recommended by the Comité Consultatif International Télégraphique et Téléphonique) and the line pilot frequencies. If required, these units can be plugged into the corresponding carrier supply subracks.

For the whole system, the following equipment is necessary for the carrier supply.

**(A) Basic generator including the frequencies 4, 12, and 124 kilohertz and line pilot frequency generator at 60, 300, and 308 kilohertz.**

**(B) Channel and pregroup carrier generator from the 4-kilohertz basic frequency.**

**(C) Basic-group carrier generator from the 12-kilohertz basic frequency.**

**(D) Supergroup carrier generator from the 124-kilohertz basic frequency.**

Each of these four equipments, including the monitoring and switching devices, are combined in subracks and described in the following sections.

**7.1 SUBRACK OF 124-KILOHERTZ GENERATOR**

This single-row subrack comprises the highly stable crystal-controlled 124-kilohertz generator that has a stability of  $1 \times 10^{-7}$  per month, the 124 to  $n \times 4$ -kilohertz divider, two band filters for 4 and 12 kilohertz, and three amplifiers for the frequencies 4, 12, and 124 kilohertz.

## Carrier Multiplex Equipments: Front-Leadout

For grounding and amplification of the line pilots 60, 300, and 308 kilohertz, there are two band filters for 44 and 60 kilohertz, one multiplier from 60 to 300 or from 44 to 308 kilohertz; and two amplifiers (one for 60 and one for 300 or 308 kilohertz). These 16 units form one row in the subrack. In the 124-kilohertz generator the frequency can be continuously adjusted by hand; moreover, the temperature is monitored by a crystal thermostat and an alarm given when it exceeds the upper or lower limit. The amplifiers for the frequencies 4, 12, and

124 kilohertz and the line pilots have front-panel test points to check the outgoing levels.

With an operating voltage of 20 volts direct current and a current drain of 490 milliamperes in the subrack, the amplifier power outputs are 13 decibels referred to 1 milliwatt for each of the frequencies 4, 12, and 124 kilohertz, and 19 decibels referred to 1 milliwatt for each of the line pilots 60, 300, and 308 kilohertz. These outputs can drive numerous carrier supplies for the channel basic-group and supergroup modems.

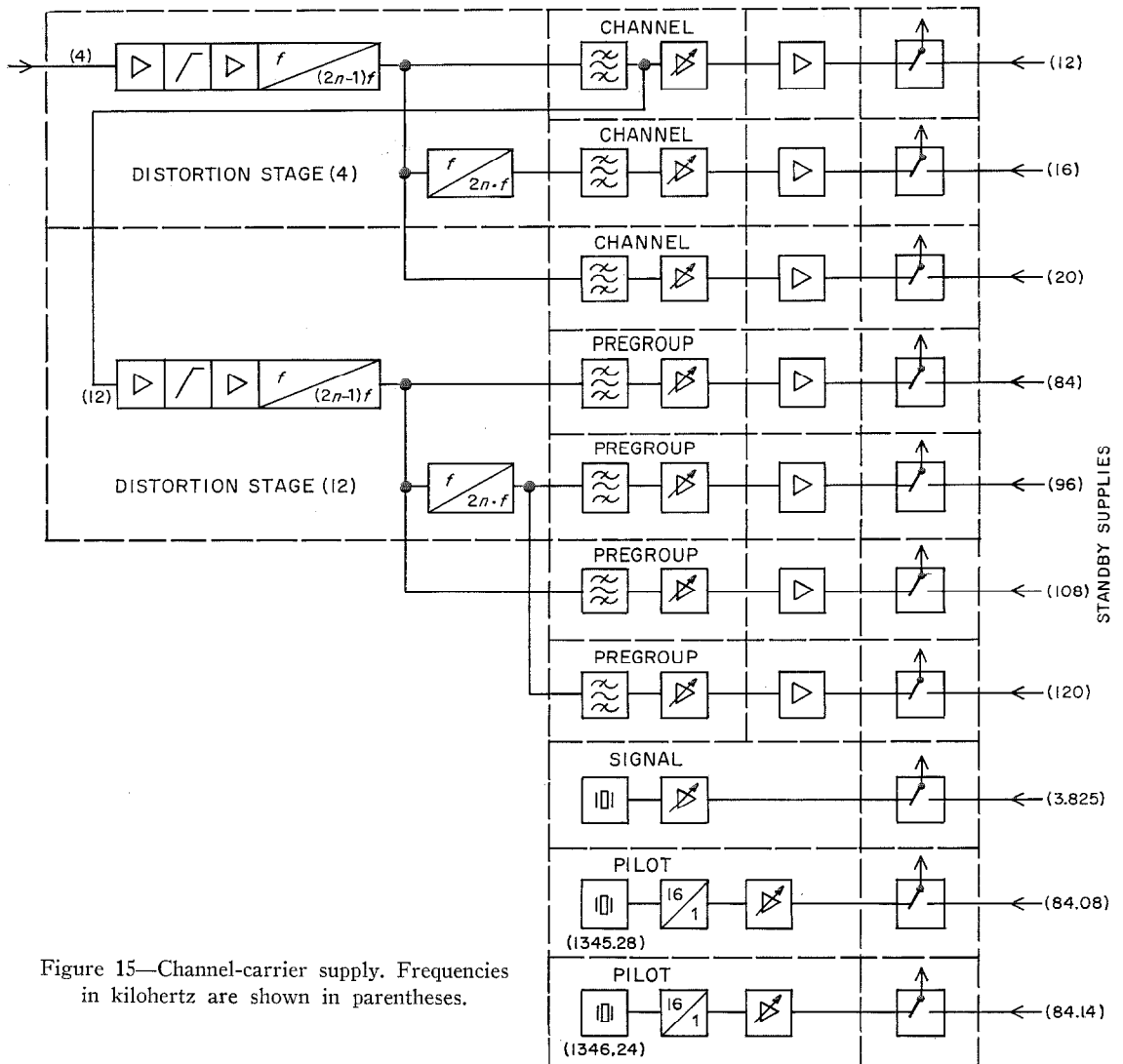


Figure 15—Channel-carrier supply. Frequencies in kilohertz are shown in parentheses.

If the 124-kilohertz generator is to be duplicated, a 2-row subrack with terminal board is available. Special plug-in units can be provided to switch the duplicated equipments automatically.

## 7.2 CARRIER SUPPLY SUBRACKS FOR CHANNEL MODEMS

To generate the three channel carriers 12, 16, and 20 kilohertz and the four pregroup carriers 84, 96, 108, and 120 kilohertz from the 4-kilohertz frequency supplied by the 124-kilohertz generator (Section 7.1), nine different single-board units are required. Seven of them are 20.4 millimeters (0.8 inch) wide and the others 25.4 millimeters (1.0 inch) wide. From the circuit diagram in Figure 15 we may see the electrical functions associated with these nine units.

The power output of the three channel carriers and of the four pregroup carriers, including filters and amplifiers, is 125 and 65 milliwatts, respectively. This power is enough to supply the channel and pregroup modems for the modulation and demodulation of 10 basic groups (120 channels). If carrier power amplifiers are added, the power output can be increased to 1000 milliwatts for each channel carrier or 500 milliwatts for each pregroup carrier, sufficient for the channel and pregroup modems for 100 basic groups. This example of supply is illustrated in Figure 15. A second power amplifier can be parallel-connected to the output of the carrier filter-plus-amplifier so that the carrier supply can be extended to cover 200 basic groups. The power amplifiers for the channel and pregroup carriers are 30.5 millimeters (1.2 inches) and 25.4 millimeters (1.0 inch) wide, respectively.

The plug-in units of all carrier amplifiers have test points on the front panel at which the levels can be checked. Figure 16 includes a 12-kilohertz carrier power amplifier.

To complete the carrier supply subracks, the following units are available.

3825-hertz generator	35.5 millimeters (1.4 inches) wide
84.08-kilohertz generator	45.6 millimeters (1.8 inches) wide
84.14-kilohertz generator	45.6 millimeters (1.8 inches) wide
Channel carrier switcher	20.4 millimeters (0.8 inch) wide
Pregroup carrier switcher	20.4 millimeters (0.8 inch) wide
3825-hertz switcher	20.4 millimeters (0.8 inch) wide
84.08- or 84.14-kilohertz switcher	40.6 millimeters (1.6 inches) wide

In addition, three units provide monitoring and alarm-generation for all channel and pregroup carriers, for the pilot, and for the signal frequencies. Two of these units are 20.4 millimeters (0.8 inch) wide and the third is 30.5 millimeters (1.2 inches) wide.

These units can be combined in many ways into carrier supply subracks. The most-interesting ways follow.

(A) A single-row subrack for the supply of 120 channel modems (10 basic groups) with channel, pregroup, and 3825 hertz signal carriers, as well as with the group pilot frequency including its monitoring and alarm circuits. In this

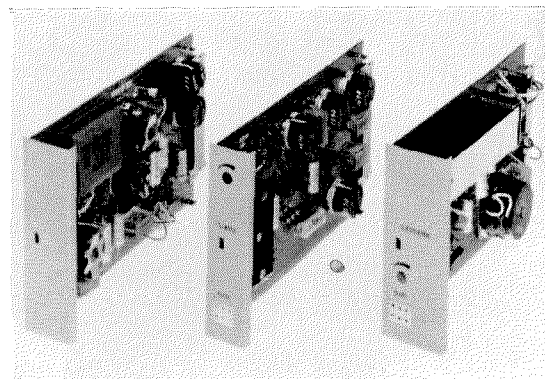


Figure 16—Units of the channel-modem carrier supply. From left to right are the 4-kilohertz distortion stage, the 12-kilohertz carrier power amplifier, and the 3825-hertz signal generator.



## Carrier Multiplex Equipments: Front-Leadout

combination the 4-kilohertz frequency must be supplied externally.

(B) A single-row subrack with the same properties as in (A), but with built-in 4- or 8-kilohertz generator (stability about  $1 \times 10^{-6}$  per month).

(C) A 2-row subrack with the same properties as in (A), but with doubled carrier signal and pilot frequency generation including automatic changeover.

(D) A 2-row subrack as in (C), but with built-in 4- or 8-kilohertz generator.

(E) A 3-row subrack to supply 1200 channel modems (100 basic groups) with all carriers and group-pilot frequencies from the duplicated generator including automatic changeover by application of the 4-kilohertz frequency.

(F) A 2-row subrack interworking with that in (E) and capable of supplying the carrier power for another 1200 channels.

The subracks listed under (A) through (C) are particularly suitable for mounting in a rack equipped with channel-modem subracks; the subracks listed under (E) and (F) are provided for central carrier supply racks.

### 7.3 CARRIER SUPPLY SUBRACKS FOR BASIC-GROUP MODEMS

The carrier frequencies 420, 468, 516, 564, and 612 kilohertz required for basic-group modems are produced from the 12-kilohertz frequency obtained from the 124-kilohertz generator in the same way as described in Section 7.1. This may be seen from a comparison of Figures 15 and 17. For obvious reasons, the equipment for the generation of basic-group carriers is subdivided into functional single-board units as in the case of the channel and pregroup carriers. In three plug-in units, each 20.4 millimeters (0.8 inch) wide, the carriers are derived as modulation products from 540 kilohertz mixed with a pulse sequence  $(2n - 1) \times 24$  kilohertz, both of which were obtained as multiples of 12 kilohertz. The five basic-group

carriers are filtered from this modulation product and amplified. These band filters and amplifiers each form a separate unit 20.4 millimeters (0.8 inch) wide; the whole basic-group conversion therefore comprises 8 equal-width units.

The amplifier output power of each carrier is 50 milliwatts, sufficient for modulation and demodulation of two supergroups. This power can be increased to 800 milliwatts (enough to form 40 supergroups) using additional power amplifiers. Each carrier power amplifier forms a unit 25.4 millimeters (1.0 inch) wide; electrically, however, they are different. If additional 564-kilohertz and 612-kilohertz carrier power amplifiers are connected in parallel to the input, the carriers for supergroup 1 and supergroup 1\* can be provided.

Units similar to those described in Section 7.2 are available for carrier monitoring and alarm generation or automatic changeover to a standby carrier supply. One unit 45.8 millimeters (1.8 inches) wide provides the two supergroup pilots of 411.92 and 411.86 kilohertz, and one unit 40.6 millimeters (1.6 inches) wide provides changeover.

The following types of subracks are available.

(A) A single-row subrack to house basic-group and supergroup modems for supergroups 1 and 2 or 1\* and 2, including a carrier monitor and alarm circuit for two supergroups (120 channels).

(B) A 2-row subrack as in (A), but with duplicated carrier generator and including automatic changeover.

(C) A 3-row subrack for basic-group modems for 40 supergroups, including the pilot frequencies, from duplicated carrier and pilot generators, with automatic changeover.

### 7.4 CARRIER SUPPLY SUBRACKS FOR SUPERGROUP MODEMS

The supergroup carrier frequencies 1116, 1364, . . . , 4340 kilohertz for modems 3 through 16

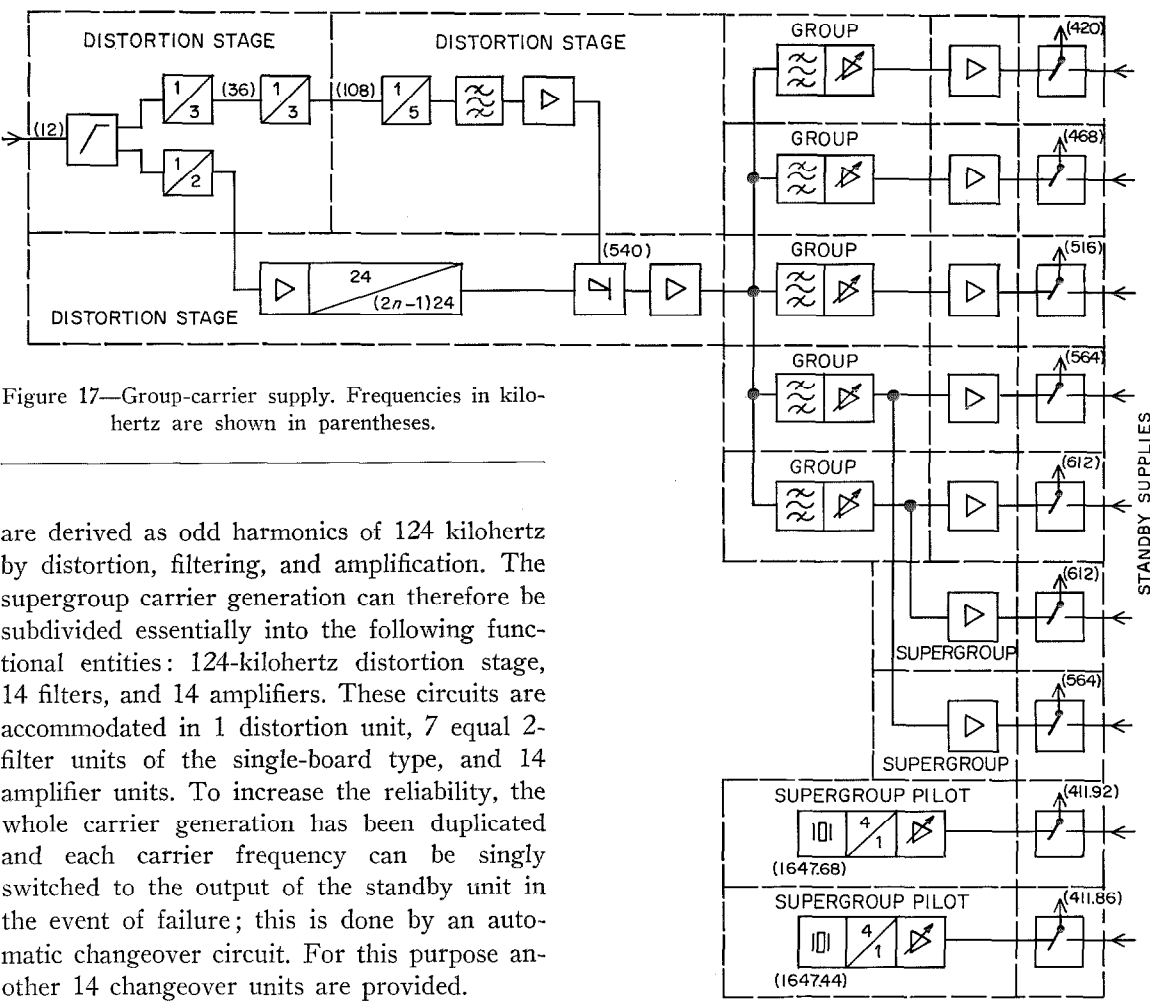


Figure 17—Group-carrier supply. Frequencies in kilohertz are shown in parentheses.

are derived as odd harmonics of 124 kilohertz by distortion, filtering, and amplification. The supergroup carrier generation can therefore be subdivided essentially into the following functional entities: 124-kilohertz distortion stage, 14 filters, and 14 amplifiers. These circuits are accommodated in 1 distortion unit, 7 equal 2-filter units of the single-board type, and 14 amplifier units. To increase the reliability, the whole carrier generation has been duplicated and each carrier frequency can be singly switched to the output of the standby unit in the event of failure; this is done by an automatic changeover circuit. For this purpose another 14 changeover units are provided.

Since the amplifier and filter units are 30.5 millimeters (1.2 inches) wide and the changeover units are 25.4 millimeters (1.0 inch) wide, the whole supergroup supply comprises 61 units including standby and automatic changeover units, equivalent to 3.5 or, rounded, 4 subrack rows. To provide for medium and small stations, these units are distributed among two 2-row subracks; one accommodates the duplicated distortion, filter, amplifier, and changeover-circuit units for supergroup carriers 3 through 10, and the other holds the same units for supergroup carriers 11 through 16.

The supergroup carriers have a power of 80 milliwatts (+19 decibels referred to 1 milliwatt) at the amplifier outputs, enough to supply

supergroup modems 3 through 16 of two systems.

Test points on the front panels of the amplifier units permit measurements to be obtained of each outgoing carrier level.

7.5 AUTOMATIC CARRIER CHANGEOVER AND CARRIER ALARM

The carrier supply equipments described in the preceding subsections, featuring high-speed automatic changeover, all operate on the same principle. Each individual frequency is automatically switched from the operating to the standby supply if the output voltage of the

## Carrier Multiplex Equipments: Front-Leadout

operating supply falls below or exceeds a certain value; at the same time an alarm indicator operates a ringer and lamps identifying the row of racks, rack, and subrack at fault. The same happens if the standby supply voltage is off limits and it is not possible to switch to such a unit.

To switch back to the original supply, a push button must be operated manually; however, this operation remains ineffective if the original supply is still out of order.

### 7.6 RATINGS

#### (A) Frequency Stability (Temperature Range +10 to +40 Degrees Centigrade)

124 kilohertz	$<1 \times 10^{-7}$ per month
8 kilohertz:	
+55-degree oven	$<3 \times 10^{-7}$ per month
+70-degree oven	$<1 \times 10^{-6}$ per month
84.08 kilohertz and	$<2 \times 10^{-6}$ per month
411.92 kilohertz	

#### (B) Amplitude Stability (Temperature Range +10 to +40 Degrees Centigrade)

Carrier frequencies	$<0.5$ decibel per month
Pilot frequencies	$<0.1$ decibel per month

Differences between operating and standby supplies:

Carriers	$<0.2$ decibel per month
Pilots	$<0.1$ decibel per month

#### (C) Current Drain (for Duplicated Carrier Supplies and Highest Load in Case of Alarm)

Channel-carrier supply (1200 channels)	2.4 amperes (normally 2.0 amperes)
Basic-group carrier supply	2.0 amperes (normally 1.7 amperes)
Supergroup carrier supply	4.7 amperes
124-kilohertz generator	1.0 ampere

## 8. Power and Alarm Circuits

### 8.1 POWER SUPPLY UNITS

In all racks 2.6 meters (8.5 feet) high, the lowest 12 vertical mounting-hole divisions directly above the base box are always reserved for the power supply. The rack framework can accommodate two identical power supplies, one atop the other, that can be slid in on rails. Each of these plug-in chassis has the positive terminal grounded and supplies 20 volts  $\pm 2.5$  percent direct current for load variations from 0.1 to 5.5 amperes. One power-supply chassis is thus capable of supplying any subracks encountered in practice that can be mounted in one rack. The second power supply is provided for greater reliability. If two power supplies are used in one rack, they are parallel-connected via a diode circuit; if one supply fails, the other assumes the full load without disrupting operation. The failure gives rise to an alarm.

Power supplies are available for operation from power lines of 220 volts, +1, -2 percent, 47 to 53 hertz; of 220 volts, +10, -20 percent, 47 to 65 hertz; and from central batteries of 60, 48, and 24 volts, +22, -12 percent.

The voltage tolerances stated for the central battery allow for high-current battery charging or if, after a prolonged failure of the power line, a battery is excessively discharged.

### 8.2 POWER DISTRIBUTION, FUSES, AND ALARMS

As stated in Section 1.7, each rack includes a central subrack that always contains a plug-in fuse unit and a plug-in alarm unit. The central subrack is always mounted in the same place regardless of the rest of the equipment.

In the fuse unit, which is permanently fixed to the subrack, the operating voltages obtained from the power supply chassis are distributed via fuses to the subracks. If the power supply is duplicated, the fuse unit also provides for the parallel connection between both power sup-

ply chassis. The fuses are accessible from the front.

The alarm unit contains circuits that monitor the operating voltages, fuses, carrier and pilot frequencies, and circuits that transmit an alarm to either the station alarm system or in an unattended exchange to a telemetering system. The front panel displays alarm lamps and controls. The unit may be pulled out of the subrack without disturbing operation.

### 9. Versatility in Equipping Racks

As stated in Section 1, the new front-leadout design of type *ISEP-T* permits equipping the rack framework on site in several combinations without extensive planning. Thus the various modems can be combined not only with their carrier supplies, but also with the modems of the next-higher rank. While the advantages of such versatility are evident and need not be elaborated on here, some examples may help to show the extent of the versatility offered. In all examples that follow, a rack 2.6 meters (8.5 feet) high and 0.6 meter (2.0 feet) wide is assumed. The fully equipped rack has a depth of 0.225 meter (0.738 foot) for convenient wall and back-to-back mounting. No access from the rear is necessary because of the front leadout of the rack cabling. It is further assumed that two power supply units are included.

#### 9.1 CHANNEL-MODEM RACK

The rack framework can be equipped with 5 channel-modem subracks and 1 central subrack, all of the 3-row type. One channel-modem subrack comprises 24 channel modems, 24 signal modems, the associated pregroup modems, and two 84.08-kilohertz monitoring receivers (refer to Section 2).

Four types of central subracks are available. They can accommodate, in addition to 1 fuse unit and 1 alarm unit, the following combinations.

(A) For the 5 channel-modem subracks (10 basic groups), the channel, pregroup, signal, and 84.08-kilohertz-pilot units as well as the units for carrier and pilot monitoring and, if necessary, the 4-kilohertz basic-group carrier generators (refer to (B) of Section 7.2).

(B) Same as (A) (except the monitoring units), plus units for automatic carrier and pilot changeover (refer to (C) of Section 7.2).

(C) Same as (A), plus units of type *N* for 2 basic-group translations (2 basic supergroups) and the basic-group carrier supply (refer to Section 3.1 and (A) of Section 7.3).

(D) Same as (C), plus units required for two supergroup translations (supergroups 1 and 2).

Space is left in the rows of the four types of central subrack for mounting a level generator, a level receiver, and an order-wire unit, if necessary.

#### 9.2 BASIC-GROUP-MODEM RACK

This rack can be equipped with 5 basic-group subracks and 1 central subrack, each comprising 3 rows.

The 3 rows of the basic-group-modem subrack are also equipped with units of the basic-group modem in type *N* design (refer to Section 3.3). A basic supergroup can be formed and resolved with the units of each row.

Two central subracks are provided if the fuse and alarm units are mounted in the same places in the central row. These subracks differ from the equipping pattern as follows.

(A) The upper row and the lower row can be equipped with the same units as the rows of the basic-group-modem subracks.

(B) An operational or standby basic-group carrier supply can be mounted in the upper or the lower row; the central row can then mount the associated changeover switching units. This supplies all carriers and the supergroup pilot for  $40 \times 5$  basic-group modems (refer to (C) of Section 7.3).

## Carrier Multiplex Equipments: Front-Leadout

With two fully equipped basic-group-modem racks, one in accordance with (A) and the other with (B) above, 17 and 15 basic supergroups can be formed and resolved. The required carrier power can be taken from the basic-group carrier supply mounted in the central subrack.

### 9.3 SUPERGROUP-MODEM RACK

The following subracks are included in a rack that mounts supergroups 1 through 16.

(A) Modems of supergroups 1 through 16 for the transmit branch (refer to Sections 4 and 4.1).

(B) Modems of supergroups 1 through 16 for the receive branch (refer to Sections 4 and 4.1).

(C) Carrier supply for supergroups 3 through 16, operational and standby (refer to Section 7.4).

(D) Operational and standby 124-kilohertz generator (refer to Section 7.1).

These 4 subracks plus 1 central subrack can be used to provide two types of supergroup-modem racks. The first type accommodates the supergroup modems for a 960-channel system, one supergroup carrier supply (operational and standby), and two 124-kilohertz generators. The second type accommodates the supergroup modems for two 960-channel systems, with the carrier and pilot supply being provided by the supergroup carrier supply mounted in the first type.

**Richard Rabe** was born in Stuttgart on 28 November 1911. He studied communication engineering at the Stuttgart Technical College, remaining there as a scientific assistant after graduation, and obtained his Dr. Ing. degree in 1939.

He then joined the Allgemeine Elektrizitäts-Gesellschaft (AEG) communication-equipment manufacturing division in Berlin where he headed a development team for carrier-frequency equipment.

### 9.4 CARRIER-SUPPLY RACK

One carrier supply rack can be built up with the subracks of the 124-kilohertz generator (Section 7.1), channel carrier supply ((E) of Section 7.2), channel and pregroup carrier amplifiers ((C) of Section 7.3), and basic-group carrier supply ((C) of Section 7.3). A carrier supply rack fully equipped with these subracks supplies all carriers for the channel, signal, pregroup, and basic-group modems; the pilots 60, 300, 308, 84.08, 84.14, 411.92, 411.86 kilohertz; and supergroup carriers 564 and 612 kilohertz from the duplicated carrier supplies, including automatic changeover. The carrier power thus available is sufficient for the modulation and demodulation of 200 basic groups and 40 basic supergroups.

## 10. Acknowledgments

The authors wish to thank their co-workers and colleagues for their assistance and cooperation.

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In 1947, Dr. Rabe joined Standard Elektrik Lorenz. He started in the development department of the telephone division and is now head of a planning group for wire communication in the transmission and navigation division.

**L. C. Deschuytere.** Biography appears on page 47.

# Statistical Method of Analyzing Long-Term Tropospheric Loss

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## 1. Introduction

A major problem in designing a tropospheric-scatter communication system is to predict the transmission loss so that equipment may be selected that is capable of providing a given degree of propagation reliability. It seems quite likely from the analysis to be presented that it will be possible to obtain more-accurate ways of predicting tropospheric loss.

Currently, the only weather variable used in predicting tropospheric-scatter loss is the refractive index  $N$  [1-4]. Through the use of a statistical technique called multiple correlation, it will be shown that other weather variables correlate with signal strength, sometimes to a higher degree than  $N$ . These weather variables are the atmospheric pressures at ground level and in the troposphere. They are as easy to obtain as  $N$  and therefore are valuable for forecasting.

The data for this paper were obtained from path-loss tests conducted in the Mediterranean area [5]. Table 1 lists the path characteristics.

## 2. Multiple Correlation

The theory of multiple correlation, as applied to signal levels, assumes that the signal

level is a linear function of certain weather variables, plus an error quantity. This may be written symbolically as

$$S = f(w) + K$$

where  $S$  = signal strength  
 $w$  = various weather variables  
 $K$  = error quantity.

The procedure is, symbolically, to find the function  $f$  that minimizes the error  $K$  (by the least-squares method) and then to see how much smaller the error  $K$  is than the original variation of  $S$ . If the value of  $K$  is less than the variation of  $S$ , then it may be said that the weather variables explain part of the variation of  $S$  or that knowledge of the weather gives additional knowledge of the signal strength. This increase in information may be expressed precisely as the ratio

$$p^2 = 1 - \frac{\text{variance } K}{\text{variance } S}$$

$p$  = correlation coefficient

where  $100p^2$  has the interpretation of being the percentage of variation of  $S$  explained by the weather. Hence, for example, in the case of the London-Paris path, Table 5, the variable  $P_0$  explains 68.89 percent of the

TABLE 1  
 PATH CHARACTERISTICS

Path	Date	Frequency in Mega-cycles per Second	Distance in Miles (Kilometers)	Scatter Angle in Degrees
Majorca-Sardinia	12 April-17 May	1965	344 (553)	32
Minorca-Sardinia	12 June-17 July	1965	279 (449)	31
Reggio di Calabria, Italy-Wheelus Air Force Base, North Africa	6 May-17 June	1965	391 (629)	51.7
	6 May-17 June	872	391 (629)	51.7
Catanzaro, Italy-Kefallinia, Greece	29 March-6 May	872	239 (385)	7
London-Paris	18 January-15 February	749	180 (290)	10

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variation of the signal strength, an evidently considerable amount.

To proceed precisely let

$$S_i = A_1 N_i + A_2 H_{500i} + A_3 P_{gi} + A_4 T_{uai} + A_5 \tau_i + B + K \quad (1)$$

where  $A_1 \cdots A_5$  and  $B$  are constants and

$S_i$  = signal strength in decibels referred to 1 milliwatt on the  $i$ th day of the test

$N_i$  = refractive index on the  $i$ th day of the test

$H_{500i}$  = height necessary to achieve 500-millibar pressure on the  $i$ th day of the test

$P_{gi}$  = ground pressure on the  $i$ th day of the test

$T_{uai}$  = upper-atmosphere temperature on the  $i$ th day of the test

$\tau_i$  = dew point on the  $i$ th day of the test

$K$  = a random variable with expected value zero.

The usual least-squares method is used to find values of  $A_1 \cdots A_5$  and  $B$  so that the error is minimum, or the variance of  $K$  is as small as possible [6].

All variables in this paper are in daily units, since they were available only in that form. Other units, such as quarter days, might have been more suitable.

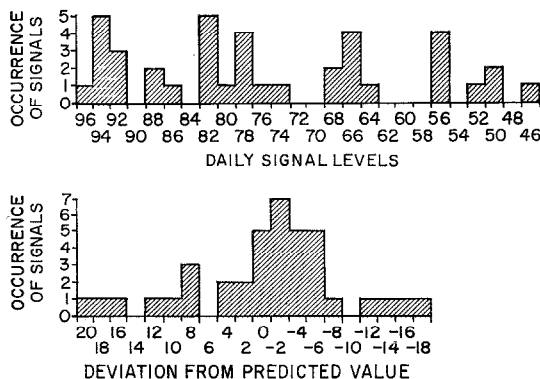


Figure 1—Signal occurrences and deviations from predicted values, Catanzaro-Kefallinia.

Application of the chi-square test [7] has shown that the distributions of quarter-hourly medians of the signals on the paths studied in this paper are not log-normal. However, the random variable  $K$  was tested for the Catanzaro-Kefallinia path and found to be normally distributed. Table 2 and Figure 1 give the details. This result is inconclusive since only 39 readings were taken on this path, and the chi-square test ideally requires large amounts of data. Also, the test was applied on only one path because the data on the other paths were insufficient.

On the assumption that  $K$  is normally distributed, the following mathematical model may be used to predict signal strength. The signal is a linear function of the above-mentioned weather variables plus a normally distributed error quantity.  $K$  is normally distributed presumably because the effects of the non-normal weather variables have been removed and only the random normal effects of the troposphere act on the signal.

To determine whether the added weather variables are helpful in explaining signal-strength variation, the correlation coefficient of the signal was considered first as a function

Deviation	Actual Occurrences	Theoretical Occurrences Assuming Normality (Standard Deviation = 9; Mean = 0)
10 and higher	5	5.2
4 to 10	5	7.6
0 to 4	7	6.6
0 to -4	9	6.6
-4 to -10	9	7.6
-10 and lower	4	5.2
	39	38.8

$$S = -0.4941 T_{ua} - 0.007399 H_{700} - 0.04719 H_{300} - 0.0419 H_{500} - 0.2927 N - 0.1340 \tau + 874$$

Chi-square statistic = 2.1.  
Chi-square statistic for 50-percent confidence with three degrees of freedom = 2.3.

of  $N$  alone and then as a function of all the variables. For the Catanzaro-Kefallinia path, the correlation coefficient squared as a function of  $N$  alone was 0.20 and as a function of other weather variables was 0.63. This change is statistically significant and clearly indicates that variables other than  $N$  are important in predicting signal strength [7].

Since the addition of weather variables  $H_{500i}$ ,  $P_{\theta i}$ ,  $T_{u\theta i}$ , and  $\tau_i$  increased the correlation coefficient, it was decided to add still more variables. These were functions of the original variables. Thus far only

$$S_i = A_1X_{i1} + A_2X_{i2} + \dots + A_5X_{i5} + B + K_i \quad (2)$$

has been considered. Signal strength might be more accurately shown by a curve of

$$S_i = A_1X_{i1} + B_1X_{i1}^2 + C_1X_{i1}^3 + D_1 \log X_{i1} + E_11/X_{i1} + A_2X_{i2} + B_2X_{i2}^2 + \dots + E_51/X_{i5} + B + K_i \quad (3)$$

Equation (3) has 25 terms. Assuming that each term is a separate variable [7], (3) is rewritten

$$S_i = \sum_{j=1}^{25} A_jX_{ij} + B + K_i \quad (4)$$

It is useful to add still more terms to (4). The theory of multiple correlation assumes that the number of variables is small compared with the number of readings taken. Also, we should expect that only a few of the 25 variables will explain most of the signal-strength variation and that the others then add little information. Thus a method was needed to determine the variables that explain most of the variation.

A method used in meteorological studies, called the screening procedure, is used to find the most-significant variables [8]. The method described here is a modification of [8] used because it is more easily programmed for computer solution.

The computer is programmed to compute the correlation coefficient of  $S$  on each of the 25

variables in (4) separately. It then determines the highest one. Suppose that  $X_{17}$  is the variable with the highest correlation coefficient. The computer then calculates the correlation coefficient of  $S$  with  $X_{17}$  and all the other variables and determines which expression of the form  $AX_{17} + BX_j + D$  has the highest correlation with  $S$ , where  $X_j$  is the variable other than  $X_{17}$  that produces this highest correlation.

Suppose that  $X_2$  is the variable which, with  $X_{17}$ , best explains  $S$ . The computer then determines the best equation of the form  $A^*X_{17} + B^*X_2 + CX_j + D$ , where  $X_j$  is a variable other than  $X_{17}$  or  $X_2$ . In this manner as many variables are added as desired. Note that at each stage the correlation coefficients of all variables must be recomputed. Also, as shown in Tables 3 through 10, variables that were insignificant after the first set of calculations may become important after the second. The reverse is also true; variables that were relatively important after the first set of calculations may become insignificant after the second.

These computed values change because the different weather variables are related not only to the signal strength but also to each other. For example, the pressures in the upper atmosphere are evidently related to the ground pressures. Two variables may explain the same change in the signal and therefore one is superfluous. Alternatively, the change in signal may be caused by the difference or sum of two weather variables, in which case both are needed.

It often happens that the signal strength and weather variables change together, but not exactly at the same time. A possible reason is that the weather variables are not measured at the location where they affect the signal. Thus a weather front may affect the weather-measuring devices a day or two earlier or later than it affects the signal.

Accordingly, another way to improve the correlation is as follows. It was assumed that



## Analyzing Long-Term Tropospheric Loss

TABLE 3  
REGGIO DI CALABRIA-WHEELUS AIR FORCE BASE CORRELATION COEFFICIENTS SQUARED AT 1965  
MEGACYCLES PER SECOND

Variable*	S on	S on 6 and	S on 6, 9, and	S on 6, 9, 8, and	S on 6, 9, 8, 1, and
1. $H_{500}$ - (Reggio)	0.0563	0.4277	0.5301	<b>0.6044</b>	
2. $N$ - (Reggio)	0.1226	0.4183	0.5208	0.5700	0.6046
3. $N$ (Reggio)	0.2955	0.4802	0.5329	0.5798	0.6239
4. $N$ (Wheelus)	0.0968	0.4237	0.5357	0.5737	0.6104
5. $P_g$ (Reggio)	0.2619	0.4271	0.5432	0.5686	0.6136
6. $P_g$ (Wheelus)	<b>0.4148</b>				
7. $T_{ua}$ (Reggio)	0.2131	0.4271	0.5214	0.5800	<b>0.6268</b>
8. $H_{500}$ (Reggio)	0.0533	0.4459	<b>0.5653</b>		
9. $H_{500}$ (Wheelus)	0.2202	<b>0.5205</b>			

$S = -0.9200 H_{500} + 2.585 P_g - 1964.$

\* Each minus (or plus) sign following a variable means that the variable was measured one day later (or earlier) than the signal strength was measured.

TABLE 4  
REGGIO DI CALABRIA-WHEELUS AIR FORCE BASE CORRELATION COEFFICIENTS SQUARED AT 872  
MEGACYCLES PER SECOND

Variable	S on	S on 8 and	S on 8, 2, and	S on 8, 2, 9, and	S on 8, 2, 9, 3, and
1. $H_{500}$ - (Reggio)	0.1851	0.5711	0.6581	0.6739	0.6808
2. $N$ - (Reggio)	0.0828	<b>0.6563</b>			
3. $N$ (Reggio)	0.0135	0.5610	0.6681	<b>0.6786</b>	
5. $N$ (Wheelus)	0.0004	0.5514	0.6621	0.6743	0.6791
5. $P_g$ (Reggio)	0.1394	0.5709	0.6563	0.6746	<b>0.6810</b>
6. $P_g$ (Wheelus)	0.0464	0.5657	0.6573	0.6731	0.6797
7. $T_{ua}$ (Reggio)	0.3133	0.5547	0.6658	0.6762	0.6800
8. $H_{500}$ (Reggio)	<b>0.5404</b>				
9. $H_{500}$ (Wheelus)	0.3455	0.5441	<b>0.6731</b>		

$S = -0.5763 H_{500} + 0.2585 (N-) + 366.$

TABLE 5  
LONDON-PARIS CORRELATION COEFFICIENTS SQUARED

Variable	S on	S on 1 and	S on 1, 11, and	S on 1, 11, 7, and	S on 1, 11, 7, 3, and
1. $P_g$ (Paris)	<b>0.6861</b>				
2. $P_g$ (London)	0.5524	0.6889	0.7383	0.7622	0.7789
3. $\tau$ (London)	0.2235	0.6903	0.7367	<b>0.7767</b>	
4. $N$	0.3966	0.6901	0.7365	0.7627	0.7772
5. $N+$	0.1366	0.6864	0.7414	0.7628	0.7767
6. $N++$	0.0207	0.6922	0.7477	0.7620	0.7771
7. $\tau+$	0.3213	0.7045	<b>0.7620</b>		
8. $\tau++$	0.0460	0.6863	0.7432	0.7632	0.7780
9. $P_g++$ (London)	0.2205	0.6921	0.7547	0.7671	<b>0.7843</b>
10. $P_g+$	0.3604	0.6893	0.7368	0.7624	0.7768
11. $N-$	0.3516	<b>0.7365</b>			

$S = -0.4313 P_g + 528.$

TABLE 6  
KEFALLINIA-CATANZARO CORRELATION COEFFICIENTS SQUARED

Variable	S on	S on 7 and	S on 7, 5, and	S on 7, 5, 6, and	S on 7, 5, 6, 1, and
1. $P_\theta$ (Kefallinia)	0.3070	0.5552	0.6335	<b>0.6744</b>	
2. $P_g$ (Catanzaro)	0.2854	0.5522	0.6242	0.6481	0.6773
3. $N-$	0.2080	0.5803	0.6275	0.6424	<b>0.6851</b>
4. $N$	0.3756	0.5664	0.6286	0.6489	0.6745
5. $N--$	0.1772	<b>0.6238</b>			
6. $H_{500}-$	0.4214	0.6023	<b>0.6424</b>		
7. $H_{500}$	<b>0.5521</b>				

$S = -1.211 H_{500} - 0.7828 (N--) + 1012.$

TABLE 7  
SARDINIA-MAJORCA CORRELATION COEFFICIENTS SQUARED

Variable	S on	S on 8 and	S on 8, 4, and	S on 8, 4, 5, and	S on 8, 4, 5, 3, and	S on 8, 4, 5, 3, 1, and
1. $N-$	0.0091	0.3457	0.3842	0.4499	<b>0.4769</b>	
2. $H_{500}-$ (Sardinia)	0.1083	0.3701	0.3871	0.4434	0.4662	0.4784
3. $N$	0.1055	0.3632	0.3990	<b>0.4659</b>		
4. $P_g$ (Sardinia)	0.1291	<b>0.3734</b>				
5. $P_g$ (Majorca)	0.0047	0.3619	<b>0.4433</b>			
6. $T_{ua}$ (Sardinia)	0.2455	0.3452	0.3895	0.4433	0.4666	0.4775
7. $T_{ua}$ (Majorca)	0.1919	0.3425	0.3760	0.4436	0.4670	<b>0.4789</b>
8. $H_{500}$ (Sardinia)	<b>0.3417</b>					
9. $H_{500}$ (Majorca)	0.1107	0.3526	0.4044	0.4438	0.4659	0.4769

$S = 1.0538 H_{500} - 1.5608 P_g - 0.7904 P_g + 1069.$

the signal strength on any given day was a function of the refractive index, for example, on the day that the signal reading was taken. It was also assumed that the signal strength was a function of the refractive index measured up to two days before and two days after the signal reading was taken.

Hence, where it was assumed that  $S_i = AN_i + B + K_i$ , or that the signal strength on the  $i$ th day was given approximately as a linear function of the refractive index on the  $i$ th day, it was now assumed that

$$S_i = AN_i + A_{-1}N_{i-1} + A_{-2}N_{i-2} + A_{-3}N_{i-3} + A_{+1}N_{i+1} + A_{+2}N_{i+2} + A_{+3}N_{i+3} + B + K_i. \quad (5)$$

We may say that the signal is a function not only of the present refractive index but also

of past and future refractive indexes. The idea is similar to that used in filter theory, where the signal coming out of a filter is not only a function of the signal going into it but also a function of the past signal going into it.

We must determine whether the assumptions in (5) are justified for both the refractive-index variable and the other weather variables. The coefficients in (5) are found using the least-squares method and the assumptions are justified if there is a significant increase in the correlation coefficient  $P$  above that derived from  $N$  alone.

For example, where the signal lags behind the refractive index by exactly one day, the screening procedure shows that  $N_{i-1}$  is the only significant variable.

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TABLE 8  
SARDINIA-MAJORCA CORRELATION COEFFICIENTS SQUARED

Variable	S on	S on 8 and	S on 8, 34, and	S on 8, 34, 4, and	S on 8, 34, 4, 16, and
1. $N-$	0.0091	0.3457	0.5543	0.6536	0.7046
2. $H_{500}-$ (Sardinia)	0.1083	0.3701	0.5552	0.6579	0.7038
3. $N$	0.1055	0.3632	0.5573	0.6615	0.7156
4. $P_g$ (Sardinia)	0.1291	0.3743	0.6528		
5. $P_g$ (Majorca)	0.0047	0.3619	0.5785	0.6544	0.7039
6. $T_{ua}$ (Sardinia)	0.2455	0.3452	0.5720	0.6588	0.7039
7. $T_{ua}$ (Majorca)	0.1919	0.3425	0.5830	0.6931	0.7051
8. $H_{500}$ (Sardinia)	0.3417				
9. $H_{500}$ (Majorca)	0.1107	0.3527	0.5502	0.6578	0.7039
10. $1/N-$	0.0162	0.3446	0.5575	0.6530	0.7040
11. $1/H_{500}-$	0.0420	0.3769	0.5619	0.6537	0.7036
12. $1/N$	0.0801	0.3580	0.5615	0.6701	0.7214
13. $1/P_g$ (Sardinia)	0.0000	0.3417	0.5498	0.6528	0.7034
14. $1/P_g$ (Majorca)	0.0000	0.3417	0.5498	0.6528	0.7034
15. $1/T_{ua}$ (Sardinia)	0.1491	0.3566	0.5879	0.6709	0.7068
16. $1/T_{ua}$ (Majorca)	0.1316	0.3450	0.5811	0.7034	
17. $1/H_{500}$ (Sardinia)	0.1839	0.3547	0.5505	0.6528	0.7035
18. $1/H_{500}$ (Majorca)	0.0337	0.3460	0.5538	0.6671	0.7056
19. $(N-)^2$	0.0098	0.3457	0.5543	0.6537	0.7047
20. $(H_{500}-)^2$	0.1078	0.3707	0.5552	0.6608	0.7038
21. $N^2$	0.1070	0.3632	0.5572	0.6614	0.7158
22. $P_g^2$	0.1291	0.3742	0.6527	0.6607	0.7078
23. $T_{ua}^2$ (Sardinia)	0.2872	0.3609	0.5654	0.6556	0.7035
24. $T_{ua}^2$ (Majorca)	0.2090	0.3454	0.5841	0.6891	0.7040
25. $H_{500}^2$ (Sardinia)	0.3380	0.5495	0.5498	0.6528	0.7035
26. $H_{500}^2$ (Majorca)	0.1114	0.3529	0.5502	0.6579	0.7038
27. $(N-)^3$	0.0104	0.3456	0.5542	0.6538	0.7048
28. $(H_{500}-)^3$	0.1073	0.3712	0.5551	0.6581	0.7038
29. $N^3$	0.1084	0.3632	0.5571	0.6614	0.7160
30. $P_g^3$ (Sardinia)	0.1292	0.3740	0.6525	0.6701	0.7076
31. $P_g^3$ (Majorca)	0.0047	0.3620	0.5783	0.6544	0.7039
32. $T_{ua}^3$ (Sardinia)	0.3184	0.3815	0.5603	0.6540	0.7035
33. $T_{ua}^3$ (Majorca)	0.2182	0.3489	0.5845	0.6856	0.7035
34. $H_{500}^3$ (Sardinia)	0.3342	0.5498			
35. $H_{500}^3$ (Majorca)	0.1121	0.3531	0.5502	0.6579	0.7038
36. $\log N-$	0.0108	0.3427	0.5514	0.6529	0.7035
37. $\log H_{500}-$	0.0366	0.3828	0.5799	0.6591	0.7130
38. $\log N$	0.1554	0.3941	0.5696	0.6676	0.7171
39. $\log P_g$ (Sardinia)	0.0003	0.3556	0.5774	0.6667	0.7105
40. $\log P_g$ (Majorca)	0.0083	0.3460	0.5834	0.6691	0.7214
41. $\log T_{ua}$ (Sardinia)	0.1969	0.3425	0.5801	0.6632	0.7039
42. $\log T_{ua}$ (Majorca)	0.1607	0.3420	0.5827	0.7007	0.7079
43. $\log H_{500}$ (Sardinia)	0.2919	0.3520	0.5540	0.6558	0.7079
44. $\log H_{500}$ (Majorca)	0.0133	0.4069	0.5522	0.6891	0.7162

$$S = -1.611 P_g - 62.41 H_{500} + 0.0000629 (H_{500})^3 + 25.645.$$

If adding the variables  $N_{i-1}$  and  $N_{i+1}$  to the multiple correlation equation tended to increase the correlation with signal strength, this might indicate that it is the change in refractive index that determines signal strength and not the value, as such, of the refractive index. When we optimize the  $A$ 's in  $S_i = AN_i + A_{-1}N_{i-1} + A_{+1}N_{i+1} + B + K_i$ , we might derive an expression of the form  $S_i = A(N_i - N_{i-1}) + B(N_i - N_{i+1}) + C + K_i$ .

Thus, if the change of refractive index accounts for the value of the signal strength, our equations will indicate it.

Another approach to the problem is to consider weather data from more than one station. We have previously considered

$$S_i = AN_i + A_{+1}N_{i+1} + A_{+2}N_{i+2} + A_{-1}N_{i-1} + A_{-2}N_{i-2} + B + K_i.$$

TABLE 9  
SARDINIA-MINORCA CORRELATION COEFFICIENTS SQUARED

Variable	S on	S on 3 and	S on 3, 1, and	S on 3, 1, 9, and
1. $H_{500}-$ (Minorca)	0.0627	<b>0.4581</b>		
2. $N-$	0.0279	0.2420	0.4781	0.5144
3. $N$	<b>0.2417</b>			
4. $P_g$ (Sardinia)	0.0513	0.3093	0.4813	0.4970
5. $P_g$ (Minorca)	0.0057	0.3485	0.4826	0.5054
6. $T_{ua}$ (Sardinia)	0.0304	0.3000	0.4779	<b>0.5298</b>
7. $T_{ua}$ (Minorca)	0.0295	0.2838	0.4646	0.4936
8. $H_{500}$ (Sardinia)	0.0512	0.2800	0.4638	0.4956
9. $H_{500}$ (Minorca)	0.0606	0.3555	<b>0.4863</b>	

$S = -1.929 (H_{500}-) - 0.8955 N + 1753.$

TABLE 10  
SARDINIA-MINORCA CORRELATION COEFFICIENTS SQUARED

Variable	S on	S on 10 and	S on 10, 8, and	S on 10, 8, 12, and	S on 10, 8, 12, 28, and
1. $H_{500}-$ (Minorca)	0.0627	0.4666	0.4856	0.5383	0.5904
2. $N-$	0.0279	0.2501	0.4988	0.5538	0.6181
3. $N$	0.2417	0.2725	0.5038	0.5381	0.5888
4. $P_g$ (Sardinia)	0.0513	0.3138	0.5087	0.5401	0.5891
5. $P_g$ (Minorca)	0.0057	0.3512	0.5112	0.5369	0.5954
6. $H_{500}$ (Sardinia)	0.0512	0.2870	0.4930	0.5584	0.5902
7. $H_{500}$ (Minorca)	0.0606	0.3594	0.5243	0.5847	0.6079
8. $1/H_{500}-$ (Minorca)	0.0998	<b>0.4856</b>			
9. $1/N-$	0.0251	0.2500	0.5005	0.5575	0.6216
10. $1/N$	<b>0.2492</b>				
11. $1/P_g$ (Sardinia)	0.0012	0.2503	0.4867	0.5401	0.6184
12. $1/P_g$ (Minorca)	0.0163	0.2930	<b>0.5368</b>		
13. $1/H_{500}$ (Sardinia)	0.0524	0.2932	0.4964	0.5638	0.5880
14. $1/H_{500}$ (Minorca)	0.0430	0.3329	0.5230	0.5756	0.5921
15. $(H_{500}-)^2$ (Minorca)	0.0612	0.4645	0.4857	0.5381	0.5915
16. $(N-)^2$	0.0310	0.2499	0.4965	0.5480	0.6130
17. $N^2$	0.2181	0.2808	0.4973	0.5383	0.5891
18. $P_g^2$ (Sardinia)	0.0446	0.3054	0.5026	0.5379	0.5936
19. $P_g^2$ (Minorca)	0.0115	0.3511	0.5123	0.5369	0.5990
20. $H_{500}^3$ (Sardinia)	0.0435	0.2851	0.4923	0.5582	0.5924
21. $H_{500}^3$ (Minorca)	0.0589	0.3604	0.5247	0.5859	0.6084
22. $(H_{500}-)^3$ (Minorca)	0.0597	0.4623	0.4859	0.5378	0.5928
23. $(N-)^3$	0.0336	0.2497	0.4941	0.5432	0.6075
24. $N^3$	0.1884	0.2882	0.4974	0.5390	0.5886
25. $P_g^3$ (Sardinia)	0.0380	0.2977	0.4974	0.5369	0.5989
26. $P_g^3$ (Minorca)	0.0160	0.3423	0.5093	0.5369	0.6023
27. $H_{500}^3$ (Sardinia)	0.0365	0.2833	0.4917	0.5580	0.5901
28. $H_{500}^3$ (Minorca)	0.0571	0.3536	0.5251	<b>0.5871</b>	
29. $\log H_{500}-$ (Minorca)	0.0668	0.3613	0.4974	0.5387	0.5954
30. $\log N-$	0.0550	0.2492	0.4968	0.5498	0.6118
31. $\log N$	0.2329	0.2492	0.5090	0.5775	0.6131
32. $\log P_g$ (Sardinia)	0.0110	0.2494	0.5093	0.5494	0.6083
33. $\log P_g$ (Minorca)	0.0074	0.2603	0.4859	0.5474	0.5888
34. $\log H_{500}$ (Sardinia)	0.0755	0.2660	0.4866	0.5389	0.6110
35. $\log H_{500}$ (Minorca)	0.0668	0.2817	0.4900	0.5426	0.5909

$S = 891\,204 (1/N) + 613\,138 (1/H_{500}-) + 131\,187 (1/P_g) - 2213.$

We now consider

$$S_i = A_1N_{i1} + A_2N_{i2} + A_3N_{i3} + A_4N_{i4} + B + K_i \quad (6)$$

where  $N_{i1}$ ,  $N_{i2}$ ,  $N_{i3}$ , and  $N_{i4}$  are values of the refractive index from different weather stations along the path. There is certainly a station whose measurement of the refractive index will correlate best with the signal strength. We thus might compute the correlation coefficient of each weather station's measurement with the signal strength  $S$  and use the highest. However, a better approach may be to use all the variables in (6). It is likely that, although there is one best station, the other stations are able to add useful information. We agreed earlier that changes in time may affect the signal; by using the extra variables in (6), geographical changes may also prove significant in predicting the signal.

We derive finally

$$S = A_1X_1 + A_2X_2 + \cdots + A_PX_P + B + K_i \quad (7)$$

where the variables  $X_1$ ,  $X_2$ ,  $\cdots$ ,  $X_P$  are the original weather variables such as refractive index, ground pressure, upper-atmosphere pressure, and dewpoint

- (A) taken at different times
- (B) taken at different locations
- (C) functions of these variables.

This gives an impracticable number of variables. Hence we use the screening procedure to find the five most important.

Due to lack of time, almost all the computer runs were made assuming that the signal was a linear function of the weather variables. Tables 8 and 10 show the effect of considering the signal as a function or functions of the weather variables for the Sardinia-Majorca and Sardinia-Minorca paths. The linear cases for these paths are presented in Tables 7 and 9 for comparison.

### 3. Evaluating Results

It is evident from Tables 3 through 10 that there is very-little increase in correlation after the two or three most-significant variables are used. For example, in Table 4, the 500-millibar pressure level and the refractive index phased one day behind have a correlation coefficient squared of 0.6563. Adding the three next-highest variables increases the correlation coefficient squared only to 0.6810. To minimize the number of independent variables used, the final equation will use only those that give a significant increase in correlation.

A significant increase in correlation can be defined rigorously by use of the  $F$  ratio [7]. In this study, if the addition of a variable to the equation did not lead to an increase in the correlation coefficient squared of at least 0.05, its effect was considered to be the result of chance.

Tables 3 through 10 present the final correlation coefficients and multiple correlation equations. The main purpose of this study was to find an equation that held for all sites. While the equations of Tables 3 through 10 are similar, their differences are clearly not the results of chance. However, despite the failure to achieve a prediction equation, some significant facts become clear.

The first is that the outstanding measure of signal strength is the 500-millibar upper-atmosphere variable. It was one of the significant variables on every path for which it was available.

Furthermore, while the coefficient changes of the 500-millibar variable were large, their deviations were not as great as the coefficient deviations of the other variables. This variable seems to be a more-stable measure of signal strength than the refractive index.

A second significant fact is that a change in space or time in any of the variables does not influence signal strength.

A third significant fact is that the final correlation coefficients tend to group around 0.75. Thus while the individual variables tend to have a wide range of coefficients, the maximum amount of information about the signal that can be extracted from the variables considered here tends to remain relatively constant from site to site.

It is impossible to tell at this time why the equations differ so much from site to site. A possible explanation is that the characteristics of the paths differ. All the paths were over water except for London-Paris. This seems to be their only common characteristic. A fairly random mixture of frequencies, scatter angles, and lengths existed for the paths; any of these factors could conceivably influence the coefficients of the equations.

Another possible explanation for the large variations in coefficients is that the mathematical model is incorrect (refer to Section 4).

A third possible explanation is the presence of errors in the input data. For example, 36 percent of the low-signal data was lost on the Reggio-Wheelus 1965-megacycle-per-second path. The 500-millibar data were collected from weather maps, resulting in some inaccuracies. Some of the ground-pressure data were collected from weather maps and some from barometers at the sites.

Another possible explanation is that the weather variables were probably measured at different locations with respect to the incoming weather fronts at different sites. Since the location of the weather station makes a difference in the coefficients, and on no path are we sure that we are measuring at the best place, the accuracy of the equations derived from these inputs suffers. To avoid this, we might use the information from the weather station that correlates highest for each path. Incidentally, the best station may not be located in the middle of the path but at some point off the line between the two path terminations. For example, weather fronts generally come from the same direction and can conceivably

be measured more accurately before they move over the place where they affect the signal.

#### 4. Possible Improvements in Model

The theory of multiple correlation makes the following three assumptions:

- (A) The residuals  $K_i$  are normally distributed.
- (B) The values of  $K_i$  are independent of each other.
- (C) The expected value of  $K_i$  is the same for all  $i$  [6].

Even if the first two assumptions are untrue, the least-squares estimate of the coefficients  $A_j$  are unbiased and consistent [9]. This, however, is not true if the third assumption is untrue. The third assumption means that the signal strength can be predicted with equal accuracy on all days, whether the signal is high or low and however it is propagated.

Usually, days of low signal strength also have low variance, because their mode of propagation is probably mostly tropospheric scatter, which tends to be more stable than the ducting mode. Accordingly,  $K_i$  is smaller on days when the signal is lower.

When the expected value of all the  $K_i$  is not the same, we weight the values that are expected to have lower  $K_i$  [6]. When correlating signal strength with weather, this amounts to weighting the days during which the signal strength is lower.

This weighting was not applied in the present model because of lack of time. Weighted low-signal days would have counted more than high-signal days. Thus, for the days that interest us the most, there is the greatest degree of precision. A further possible advantage of weighting is that the equations for the different paths may be more nearly alike once the correct model is developed.

### 5. Acknowledgments

The author thanks Mr. F. J. Altman, under whose supervision this study was made and who suggested the use of the 500-millibar pressure levels. He also thanks Mr. J. Goldberg and Miss P. Moy, who did the programming.

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# Standard Telecommunication Laboratories

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## 1. Introduction

This is a survey of the organization of Standard Telecommunication Laboratories (STL), which was founded in 1945 to undertake long-term research and advanced development to support the work more closely connected with production pursued in the local laboratories of the manufacturing companies within the International Telephone and Telegraph (ITT) System.

Many of the original staff of STL were recruited from British Government war-time research establishments, and at the outset the total complement of about 200 were housed in a converted factory at Enfield on the northern outskirts of London. After a period of consolidation, STL gradually expanded as post-

war restrictions eased. In 1952, A. W. Montgomery, its first Managing Director and Director of Research, was succeeded by T. R. Scott, who negotiated and superintended STL's transfer to a new site of about 17 acres nearly 16 miles north of Enfield before himself retiring in favour of J. D. Clare in 1962.

The original plan of the new buildings, which are situated in open country, envisaged their eventual expansion from an initial 100 000 square feet (9300 square metres) to about twice this area. An extension of 14 000 square feet (1300 square metres) has already been completed.

Today, with a staff of about 600 under Mr. Clare's leadership, STL is one of the better-equipped and more-modern telecommunication

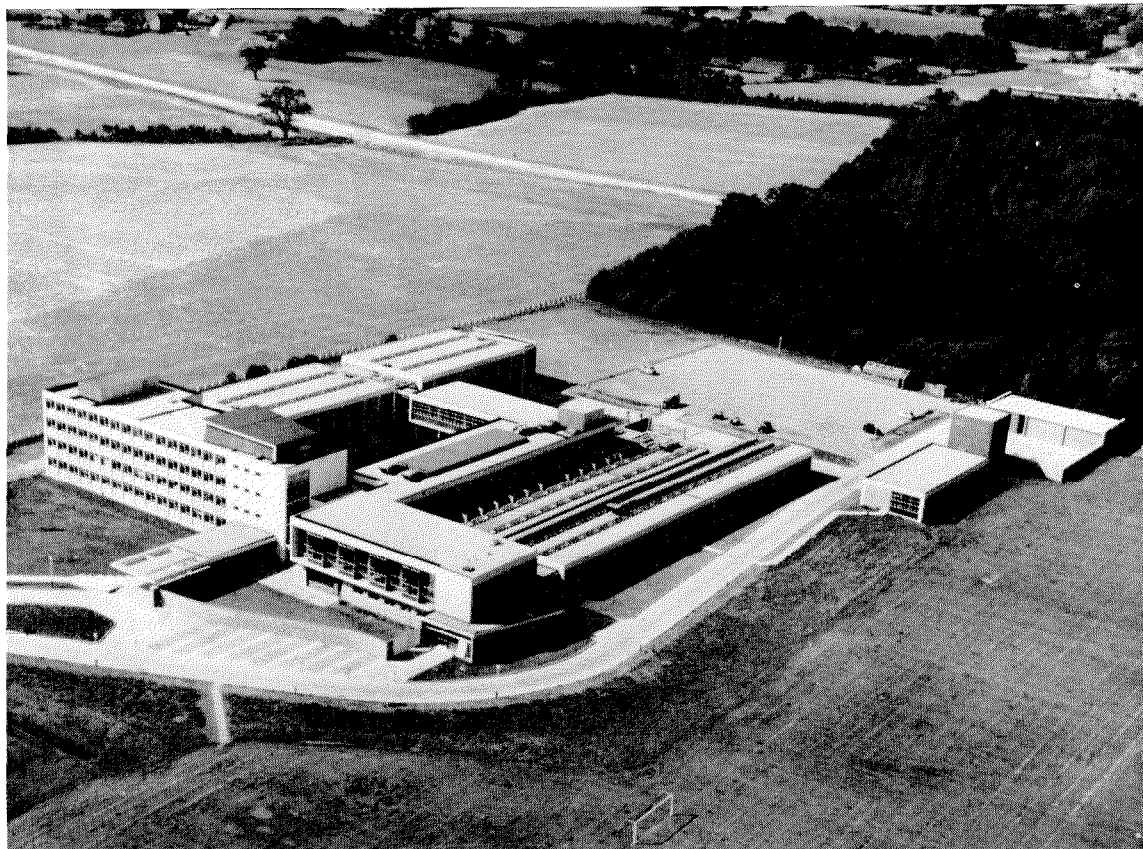


Figure 1—Aerial view of STL, taken before the addition of the third laboratory wing.



## Standard Telecommunication Laboratories

research laboratories in Europe (see Figures 1 through 4).

### 2. Research Philosophy

It is STL's main responsibility to undertake the long-term research and more-advanced development work likely to stimulate the future economic growth of the ITT system. Its programme, which includes many long-range projects unlikely to mature in less than 5 to 10 years, requires very-careful consideration if it is ultimately to yield benefits commensurate with the heavy capital and running costs involved.

It had, at the outset, to be decided how much basic research should be included in the programme, this always being a controversial subject in relation to a commercial company which is generally judged by business standards. Much basic research can perhaps most conveniently be done in universities, and STL keeps in close touch with it by financing many post-graduate research projects in colleges both at home and abroad. This, together with contacts maintained with the learned societies and with government research establishments through the work carried out for them on re-

search contracts, provides the chief external sources of information from which an Exploratory Research Group at STL prepares plans for its more-basic research programme.

Proposals for new systems originate with or are studied by an Advanced Development Planning Group which assesses desirability from all points of view, but with special emphasis on probable needs and economics. It then formulates design objectives in cooperation with Advanced Development Divisions who have the responsibility of demonstrating feasibility before handing over to manufacturing organizations for final design and manufacture.

Research and development involve a great variety of skills, both intellectual and manual. While creative thought flourishes best in an atmosphere of comparative freedom, objective research and advanced system development require, in addition, very-close cooperation between staff of different experience and specializations, with sufficient overall direction to create a single team working towards common objectives, if the results of their efforts are finally to be acceptable to the design, manufacturing, and commercial departments of the manufacturing companies responsible for their exploitation.



Figure 2—STL from the approach road, taken after the third laboratory wing was added.

### 3. Organizational Structure

The combined programme derived from all sources is put into effect by four Advanced Development Divisions in a general scheme of organization shown in Figure 5. The Exploratory Research Group at present absorbs nearly 40 per cent of the total laboratory effort, sub-contracting much of its work to the Advanced Development Divisions, on whose activities it has an important bearing. When projects are completed by the latter, they are then passed on to the design departments of the various associated manufacturing companies. These latter are kept advised of current progress through a half-yearly Development Progress Report, which also includes the work of STL's sister research company, Laboratoire Central de Télécommunications (LCT), in Paris.

Information is also disseminated throughout the ITT system by means of STL technical reports, memoranda, and documents, and through articles by STL staff published in the technical press. Such reports are supplemented by the work of a large number of technical committees and by frequent personal contact between engineers engaged in similar fields of activity in different companies.

#### 3.1 THE EXPLORATORY RESEARCH GROUP

This group, operating as it does in collaboration with the four Advanced Development Divisions to which it sub-contracts nearly half of its work, also keeps in close contact with research groups in universities and government establishments. Its programme, which includes both exploratory



Figure 3—General view of one of the transmission laboratories.

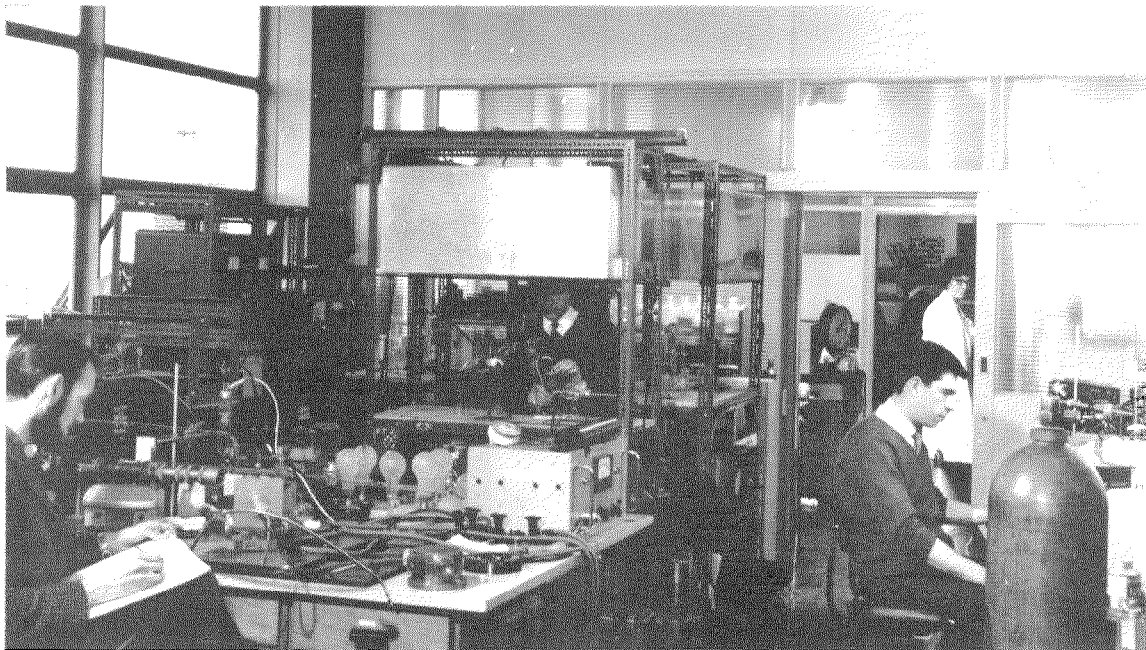


Figure 4—A smaller laboratory working on surface studies.

research and more specifically aimed projects, can best be illustrated by quoting a few typical examples of its activities.

The advent of the laser, which produces a narrow coherent beam of light, has suggested the possibility of using such beams as carrier waves for conveying information, since their extremely high frequency should enable them to accommodate an enormous number of communication channels, perhaps more than is required to meet all foreseeable needs. A start has therefore been made on a programme to develop such basic system components as modulators, detectors, and repeaters, in addition to coherent and non-coherent light sources and the transmission line itself. (See Figures 6 and 7.) These studies may also be extended to include the possibility of using optical methods to enhance the performance of digital systems.

The use of thin-film circuits incorporating resistors, capacitors, and inductors, as well as active devices such as amplifiers and modula-

tors, opens up many interesting possibilities, and a programme of work on surface physics is aimed at a better understanding of the problems involved in their development. This includes work on ultra-clean surfaces, low-energy electron emission, nucleation, deposition, and highly controlled thin-layer growth by evaporation and sputtering. Studies of the physics of ageing of the components included in thin-film modules and solid-state assemblies are also being pursued, supported by a programme of work to develop specialized test gear for the measurement of the many parameters of interest in such problems. (See Figure 8.)

Research on machines which will "learn" is being carried out with a view to constructing apparatus capable of operating effectively in complex circumstances which cannot be precisely foreseen. One application of special importance is that of speech recognition, as a result of which it may soon become possible for a machine economically to carry out any of a large

variety of instructions given to it by any of a wide range of voices.

For some time it has been known that, at elevated temperatures and at pressures of 100 000 atmospheres or more, there exists the possibility of creating materials with completely new molecular structures. Two well-known examples are the formation of diamond from graphite, and of a semi-conducting solid from liquid carbon disulphide. With the object of exploiting this new branch of chemistry, STL has set up an ultra-high-pressure laboratory in which it is intended to study the interaction between the molecular structure of a material and its physical properties. This particular laboratory was the first of its kind to be set up by a commercial undertaking in the United Kingdom. (See Figure 9.)

These are just a few examples of current projects in the Exploratory Research Group, much of the experimental side of whose work is sub-contracted to one or other of the Advanced Development Divisions.

### 3.2 THE ADVANCED DEVELOPMENT PLANNING GROUP

The ADPG comprises a number of senior engineers, all of whom have had considerable experience in the telecommunications field, and

many of whom have contributed extensively to such bodies as the CCITT \* and CCIR.† Their primary task is to assess long-term trends and prospects in the application of new types of systems. With this aim, they study feasibility, system performance, and economics, and consider probable fields of use, growth rates, relative costs, et cetera. Subjects for their investigations include those arising within STL, as well as many from external sources.

Results of the ADPG's studies are of great use in planning the programmes of work to be undertaken by the four Advanced Development Divisions by giving to them general performance objectives and keeping these objectives under constant review and in line with changing conditions in the outside world.

### 3.3 THE ADVANCED DEVELOPMENT DIVISIONS

At present there are four of these divisions, covering transmission systems, digital systems, materials and components, and acoustics. A brief description of their activities follows.

\* Comité Consultatif International Télégraphique et Téléphonique.  
 † Comité Consultatif International des Radio-Communications.

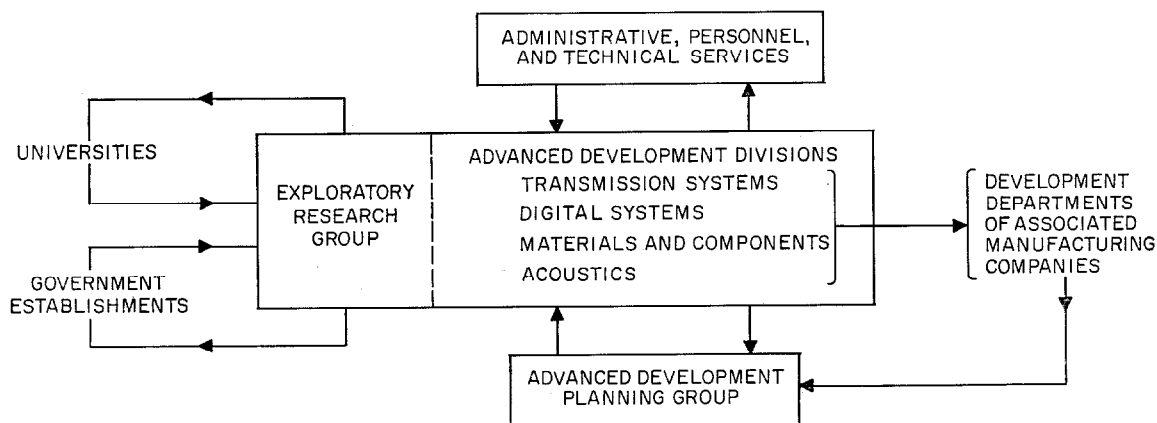


Figure 5—General organization plan of STL.

## Standard Telecommunication Laboratories

### 3.3.1 *Transmission Systems*

Very-rapid advance has taken place in transmission techniques during this century, and this has been possible only as a result of intense development and increasing system complexity. There have been continuous demands for more circuits per cable pair, radio channel, and square foot of floor space in terminal buildings. After the last war, ultra- and super-high-frequency radio systems operating at frequencies

up to 11 gigahertz came to the aid of the hard-pressed cable network, and STL, in conjunction with Standard Telephones and Cables (STC), developed and launched the first mainline super-high-frequency system to be put into service in Europe. This was the first such installation to include travelling-wave amplifiers.

To-day, progress is being made on the introduction of solid-state components into microwave radio systems, on the design of transistorized

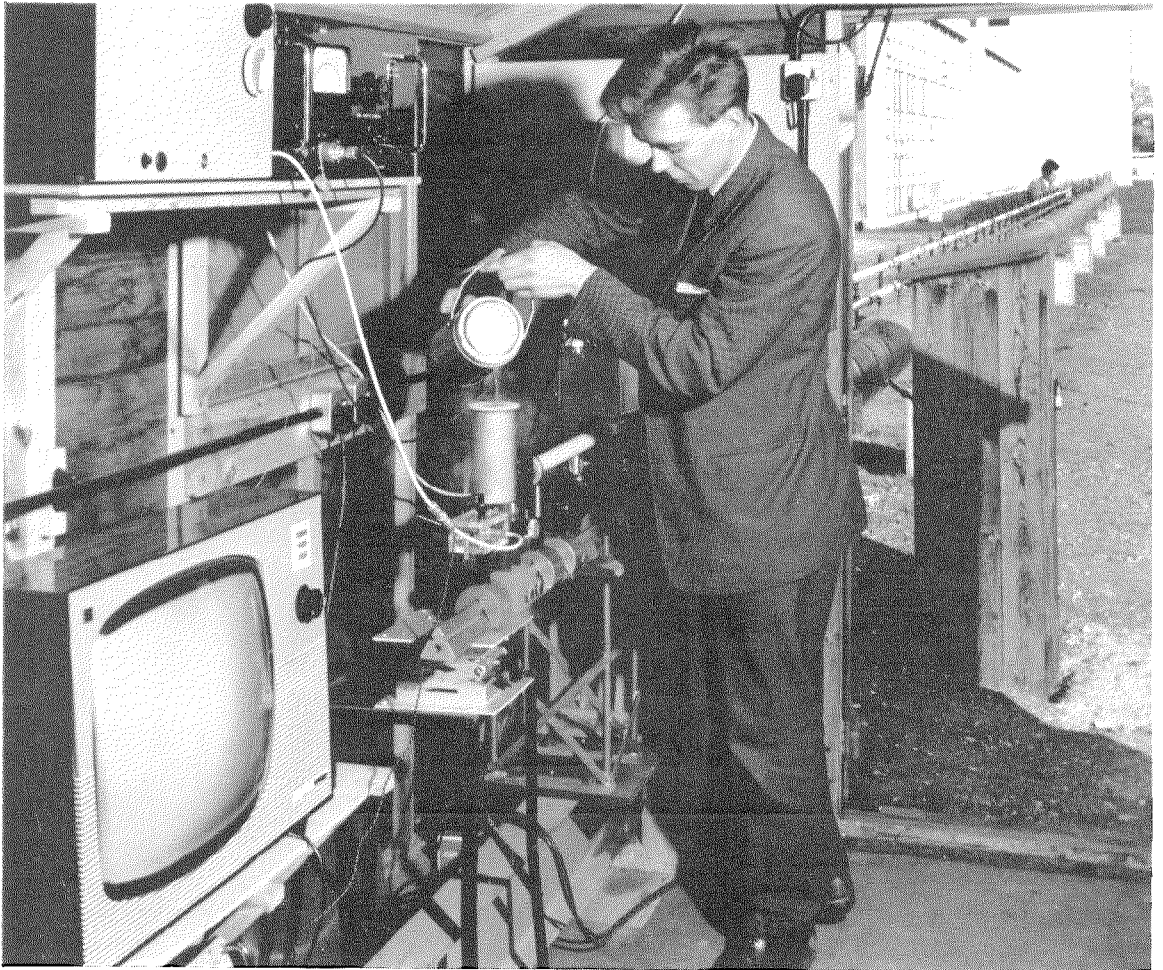


Figure 6—A demonstration of the modulation of a light beam by a television video signal transmitted over an optical pipe line. The engineer is filling a cryostat with liquid nitrogen in which a gallium-arsenide diode is situated. The television signal is fed via a transistor modulator (in front of the cryostat) to the diode, the modulated light from which is transmitted along the lower small-bore pipe to a mirror assembly (being adjusted by another engineer) and back along the upper pipe to a photomultiplier with a television monitor. The larger pipe is used for a multi-pass experiment with confocal mirrors.



repeaters for land and submarine cables, on improved electromechanical filters which may contribute to the reduction in size of terminal equipment, and on frequency-division systems and associated circuitry, taking advantage of the speed, low power requirements, reliability, and compactness of the latest semiconductor devices.

At the same time, work has been started on the realization of radically new types of transmission systems. Prominent amongst these is pulse-code modulation, an invention of A. H. Reeves of STL (seen holding the module in Figure 10). By means of new types of regenerative repeaters, pulse-code-modulated (pcm) signals can be transmitted long distances without cumulative impairment. Practical systems permitting the application of pcm to local-area teleph-

ony are now in an advanced stage of development. New types of circuit have been designed and new techniques of modular construction evolved to meet the ever-increasing demand for compactness and reliability.

In all of this work the requirements of both civil and military services have to be studied, and the development programme evolved is aimed at providing solutions to both sets of problems.

### 3.3.2 *Digital Systems*

The past decade has seen a rapid growth in the application of computers and other electronic data-processing devices to many fields, and a growing demand for the rapid, accurate, and economical collection of business statistics for transmission in digital form over existing

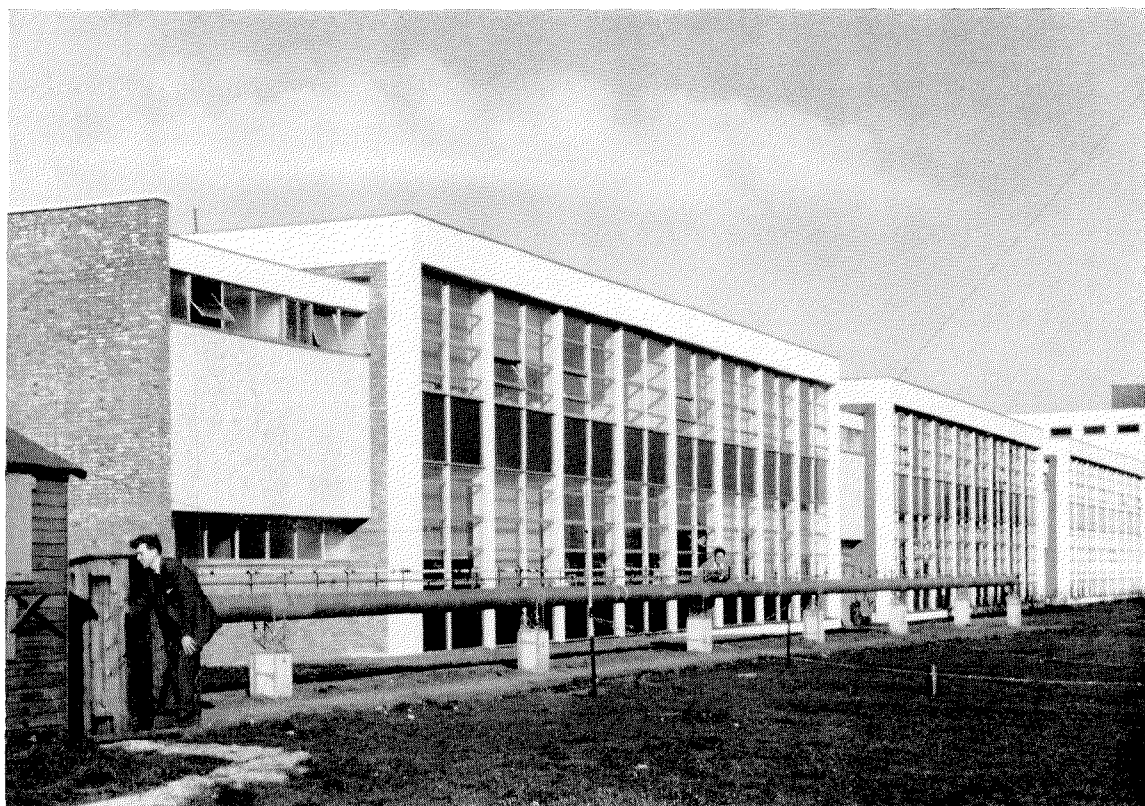


Figure 7—Another view of the experimental optical pipe lines with three of the laboratory wings in the background.

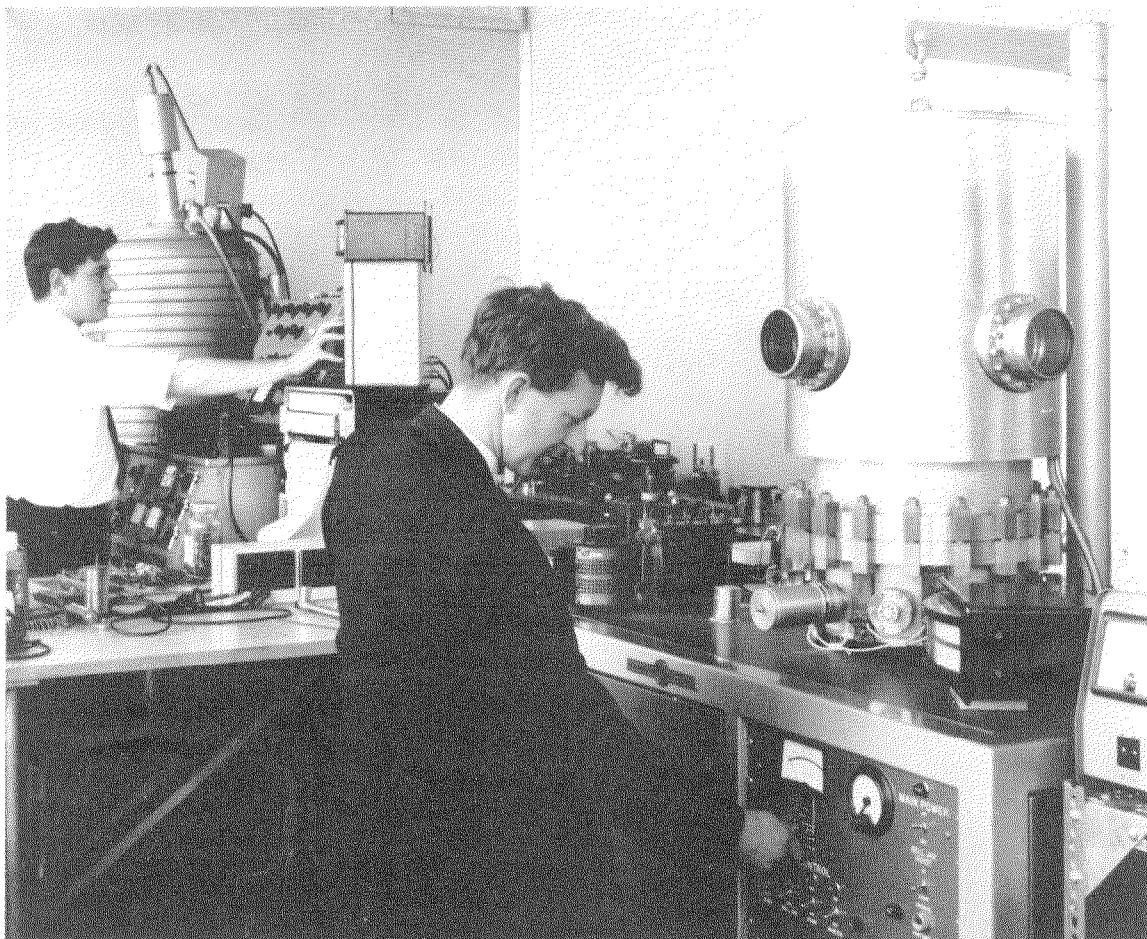


Figure 8—Ultra-high-vacuum ( $10^{-9}$  torr) equipment being used for the evaporation of silicon, including an evaporator for the deposition of thin films for optical filters.

communication networks. In fact, in all forms of communication, there is a trend towards digitalization.

The Digital Systems Division is actively engaged in the study, development, and application of digital techniques to meet future requirements. Several modulation methods offering higher transmission speeds for information in digital form on existing circuits are under consideration, and a programme of error rate measurements is being undertaken to cover them.

Development is well advanced on an interpolated data and speech transmission system in

which blocks of data in digital form are transmitted during pauses of the order of a tenth of a second in speech, thus achieving better economic utilization of telephone circuits. In an attempt to cope with the ever-increasing spate of technical literature, the application of digital techniques for information retrieval is being studied. Considerable attention is being given to non-percussive printing methods. An extensive programme on speech recognition of limited vocabulary by electronic means has been commenced in conjunction with the Acoustics Division.



Figure 9—A machine which can apply pressures of more than 100 000 atmospheres, or 1.5 million pounds per square inch (105 megagrammes per square centimetre) to a sample of material, which can be heated simultaneously to 2000 degrees centigrade. The aim is to produce new materials with improved properties which may be useful in new types of transistors or insulators.



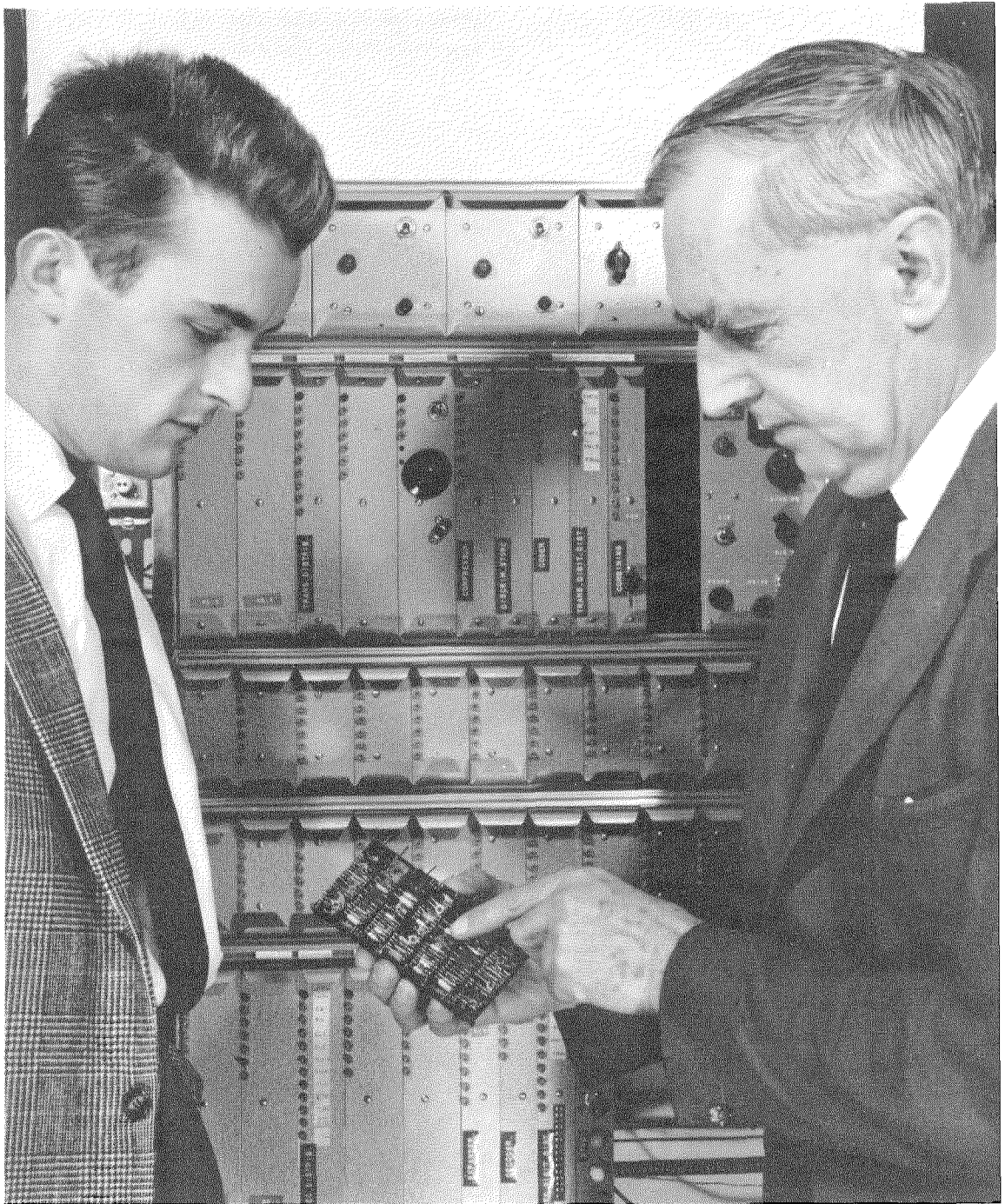


Figure 10—Pcm equipment, developed at STL, which enables 23 telephone circuits to be provided when previously there was only one four-wire circuit. To do this, miniaturization is essential, since the apparatus must, in general take up no more space than the single-circuit termination equipment which it replaces. The item being discussed is a 2-way repeater for all 23 channels and illustrates the degree of miniaturization achieved with these modules.

The programme also includes the integration of large-scale communication networks to cover the transmission of both speech and data.

### 3.3.3 *Materials and Components*

The Materials and Components Division (M&C) is concerned with the preparation, investigation, and evaluation of new materials, including magnetic materials, dielectrics, and semiconductors. It also covers the construction and evaluation of new devices ranging from silicon controlled rectifiers to millimetre reflex klystrons.

The silane-silicon production process, which enabled an ultra-pure silicon to be produced on a commercial scale, was an STL development. More recently, a grade of gallium arsenide electrically superior to any other available has been produced within the division. With this material, STL was successful in making one of the first gallium-arsenide lasers in Europe.

Apart from the work on improvement of crystal growing and zone refining techniques particularly applicable to semiconductors, effort is being directed towards developing methods of producing epitaxial layers of semiconductors, both elemental and compound, enabling new families of devices of improved performance and reliability to be developed.

In the materials evaluation department, research is carried out with specialized equipment which is also available to other sections. A high-resolution electron microscope is used in transmission, reflection, and diffraction studies, in particular for observing the lattice defects in semiconductors, and the nucleation process during the evaporation of thin films (see Figure 11). In the X-ray crystallographic section, investigations are undertaken concerned with imperfections in single crystals, detection and identification of new phases formed in special systems by the applications of ultra-high pressures, and the examination of materials in thin-film form using diffraction and fluorescence. The investigation of impurity behaviour in

semiconductor and other materials is carried out in the low-temperature section where studies involving Hall effect and intrinsic resistivities are made. An infra-red spectrometer is employed in studying new polymers and impurities in semiconductors.

Work on stable polymers for use as high-voltage or high-temperature insulation is sponsored by the Exploratory Research Group. A high-voltage test laboratory has been set up for measuring the more-usual dielectric properties, such as permittivity, power-factor, and breakdown strength at power frequencies. It is hoped that an understanding of the mechanism of high-voltage breakdown in polymers such as polyethylene will lead to improvement in the stability of these materials at high voltages. Considerable effort is also being directed to the synthesis of new polymers for high-voltage use. Besides the facilities made available to it by the materials evaluation section, the polymer section has a 2-million-electron-volt (MeV) Van de Graaff electron accelerator for radiation stability studies and a well-equipped chemical laboratory. A link between fundamental work and commercial exploitation is provided by a plastics laboratory in which the technological properties of polymer materials are examined and applied, as for example, to high-frequency cables.

A magnetics and ceramics laboratory is currently evaluating high-speed memory devices, and a further section is studying the theory of dielectric amplifying devices and, in this work, bringing to bear many techniques developed by the semiconductor technology sections. Another department is designing, building, and testing millimetre slow-wave tubes and special-purpose klystrons, some of which operate at shorter wavelengths and higher powers than existing ones. This work demands great skills and precision in metal working and device assembly, an important part of the technique being that of spark erosion machining. STL improvements in this field have resulted in the construction of spark erosion machines having tolerance and resolution limits nearly one order of magnitude

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better than attainable with existing commercial machines and capable of cutting complex shapes and very-narrow slots in a variety of materials. A programme of fundamental research on beam and spark erosion processes is now under way. (See Figure 12.)

In much of the Materials and Components Division's work there is a considerable interchange of ideas between STL and other ITT companies. Joint programmes on materials and device development are in operation, and longer-

term projects are carried out for the Exploratory Research Group in such areas as the ultra-high-pressure laboratory.

### 3.3.4 Acoustics

The Acoustics Division is particularly concerned with the transmission of speech with adequate intelligibility and maximum efficiency.

The study of the information content of speech is an important part of the programme. Such a



Figure 11—A field-emission microscope used in the study of semiconductor surfaces. This equipment enables an image of the surface of a fine point of the material under investigation, magnified some 100 000 times, to be observed on the fluorescent screen (seen on the extreme left). The liquid air being poured into the Dewar flask is to maintain an ultra-high vacuum ( $10^{-9}$  torr) within the system. The glass-work is of special construction required for ultra-high-vacuum studies.

study includes the articulating organs themselves as a source of speech, the analysis of the speech sounds, and the way in which they are recognized by the listener. An artificial mouth has been developed with output characteristics in good agreement with measurements on real speech. Special equipment developed for speech analysis includes a "speech microscope" which enables the auditory perception of sounds and their visual waveforms to be studied simultaneously.

Subjective assessment of the performance of communication systems by a specially trained

test team is an important part of the work. This enables the relevance of the objective measurements to be determined, in both the performance of telephone sets and of complete communication systems. The team uses a special phonetic language in which the whole range of vowel and consonant sounds occurs with the same relative frequency as in actual speech, so that its measurements can be directly related to real speech transmission.

The pre-eminent position so long held by ITT manufacturing associates in the field of microphones and telephone receivers is supported by



Figure 12—Equipment for machining to extremely close tolerances by spark erosion, built as a research tool to facilitate a study of the physics of erosion and to establish the ultimate limitations of the process. Individual spark discharges, occurring at high frequency, remove micron-size particles without physical contact between the electrode and workpiece contained in the bowl. The machine is being used in the construction of millimetre-wave tubes and components, thin-film evaporation masks for microcircuits, and the direct machining of semiconductor materials.

Results obtained would not be possible by any other means.

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special work on acoustic measurement techniques. These enable accurate measurements to be made by the designers of electro-acoustic transducers and lead to improved production-testing methods in the factories.

Other subjects being studied by the division include the effects of loudness and noise on sound recognition, the performance of the many items which form part of the new telephone sets, methods of time and amplitude quantization of speech for pcm systems, and digital methods of speech transmission.

### 3.3.5 *Technical Services*

This division includes an Overall Systems Planning Section, which is available to assist ITT manufacturing and sales companies to plan the most-suitable transmission and other systems to meet the requirements of customers, particularly telephone, telegraph, and radio operating authorities, in all parts of the world. Their activities include the planning of such telecommunication systems as land-line, line-of-sight microwave, tropospheric scatter, and very-high-frequency multi-channel radio.

Other technical services provided by this division on a communal basis within STL include information, library, drawing office, reproduction, model shop, editorial, and photographic. The information section, in addition to serving STL, provides a service for some 22 widely dispersed STC locations. The technical library, which takes over 500 technical publications, has both reference and lending facilities.

### 3.3.6 *Administration and Personnel*

This division provides other supporting services, such as personnel, accounts, purchasing, clerical, plant and building maintenance, and ancillary services. Its accounts section produces regular detailed statements of costs incurred on all the laboratories' projects in a form that enables project leaders to control their expenditures within their allocations without being

overburdened with clerical work. This is in addition to the usual monthly balance sheet which provides information for the overall management of the laboratories.

## 4. **Link with ITT Europe**

The fact that information is available from so many associated European companies is of great advantage to STL in planning its research programmes. It also permits co-ordination of its effort with that of its sister European laboratory, LCT, in Paris, so that work is not duplicated in the two laboratories, and a wider coverage is assured.

The close connection between ITT Europe and the world-wide ITT network also provides a channel for the interchange of information which is of considerable value, particularly in planning international communications.

STL's home and overseas connections are reflected in the constitution of its board of directors which include, beside Mr. J. D. Clare (Managing Director and Director of Research of STL), Mr. Rex B. Grey (Managing Director of STC), Professor G. Goudet (until recently Managing Director of LCT, in Paris), and Dr. G. Haessler (Technical Director of ITT Europe).

At a period during which new telecommunication requirements are arising in many parts of the world at an ever-increasing rate, STL's international backing greatly assists it in making a significant contribution towards the future prosperity of the whole ITT system.

**J. K. Webb** was born in Glasgow in 1901. He graduated in electrical engineering from Manchester University in 1924 and in 1927 was awarded the degree of M.Sc. (Eng) by London University.

In 1924 he joined Western Electric Company in London, soon being assigned to research and development of high-voltage power cable. From

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1928 to 1933 he was with the ITT Laboratories at Hendon. He was then transferred to Standard Telephones and Cables until 1945, when he became one of the founder members of Standard Telecommunication Laboratories as head of its Electrical Measurements Laboratory. In 1955 he was appointed head of the Technical Service

Division, and is now mainly concerned with publications and contracts.

Mr. Webb is a Member of the Institution of Electrical Engineers and has served on many of its committees. He was Chairman of its Measurement and Control Section during the 1958-1959 session.



# Multiplier Phototubes for Single-Electron Counting\*

E. H. EBERHARDT

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A unique line of multiplier phototubes has been developed that departs considerably from the almost-universal trend toward comparatively large photocathodes for the detection of multiphoton pulses from high-energy scintillations. Our efforts have been directed instead toward developing a detector able to count single photoelectrons with minimum dark noise interference. Applications requiring this type of detector might include the monitoring of low-energy beta rays or the observation of single Cerenkov events, but would certainly include the detection of low-intensity radiation from X-ray sources, incandescent lamps, stars, spectrometers, and lasers.

To achieve efficient counting of single photoelectrons with a multiplier phototube, it is essential that the maximum number of individual emitted photoelectrons result in count-

able output pulses, while the total number of dark pulses of comparable amplitude be minimized. We recognize that high photocathode quantum efficiency and low photocathode thermionic emission are in general desirable objectives in multiplier phototube design. However, the equally significant requirements that each emitted photoelectron, after amplification in the electron multiplier, should result in a countable output pulse, while dark pulses from all other sources should have minimal amplitudes, may have received somewhat less attention. Experiments in our laboratories have indicated in fact that substantial improvements in overall multiplier phototube performance can be achieved by close attention to the latter two objectives.

Figure 1 compares the basic design used in most commercial multiplier phototubes with our special design. In the usual design (Figure 1A), a nonimage-forming electron lens concentrates emitted electrons (both photo and dark) from a maximum area in the front end of the tube, including the tube sidewalls, onto a comparatively large secondary emitting surface on the first dynode.

In our design (Figure 1B) a true image-forming electron lens generates an electron image of the emitting photocathode in the plane of a small aperture immediately preceding the first dynode. This aperture then stops all electrons except those emitted from a restricted central area of the photocathode. The net result of this unusual configuration is to have a detector with a comparatively small effective photocathode area, combined with a small bombarded area on the first dynode and effective suppression of dark emission from the remaining unused portions of the tube. Absolute maximum use of all available photons from a single nuclear event may be a prerequisite for optimum energy resolution of high-energy particle detection, particularly from large-volume scintillating sources, and therefore requires the large emitting areas of conventional multiplier phototubes. However, our design shows promise for applications in

\* Presented at the Ninth Scintillation Counter Symposium, Institute of Electrical and Electronics Engineers, Washington, District of Columbia; 26-28 February 1964. Reprinted from *IEEE Transactions on Nuclear Science*, volume NS-11, number 3, pages 48-55; June 1964.

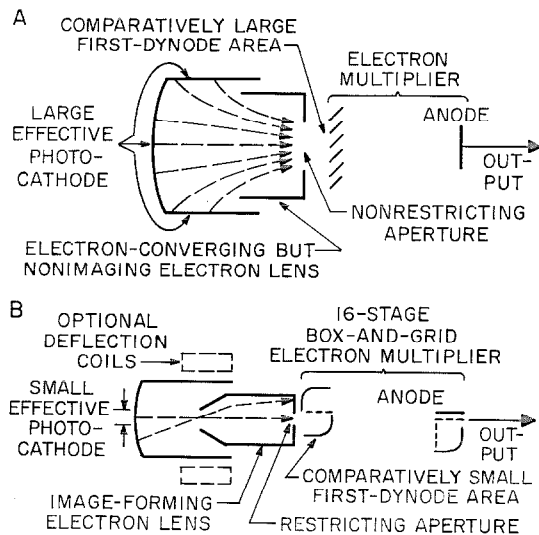


Figure 1—Comparison of multiplier phototube designs. A shows the conventional scintillation type and B is a low-noise design.

TABLE 1  
DATA FOR CURVES IN FIGURE 2

Characteristic	Unit of Measurement	Curve in Figure 2				
		A	B	C	D	E
Tube type (ITT Industrial Laboratories)	—	FW-129	FW-129	FW-129	FW-143	FW-143
Tube number	—	096203	106208	106207	036312	046303
Instantaneous effective photocathode diameter	Inches	0.1	0.007	0.007	0.021	0.021
	(Millimeters)	(2.54)	(0.178)	(0.178)	(0.533)	(0.533)
Overall voltage applied	Volts	2200	1750	1620	1560	1750
Type of photocathode	—	S11	S11	S11	S20	S20
Expected average pulse amplitude ( $\bar{V}$ )	Volts	25.3	38.4	11.3	8.16	29.6
Estimated total emission test rate $I_0$ (neglecting abruptly rising portion of curve)	Photoelectrons per second	6500	2100	3500	2000	3900

which the input flux can be confined to a more-restricted area, or if maximum differentiation of single photoelectrons from dark noise is required.

Possibly one of the most-significant performance characteristics of the new design is the appearance of a single-electron peak in the pulse height spectrum of the output pulses, as shown in Figure 2 and Table 1 for several selected tube samples. Analogous to the multi-electron peaks observed in high-energy scintillation applications, the appearance of this single-electron spectrum line permits nearly positive identification of either photo or thermionic single electrons emitted from the photocathode (hence the term "single-electron counter" for these tubes). The general shape of the spectra, except the suddenly rising portion for small amplitudes even after dark counting rates have been subtracted, as was done in Figure 2, follows the predictions of Lombard and Martin [1]. These predictions were based on the assumption of Poisson statistics for the fundamental secondary-emission processes involved and were found experimentally by others [2-9].

Further confirmation that these peaks do correspond to single-electron emission from the photocathode lies in the fact that the

range of observed absolute pulse amplitudes agrees approximately with the average expected absolute pulse amplitude  $\bar{V}$  for one electron input calculated from independently measured gain characteristics of the multiplier phototube and used to normalize the abscissa

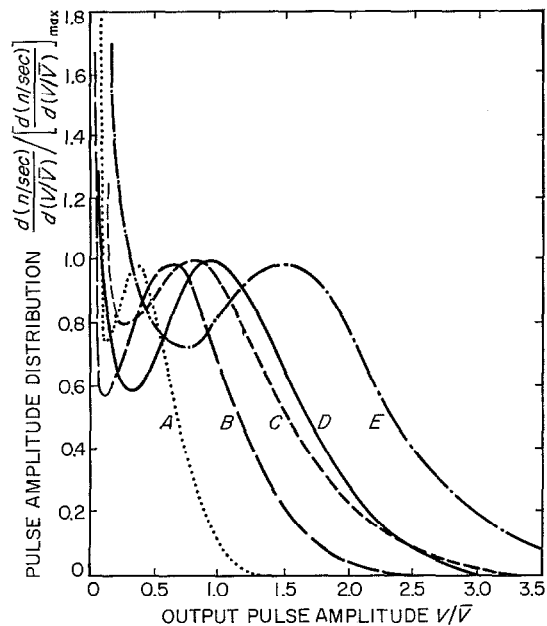


Figure 2—Differential output pulse height spectrum for single-photoelectron inputs. All curves are corrected for their respective dark-emission spectra. Refer to Table 1.



## Multiplier Phototubes for Single Electrons

scale in Figure 2. This approximate correlation (within about a factor of 3) between the observed and expected pulse amplitudes is also an indication that the small pulses in the suddenly rising portion of the spectra in Figure 2 do not carry a disproportionately large amount of signal photoelectron information and can therefore perhaps be biased off without interfering seriously with the ability of the multiplier phototube to count single electrons. This tentative conclusion also appears to be at least partially substantiated by the results of Tusting, Kerns, and Knudsen [3]. This rising portion of the spectrum was not observed in the tubes they tested using gating techniques to assure observation of only true photoelectron pulses. If these small pulses are indeed anomalous and can be eliminated, then the *FW-141* electron multipliers offer a valuable tool for investigation of the statistics of the secondary-emission processes as described by Bay and Papp [10].

Assuming that the small pulses can be neglected without serious error, an absolute photoelectron counting efficiency for a multiplier phototube having a single-electron peak can be computed from the observed pulse

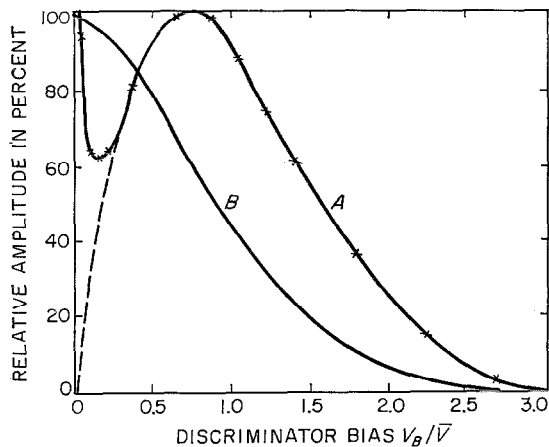


Figure 3—Single-electron pulse height spectrum (curve *A*) and corresponding absolute counting efficiency (curve *B*). The dashed portion of curve *A* was assumed for computing curve *B*. The characteristics of the phototube used are listed under curve *C* of Table 1.

height spectrum (see Figure 3). In this case an absolute counting efficiency of 80 percent was achieved with discriminator bias set at 50 percent of the most-probable signal pulse amplitude  $\bar{V}$  (that is,  $V_B/\bar{V} = 0.5$  on the abscissa). The selection of an appropriate relative bias  $V_B/\bar{V}$  for any specific tube in a specific application depends, as discussed by Baum [11], on a comparison of the photoelectron spectrum with the corresponding dark pulse spectrum. A setting of  $V_B/\bar{V}$  approaching zero, giving an absolute counting efficiency approaching 100 percent, is not realizable in practice, for the dark count would then include an essentially infinite number of dark pulses from the amplifier and other circuit sources.

Figure 4 shows the measured dark pulse spectrum on a sample tube, curve *A* being the total dark pulse spectrum and curve *B* the dynodes-only spectrum obtained with the photocathode biased off by operating at second-dynode potential. Curve *A* clearly shows a thermionic dark electron component from the photocathode tending to show a maximum or most-probable pulse amplitude in the expected neighborhood of  $V/\bar{V} = 1$ . Curve *B* is more or less exponential, indicating multiple contributions from several different pulse sources, such as the various dynodes, amplifier noise, et cetera. The technique of observing dual dark noise spectra as in Figure 4 has proved particularly valuable in analyzing multiplier phototube behavior and in measuring photocathode thermionic emission.

Figure 5 shows the integral dark counting-rate characteristics (all pulses above a given bias discriminator level  $V_B$ ), corresponding to the differential pulse spectra of Figure 4 but measured independently. The existence of most-probable pulse amplitude is not as evident in Figure 5 as in Figure 4, but the difference between the total dark counting rate (curve *A*) and dynodes-only rate (curve *B*), is clear. Most notable, perhaps, in Figure 5 is the extrapolation of the photocathode-contributed portion of the total dark counting-

## Multiplier Phototubes for Single Electrons

the levels reported by Baum [11] on the 16 PMI tube (a predecessor to our present S1 tubes), in which dark counting rates of less than 10 per minute were reported, has not yet been evaluated quantitatively in our own laboratory. An improvement by a factor of about 100 times in the ratio of collected photoelectrons to thermionic electrons in S1 photocathodes has recently been achieved experimentally by the use of a suppressor grid

mounted close to the photocathode. This technique makes use of the greater average emission energy of photoelectrons compared with thermionic electrons.

Typical operating characteristics of three types of these special-purpose multiplier phototubes, FW-118, FW-129, and FW-130, are listed in Table 2, in general following established definitions and methods of measurement of the various parameters [12], but

TABLE 2  
TYPICAL MULTIPLIER PHOTOTUBE PERFORMANCE CHARACTERISTICS

Characteristic	Unit of Measurement	Tube Type				Notes
		FW-118	FW-118	FW-129	FW-130	
Photocathode	Joint Electron Devices Engineering Council Type	S1	S1	S11	S20	—
Formed diameter (nominal)	Inches (millimeters)	0.75 (19)	0.75 (19)	0.75 (19)	0.75 (19)	—
Effective diameter	Inches (millimeters)	0.1 (2.5)	0.1 (2.5)	0.1 (2.5)	0.1 (2.5)	1
Temperature	Degrees centigrade	25	-20	25	25	—
Number of dynodes	—	16	16	16	16	—
Overall potential difference	Volts	1800	1800	1800	1800	2, 3
Electron-multiplier gain	Electrons per electron	10 <sup>7</sup>	10 <sup>7</sup>	10 <sup>7</sup>	2×10 <sup>6</sup>	2-5
Wavelength of input radiation	Angstrom units	8000	8000	4400	4200	6
Anode sensitivity	Electrons per photon	3.2×10 <sup>4</sup>	3.2×10 <sup>4</sup>	9.3×10 <sup>5</sup>	2.6×10 <sup>5</sup>	2-5, 7
Photocathode quantum efficiency	Electrons per photon	3.2×10 <sup>-3</sup>	3.2×10 <sup>-3</sup>	9.3×10 <sup>-2</sup>	0.13	2-4, 7, 8
Anode dark current	Electrons per second	1.9×10 <sup>13</sup>	6×10 <sup>8</sup> (?)	6×10 <sup>9</sup> (?)	6×10 <sup>9</sup> (?)	2-5, 7, 9
Equivalent anode dark current input	Photons per second	6×10 <sup>8</sup>	1.9×10 <sup>4</sup> (?)	6.5×10 <sup>8</sup> (?)	2.3×10 <sup>4</sup> (?)	2-4, 7, 9
Equivalent noise input	Photons per second	1.2×10 <sup>6</sup>	8×10 <sup>8</sup> (?)	220 (?)	2.1×10 <sup>2</sup> (?)	2-4, 7, 9
Dark counting rate	Counts per second	3×10 <sup>5</sup>	30 (?)	10 (?)	10 (?)	2-4, 9, 10
Equivalent dark counting rate	Photons per second	1.1×10 <sup>8</sup>	1.1×10 <sup>4</sup> (?)	130 (?)	95 (?)	4, 7, 9-11
1-second dark counting uncertainty	Counts	1.1×10 <sup>8</sup>	11 (?)	6 (?)	6 (?)	4, 9, 10, 12
Equivalent 1-second dark counting uncertainty	Photons	4×10 <sup>4</sup>	400 (?)	78 (?)	57 (?)	4, 7, 9-11

<sup>1</sup> Other photocathode sizes are available (see text).

<sup>2</sup> See commercial data sheets for tolerances.

<sup>3</sup> Distributed according to commercial data sheet recommendation.

<sup>4</sup> Typical performance of selected samples (see text).

<sup>5</sup> Numerical magnitude depends critically on selected operating voltage.

<sup>6</sup> For nominal peak cathode response in amperes per watt.

<sup>7</sup> Photon inputs apply only for the peak response wavelengths listed.

<sup>8</sup> Measured as a diode.

<sup>9</sup> Data marked by (?) must be considered as tentative.

<sup>10</sup> For a discriminator bias of approximately 0.5 V (see text).

<sup>11</sup> For an absolute photoelectron counting efficiency of 80 to 90 percent (see text).

<sup>12</sup> Based on a standard deviation equal to twice the square root of the total number of counts in one second (see text).

with unusual units of measurement in some cases. The units selected are believed to be appropriate for evaluating the tubes as single-electron-counting devices, but for comparison Table 3 gives the conversion factors to more-usual units. The electron-multiplier gains and the resulting anode sensitivities are sufficient for most applications, with higher magnitudes readily available by an increase in the applied operating potential.

Specifications on absolute anode dark current and even on the corresponding equivalent anode dark current must be interpreted with considerable care, particularly when predicting noise behavior, since anode dark current includes leakage over stem and base, dynode emission, and other current sources of variable noise content. A more-useful parameter for predicting low-frequency-noise behavior of multiplier phototubes is the equivalent noise input, which is the magnitude of the chopped flux input giving a signal-to-dark-noise ratio of unity for a 1-hertz bandwidth. Even this parameter can be misleading when applied to tubes in which (1) tube dark noise is too low to measure properly in comparison with external noise, (2) the statistical fluctuation of photoelectrons from either signal or background flux, that is, the noise-in-signal or the background noise, is predominant over the dark noise used for the equivalent-noise-input rating, or (3) the noise does not have a flat frequency spectrum.

For evaluating single-photoelectron-counting capabilities and the corresponding photon-detector capabilities, the last four parameters

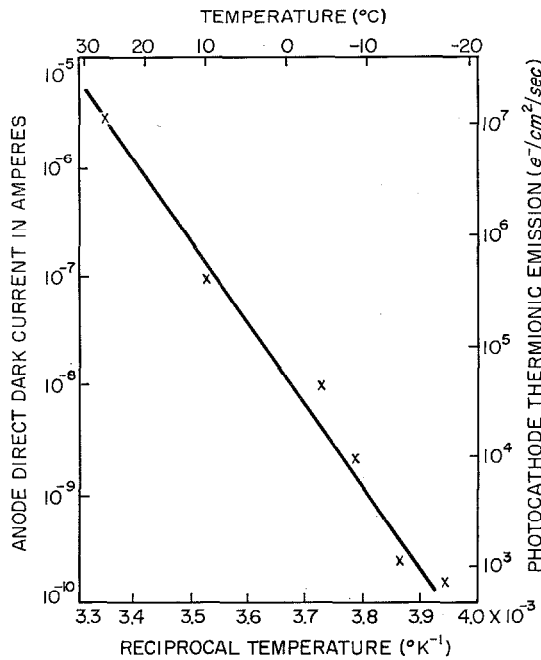


Figure 6—Thermionic emission as a function of temperature for *FW-118* tube number F6621. Characteristics of the phototube were: photocathode, *S1*; effective photocathode diameter, 0.38 inch (9.65 millimeters); overall volts applied, 1330; multiplier gain,  $2 \times 10^6$ ; cathode sensitivity, 25 microamperes per lumen (2870 degrees Kelvin flux); and 3.9 microamperes per lumen (2870 degrees Kelvin flux plus 2540 infrared filter).

TABLE 3  
CONVERSION FACTORS FOR TABLE 2

Units in Table 2	Multiply By			Corresponding Conventional Units
	For Photocathode Type			
	<i>S1</i>	<i>S11</i>	<i>S20</i>	
Photons	$2.5 \times 10^{-19}$	$4.5 \times 10^{-19}$	$4.8 \times 10^{-19}$	Joules (at peak response)
Photons per second	$2.5 \times 10^{-19}$	$4.5 \times 10^{-19}$	$4.8 \times 10^{-19}$	Watts (at peak response)
Photons per second	$2.5 \times 10^{-17}$	$3.8 \times 10^{-16}$	$2.1 \times 10^{-16}$	Lumens (2870 degrees Kelvin)
Electrons per photon	$6.3 \times 10^{-3}$	$4.3 \times 10^{-4}$	$7.7 \times 10^{-4}$	Amperes per lumen (2870 degrees Kelvin)
Electrons per photon	$6.3 \times 10^{-1}$	$3.5 \times 10^{-1}$	$3.3 \times 10^{-1}$	Amperes per watt (at peak response)
Electrons per second	$1.6 \times 10^{-19}$	$1.6 \times 10^{-19}$	$1.6 \times 10^{-19}$	Amperes

## Multiplier Phototubes for Single Electrons

in Table 2 are perhaps the most useful. The dark counting rate and the equivalent dark counting rate, in counts per second and input photons per second, respectively, are normalized by measurement at a pulse bias discriminator level corresponding to an absolute signal photoelectron counting efficiency of about 80 to 90 percent, as estimated using techniques similar to those used in plotting Figure 3. The statistical uncertainty in any given total dark counting, corresponding to a given observation time, can be taken to be approximately twice the standard deviation, that is, twice the square root of the total number of dark counts, assuming random dark events. The particular dark count uncertainty listed in Table 2 corresponds to a 1-second observation time. This dark count uncertainty or noise can also be correlated to a total number of input photons during the same 1-second observation time, as also listed in Table 2. Thus, if a total of 57 signal photons at 4200 angstrom units impinge on the effective cathode of an *FW-130* tube with a 0.1-inch (2.54-millimeter) photocathode during a 1-second observation time, they can be expected to yield a signal count just equal to the dark count uncertainty, or noise. If the observation time under the same conditions is increased to 10 seconds, 180 photons or 18 photons per second will yield a signal just equal to the noise.

The results shown in Table 2 pertain only to tubes with effective cathode areas of 0.1-inch (2.54-millimeter) diameter. Except for the uncooled *FW-118* with an *SI*-type photocathode, in which thermionic dark emission from the cathode predominates, it is difficult to predict the dark noise behavior of tubes with either smaller or larger effective cathode areas. Some of the dark noise sources are area sensitive while others are not. For this reason no figures for dark current density, noise-current density, or detectivity ( $D^*$ ) are listed in Table 2.

Effective photocathode sizes and shapes within the dimensional limits of 0.005 and 0.5 inch

(0.127 and 12.7 millimeters) are presently available. In general, tube performance has been found to improve down to about 0.005-inch diameter, assuming that the input flux can be confined to this small effective cathode area. The performance for larger cathode areas has not been investigated in detail, but can be expected to improve over tube designs in which sidewall dark emission is permitted to enter the electron multiplier.

It is not known whether the selected tubes used in compiling the data for Table 2 were representative samples. In cases where discrepancies from the commercial data sheets do exist, the differences can be at least partially explained by the refined measuring techniques used to collect the data for Table 2 and by the large variations that occur in many multiplier phototube parameters. It is not unusual, for example, to find variations of several orders of magnitude in direct-current anode dark current among tube samples, probably caused by variable stem and base leakage as well as by variable gain.

The average output-pulse amplitude  $\bar{V}$  from a multiplier phototube, corresponding to a single-electron input to the multiplier, can be determined in two ways.

(A) By direct averaging of the measured output pulse height spectrum, in some cases making certain assumptions as to the shape of the spectrum.

(B) By computation based on the measured gain characteristics of the tube according to the following approximate relationship

$$\bar{V} = \frac{AGe}{SEC}$$

$\bar{V}$  = average expected pulse amplitude in volts at pulse-height-analyzer input

$A$  = voltage gain of amplifier used, if any ( $\cong 6400$  in circuit of Figure 7)

- $G$  = anode luminous sensitivity of the tube in amperes per lumen
- $e$  = charge on the electron in coulombs ( $\cong 1.6 \times 10^{-19}$ )
- $S$  = photocathode luminous sensitivity in amperes per lumen (measured as a diode)
- $E$  = collection efficiency of the electron multiplier for photoelectrons ( $\cong 1.0$  for our tubes)
- $C$  = total anode capacitance in farads ( $\cong 175 \times 10^{-12}$  in circuit of Figure 7).

The approximate correlation, within a factor of about 3, between the average pulse amplitudes estimated for the curves of Figure 2 with unity of the abscissa scale where  $V/\bar{V} = 1$ , indicates a reasonable cross-check between the two test procedures used for these two alternative techniques, considering the many sources of possible error.

A block diagram of the rather-elementary test equipment used for measuring pulse height

spectra is shown in Figure 7. Figure 8 shows 5 multiplier phototubes presently available from our laboratories. A unique feature of these tubes is that the small effective cathode area, nominally paraxial, can be deflected magnetically as desired to any other portion of the formed photocathode area. This provides a means for image alignment and tracking [13] as well as for automatic gain calibration by deflection reference to a standard flux source. Also available are quadrant multipliers with multiple simultaneous outputs corresponding to the location of the input flux, grid-controlled multipliers for gating and dark current suppression, windowless multipliers for particle detection, and image dissectors with magnetic focusing for improved off-axis performance.

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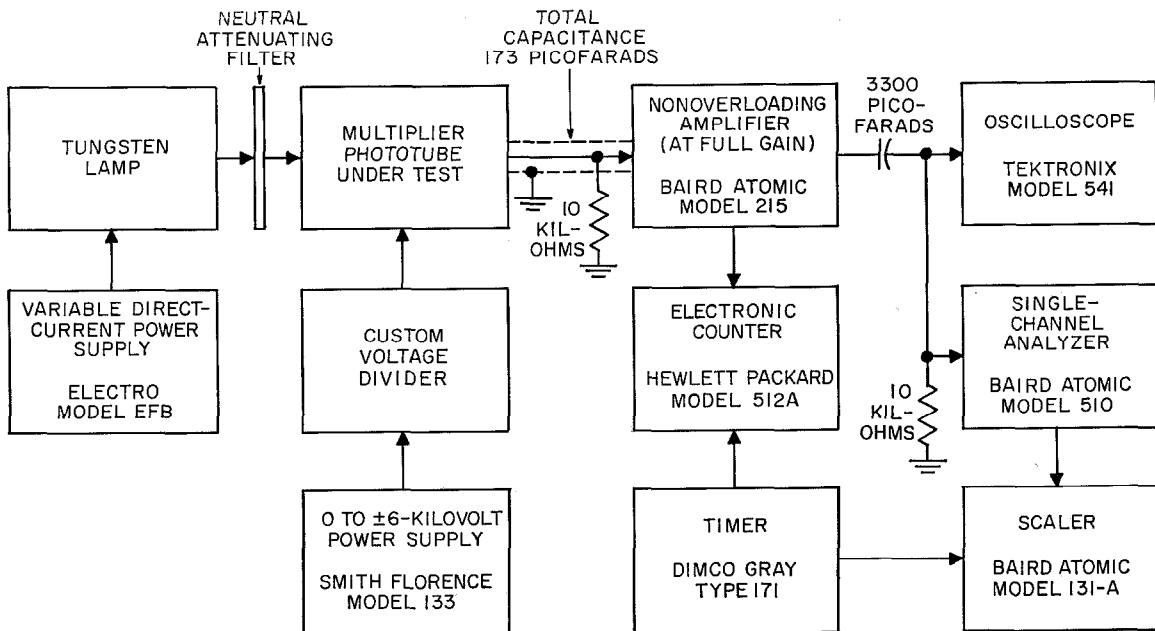


Figure 7—Test setup for measuring pulse height spectra.

## Multiplier Phototubes for Single Electrons

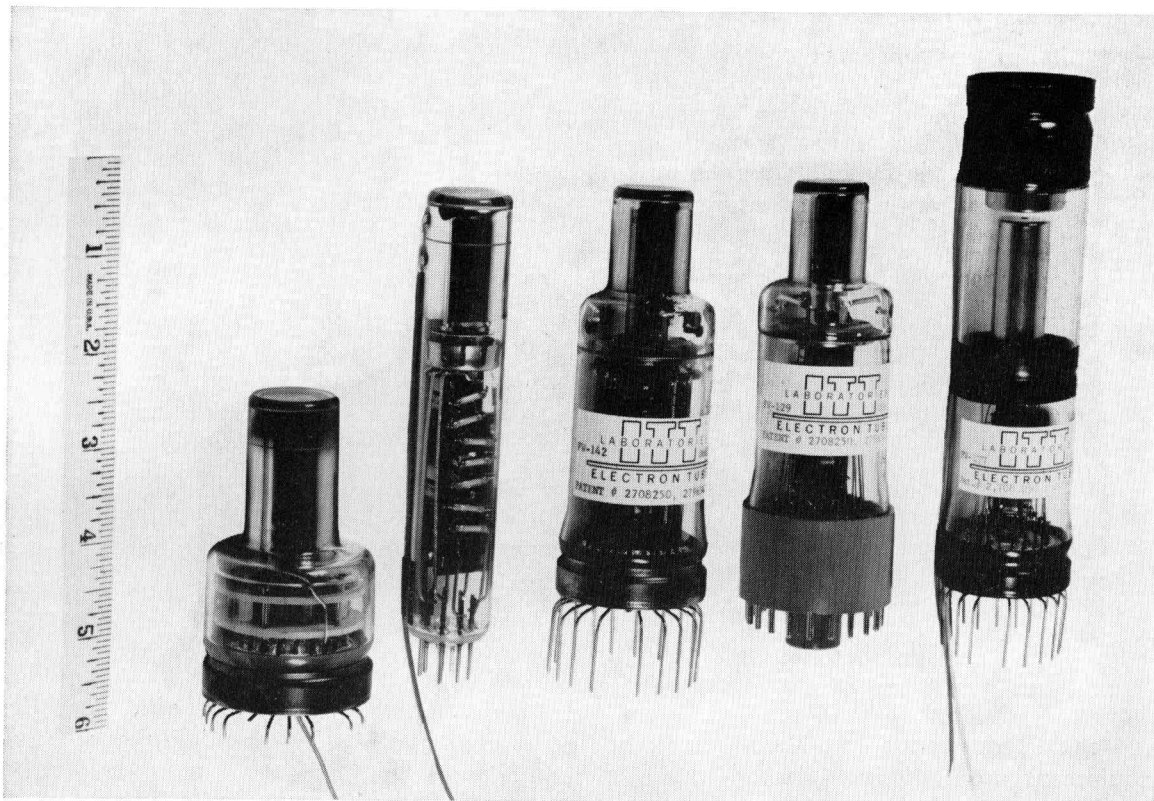


Figure 8—Typical multiplier phototubes. At the left is the F4004 short tube for gimbal mounting. Second is the F4003 slim tube with a 1-inch (25.4-millimeter) outside diameter. Third is the rugged FW-142. Fourth is the standard FW-129. At the extreme right is the F4005 high-resolution design.

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# Determination of the Probability Distribution of the Number of Secondary Electrons \*

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## 1. Introduction

Knowing the probability distribution  $p(i)$  of the release of  $i$  secondary electrons after the incidence of a primary electron forms the basis for the theoretical treatment of cascading processes in multistage electron multiplier or photomultiplier tubes. The amplitude distribution in the output is of theoretical interest and has practical importance in problems of energy resolution in scintillation counters. It is obvious that exact prediction of such amplitude distributions can only be given if  $p(i)$ , generally different for the different stages, is known for all stages. Besides its usefulness for photomultipliers, the knowledge of  $p(i)$  is important in understanding the physical processes involved in secondary-electron emission. Therefore it is of interest to have a way of determining  $p(i)$  under deliberately chosen conditions if the target and the nature of primaries are specified.

Theoretical and experimental work in the past was directed toward the reverse problem, that of drawing conclusions about the  $p(i)$  function from the measured amplitude distribution in the output, when single electrons enter the input (single-electron response). Obviously in this case the simplified assumption had to be made that  $p(i)$  is the same for all stages. This work was reviewed by Breitenberger [1], and more recently by Bertolaccini and Cova [2]. A rather-general result of this work seems to be that the  $p(i)$  distribution is broader than the corresponding Poisson distribution (the variance of  $p(i)$  is supranormal).

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\* Presented at the Ninth Scintillation Counter Symposium, Institute of Electrical and Electronics Engineers, Washington, District of Columbia; 26-28 February 1964. Reprinted from *IEEE Transactions on Nuclear Science*, volume NS-11, number 3, pages 160-168; June 1964.

It will be shown that, using an electron multiplier,  $p(i)$  pertinent to any arbitrary process (possibly quite different from the multiplying processes inside the electron multiplier) can be determined on the basis of experimentally obtained data. This method was first outlined in an earlier paper [3] and was treated mathematically as part of a more-general theory of cascading processes under idealized conditions by Farago and Takacs [4]. The mathematical treatment in the present paper is based on the use of moments to comply closely with the physical aspects of the problem.

The general method given can easily be applied to an electron multiplier having identical stages. Then the resulting  $p(i)$  is characteristic for the dynodes of the electron multiplier. An example is given for such a distribution of medium-energy electrons (230 electron-volts) impinging on a silver-magnesium target. Interestingly, the calculation gives  $p(i)$  from the observed pulse height spectra in a straightforward way, instead of calculating first the cascades from a hypothetical  $p(i)$  and fitting the results to experimental curves.

The method can be generalized to other processes in which  $i$  similar particles (possibly other than electrons) are simultaneously released.

## 2. Outline of Method

The method is based on using the electron multiplier merely as a tool (a microscope) to multiply the electrons entering the electron multiplier to an easily measurable level. Since the gain of the electron multiplier itself possesses probability characteristics, the experiment is made in two steps.

First, the pulse height distribution (density) function  $\Phi(x)$ , where  $x$  is the number of electrons at the output of the electron multiplier



or any other variable proportional to that number, is measured in the case where single electrons enter the electron multiplier. This can be achieved readily, for example, by the use of thermionic electrons or low-energy photoelectrons.

Second, the pulse height distribution  $F(x)$  is measured when the secondary electrons of the process to be investigated enter the input. (See Figure 1.)

The  $\Phi(x)$  and  $F(x)$  functions used here are not simply the amplitude distribution curves supplied by a pulse height analyzer. Such spectra do not account for the events producing no pulses in the output. "Zero-amplitude pulses" can result either from losses in focusing (collection) or from the loss of electrons in the secondary-electron emission itself (in general  $p(0) \neq 0$ ). Therefore the spectra obtained are to be complemented in the following way.

If, in the measurement with single electrons, the probability that an entering electron causes a pulse in the electron multiplier is  $\alpha$ , and the pulse height spectrum obtained in the analyzer is  $\varphi(x)$ , then

$$\Phi(x) = \alpha\varphi(x) + (1 - \alpha)\delta(x) \quad (1)$$

where  $\delta(x)$  is the Dirac  $\delta$ -function. In a similar way

$$F(x) = Af(x) + (1 - A)\delta(x) \quad (2)$$

where  $A$  is the probability that a primary particle impinging on the target (in the second experiment) produces a pulse and  $f(x)$  is the spectrum obtained from the analyzer. If  $\varphi(x)$  and  $f(x)$  are probability density functions normalized to unity area, so also are  $\Phi(x)$  and  $F(x)$ .

The probabilities  $\alpha$  and  $A$  are determined, for example, by the ratios of the direct-current gain of the system to the average pulse height (measured in electron numbers) in the respective experiment. This is easily seen as follows.

The average output direct current  $I_{out}$  is

$$I_{out} = I_{in}\alpha\bar{x}_\varphi \quad (3)$$

where  $I_{in}$  is the average input current of (single) electrons entering the electron multiplier and  $\bar{x}_\varphi$  is the average pulse height of the  $\varphi(x)$  distribution. Therefore

$$\alpha = \frac{\text{direct-current gain}}{\bar{x}_\varphi} \quad (4)$$

which quantity can be called the "counting efficiency" of the electron multiplier (as distinguished from the "collection efficiency"  $\beta$  of the input stage as used in Section 3). In a similar way the counting efficiency  $A$  is the ratio of the direct-current gain to the average pulse height of the  $f(x)$  distribution in the second experiment. Here the output current is related to the input current of primaries impinging on the target. While in the measurement of  $\alpha$ ,  $I_{in}$  is the total current of singles (the current coming from the electron source), in the  $A$  measurement  $I_{in}$  is the current of primaries actually hitting the target.

The two experiments for  $\Phi(x)$  and  $F(x)$  are to be performed under the following conditions.

- (A) The rate of events is sufficiently low that pile-up corrections (both for the numbers and for the spectra) are negligible or easily determinable.
- (B) The counting efficiency for secondary electrons in the second experiment should be

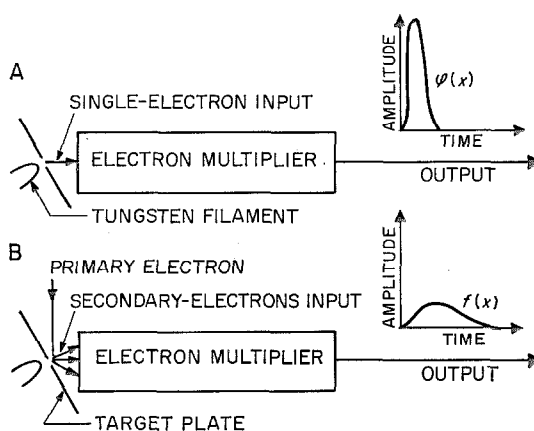


Figure 1—Determination of the distribution of output pulses for single-electron input (A) and for electrons from a bombarded target (B).

the same as that for the singles in the first experiment; this requires first, that secondaries and singles be subjected to the same focusing field (possibly both starting from the same point-source) and second, that the accelerating field be of sufficiently high intensity that small differences in initial electron velocities are of no consequence.

(C) The electron multiplier is operated in its linear region such that the pulses for the simultaneous  $i$  secondary electrons in the second experiment are far from saturating the electron multiplier.

(D) The background pulse rate in the measurement of the  $\varphi(x)$  distribution is negligible compared with the rate of events to be measured.

Condition (D) is easily satisfied using electron multipliers built with high-work-function dynodes. In the early work of Z. Bay [3], using silver-magnesium dynodes, the background rate was a few counts per minute and the single-electron response showed a definite peak in the distribution.

Low-work-function dynodes in cesiated photomultipliers usually exhibit high background rates and produce pulse spectra extended to small amplitudes such that no peak can be found in the distribution. Lombard and Martin [5] calculated the single-electron-response distribution on the basis of a Poissonian  $p(i)$ . As they found no peak in the pulse height distribution, they suggested that possibly  $p(i)$  is very different from a Poisson distribution. To explain the lack of a peak, Baicker [6] tabulates possible side effects: thermionic emission from dynodes, optical and ionic feedback, electroluminescence in the glass envelope, et cetera. Colli, Facchini, and Rossi [7] found a clearly defined peak by illuminating the photocathode. By the selection of suitable tubes with small side effects, Khlebnikov, Melamid, and Kovaleva [8], and Fleischman [9] succeeded in finding peaks in the single-electron-response distribution for thermionic electrons originating at the cathode. Eberhardt [10] reports on similar results.

Of course, any remainder of side effects in the distribution of noise pulses makes the measurement of the  $\varphi(x)$  curve and its normalization questionable. This difficulty was overcome recently by Koechlin [11], Tusting, Kerns, and Knudsen [12], and Bertolaccini and Cova [2], who pulsed the entering electron current (illumination) at the cathode and measured the pulse height spectrum in coincidence. This coincidence idea makes a low-work-function cesiated photomultiplier suitable for the method considered here.

If conditions (A) through (D) above are satisfied, the relation between  $p(i)$ ,  $\Phi(x)$ , and  $F(x)$  is

$$F(x) = \sum_{i=0}^{\infty} p(i)\Phi_i(x) \quad (5)$$

where  $\Phi_i(x)$  is the pulse height distribution of the measuring electron multiplier in the case when at each event exactly  $i$  electrons enter the input and  $\Phi_0(x) = \delta(x)$ . Mathematically,  $\Phi_i(x)$  is the  $i$ -fold folding of  $\Phi(x)$  with itself, thus

$$\Phi_i(x) = \int_{-\infty}^{+\infty} \Phi_{i-1}(y)\Phi(x-y)dy, \quad i = 2, 3, 4, \dots \quad (6)$$

where we set  $\Phi(x) = 0$ , if  $x < 0$ , and  $\Phi_1(x) = \Phi(x)$ .

### 3. Determination of the $p(i)$ Distribution

The mathematical task now is to solve (5) for  $p(i)$ .

(A) To obtain an approximate solution only the first  $N$  terms of (5) are used. The first  $N$   $\Phi_i(x)$  are calculated for this purpose by graphic integration. This abbreviated equation taken at  $N$  different experimental points ( $x$ ) gives a system of  $N$  linear equations for the values of  $p(i)$ . Of course, this method represents a reasonable approximation only if  $N$  is chosen sufficiently large that it can be foreseen on the basis of experimental data that  $p(i)$  for  $i > N$ , is negligible.

(B) The moments of the function  $p(i)$  can be determined directly from the moments of the

$\Phi(x)$  and  $F(x)$  distributions without first calculating the  $\Phi_i(x)$  functions. In certain cases it is of even-greater interest to know the moments of a probability function (average, mean-square deviation, skewness, et cetera) than the function itself. Thus in many cases the problem can be considered solved after calculating the moments. In addition, since the moments of a function in general determine the function, a further calculation from the moments can be carried out to determine the  $p(i)$  function itself. Therefore this method of moments is treated here.

The application of the well-known moment theorem of folding integrals [13] to (6) gives

$$M^{(k)}(\Phi_i) = \sum_{l=0}^k \binom{k}{l} M^{(l)}(\Phi_1) M^{(k-l)}(\Phi_{i-1}) \quad (7)$$

where

$$M^{(k)}(\Phi_i) = \int_{-\infty}^{+\infty} x^k \Phi_i(x) dx \quad (7A)$$

denotes the  $k$ th moment of the function  $\Phi_i(x)$ . Equation (7) presents an iterative method for the determination of  $M^{(k)}(\Phi_i)$  from the mo-

ments  $M^{(k)}(\Phi_1)$  for which the notation  $m_k$  is introduced. (The moments  $m_k$  are calculated from the experimental curve  $\Phi_1(x) = \Phi(x)$ .) Table 1 shows the first four moments of  $\Phi_i(x)$  in terms of  $m_k$ .

Using (5) we write for the  $k$ th moment of  $F(x)$

$$M_k = M^{(k)}[F] = \sum_{i=0}^{\infty} p(i) M^{(k)}[\Phi_i]. \quad (8)$$

Inserting the moments of  $\Phi_i(x)$ , as given in Table 1, into (8), note that sums of the form

$$\sum_0^{\infty} i^k p(i) = M^{(k)}(p(i))$$

can be factored out. These are the moments of the function  $p(i)$  and will be denoted by  $\pi_k$ . Equation (8) then leads to a method for establishing relations between the moments  $M_k$  of  $F(x)$  and the moments  $m_k$  of  $\Phi(x)$  and  $\pi_k$ . This relationship for the first four moments is given in Table 2. These equations are easily solved for  $\pi_1, \pi_2, \pi_3, \pi_4$ , et cetera, expressing them in terms of moments of the experimentally measured distributions  $\Phi(x)$  and  $F(x)$ . The usefulness of this iterative

TABLE 1  
FIRST 4 MOMENTS OF  $\Phi_i(x)$  AS EXPRESSED BY FIRST 4 MOMENTS OF  $\Phi(x)$

$$\begin{aligned} M^{(1)}(\Phi_i) &= im_1 \\ M^{(2)}(\Phi_i) &= i(m_2 - m_1^2) + i^2 m_1^2 \\ M^{(3)}(\Phi_i) &= i(m_3 - 3m_2 m_1 + 2m_1^3) + i^2(3m_2 m_1 - 3m_1^3) + i^3 m_1^3 \\ M^{(4)}(\Phi_i) &= i(m_4 - 4m_3 m_1 - 3m_2^2 + 12m_2 m_1^2 - 6m_1^4) + i^2(4m_3 m_1 + 3m_2^2 - 18m_2 m_1^2 + 11m_1^4) \\ &\quad + i^3(6m_2 m_1^2 - 6m_1^4) + i^4 m_1^4 \end{aligned}$$

TABLE 2  
RELATIONSHIP BETWEEN MOMENTS OF  $F(x)$ ,  $\Phi(x)$ , AND  $p(i)$

$$\begin{aligned} M_1 &= \pi_1 m_1 \\ M_2 &= \pi_1(m_2 - m_1^2) + \pi_2 m_1^2 \\ M_3 &= \pi_1(m_3 - 3m_2 m_1 + 2m_1^3) + \pi_2(3m_2 m_1 - 3m_1^3) + \pi_3 m_1^3 \\ M_4 &= \pi_1(m_4 - 4m_3 m_1 - 3m_2^2 + 12m_2 m_1^2 - 6m_1^4) + \pi_2(4m_3 m_1 + 3m_2^2 - 18m_2 m_1^2 + 11m_1^4) \\ &\quad + \pi_3(6m_2 m_1^2 - 6m_1^4) + \pi_4 m_1^4 \end{aligned}$$

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method shows in the fact that higher moments of  $p(i)$  are obtained by extension of the calculations without a change in the results for lower moments.

If knowledge of the  $p(i)$  function is required in addition to the knowledge of moments, some of the general procedures of probability theory should be applied [14]. We follow here the method worked out by Takacs [15] on the basis of earlier results of Jordan [16].

Using the combinatorial moments

$$C_k = \sum_{i=k}^{\infty} p(i) \frac{i!}{(i-k)!} \quad (9)$$

the  $p(i)$  values are given as

$$p(i) = \sum_{k=i}^{\infty} (-1)^{k-i} \frac{C_k}{i!(k-i)!} \quad (10)$$

According to the definitions in (7A) and (9), the relation between the first four moments and combinatorial moments of  $p(i)$  is shown in Table 3. The conversion of the moments  $\pi_k$  in Table 2 into combinatorial moments gives the relationship shown in Table 4.

Thus the moments  $C_k$  can be determined either from Table 3, if the  $\pi_k$  were already calculated, or they can be determined directly from the values of  $M_k$  and  $m_k$  by using Table 4.

In applying (10) to calculate  $p(i)$ , it is assumed that all the values of  $C_k$  are known. Of course, this is never the case in practice and therefore some approximation must be used. An approximation determined by orthogonal polynomials [15, 16] is as follows.

If  $C_k$  for  $k = 0, 1, \dots, r$  is known, then

$$p(i) \cong \sum_{m=0}^r \sum_{l=0}^m C_{ml} \binom{i}{l} \theta_m \quad (11)$$

where

$$\theta_m = \sum_{l=0}^m \frac{\beta_{ml}}{\binom{N}{l+1}} \frac{C_l}{l!} \quad (12)$$

$$\beta_{ml} = (-1)^{m+l} \binom{m+l}{m} \binom{m}{l} \frac{1}{l+1} \quad (13)$$

$$C_{ml} = (-1)^{m+l} (2m+1) \binom{m+l}{m} \frac{\binom{N-l-1}{m-l}}{\binom{N+m}{m}} \quad (14)$$

and  $N$  is a number such that  $p(i)$  is negligible if  $i \geq N$ . There are tabulated values in [16] for the coefficients  $\beta_{ml}$  and  $C_{ml}$ .

The general method given here is simplified if the electron multiplier can be assumed to consist of identical stages. In this case the resulting  $p(i)$  is characteristic for the dynodes of the electron multiplier.

If the electron-multiplier stages are equal, the procedure of putting one dynode stage before the first one required for the determination of  $f(x)$  results in the same output pulse height spectrum as putting one more dynode stage after the electron multiplier. Since in each output pulse of the electron multiplier the number of electrons is large (of the order of  $10^6$  or more), every pulse is increased simply by the average multiplication  $a$  of the additional stage. Thus the  $f(x)$  curve is a simple

TABLE 3 RELATIONSHIP BETWEEN MOMENTS AND COMBINATORIAL MOMENTS OF $p(i)$	
$C_1$	$= \pi_1$
$C_2$	$= \pi_2 - \pi_1$
$C_3$	$= \pi_3 - 3\pi_2 + 2\pi_1$
$C_4$	$= \pi_4 - 6\pi_3 + 11\pi_2 - 6\pi_1$

TABLE 4 RELATIONSHIP BETWEEN MOMENTS OF $F(x)$ AND $\Phi(x)$ AND COMBINATORIAL MOMENTS OF $p(i)$	
$M_1$	$= C_1 m_1$
$M_2$	$= C_1 m_2 + C_2 m_1^2$
$M_3$	$= C_1 m_3 + 3C_2 m_1 m_2 + C_3 m_1^3$
$M_4$	$= C_1 m_4 + C_2 (4m_1 m_3 + 3m_2^2)$ $+ C_3 6m_1^2 m_2 + C_4 m_1^4$

transform of the  $\varphi(x)$  curve

$$f(x) = \frac{1}{a} \varphi\left(\frac{x}{a}\right) \quad (15)$$

and can be calculated easily since the constant  $a$  is obtained readily by macroscopic current measurements in the last dynode stages.

Additional measurements are needed for  $\alpha$  and  $A$ . Following the general method, as given in the discussion of (4), single electrons should be ejected from the first dynode and the counting efficiency  $\alpha$  should be measured. Next, primaries should be injected to the first dynode and the counting efficiency  $A$  should be measured for primaries reaching the first dynode. However, a relationship can be found between  $A$  and  $\alpha$  for identical dynode stages, therefore only one measurement is required.

Losses in the collection of primary electrons (which can be thought of as electrons coming from a previous dynode) are disregarded in the definition of  $A$ , while in  $\alpha$  they are considered. Therefore

$$\frac{A}{\alpha} = \frac{1}{\beta} \quad (16)$$

where  $\beta$  is the collection efficiency in the identically built stages. Such losses diminish the gain per stage such that

$$a = \beta\pi_1 \quad (17)$$

and from (16) and (17)

$$\frac{A}{\alpha} = \frac{\pi_1}{a} \quad (18)$$

Thus for identically built stages the ratio of the two counting efficiencies  $A$  and  $\alpha$  is equal to the ratio of the "true" secondary-electron multiplication to the (effective) stage gain.

The true secondary-electron multiplication can be measured by the use of a sister dynode and full secondary-electron collection (or just by the use of the first dynode of the tube and rearrangement of electrode potentials for complete collection). Thus by measuring one of the counting efficiencies,  $A$  or  $\alpha$ , the other can be calculated.

This procedure, in connection with the coincidence method [2, 11, 12], enables us to determine  $p(i)$  for the dynodes of a sealed-off photomultiplier, if the dynode stages are equivalent.

Note that complete collection efficiency in the dynode stages would result in  $A = \alpha$ . Note also that errors in the  $A$  determination leave the form of the  $p(i)$ ,  $i \geq 1$ , curve unaffected. This can be seen from the fact that the moments  $M_k$  and therefore the moments  $\pi_k$  for  $k \geq 1$  in Table 2 depend linearly on  $A$ . Therefore, an error in  $A$  influences the value of  $p(0)$  relative to the values  $p(i)$ ,  $i \geq 1$ , but leaves the latter unaffected relative to each other.

#### 4. Experiments

Preliminary experiments for the determination of  $p(i)$  for silver-magnesium dynodes were made by the authors at George Washington University (Washington, District of Columbia). The experiments were interrupted and the results have not been published. Because of the apparent recent interest in secondary-electron statistics, the theory was completed as discussed in this paper and part of the experimental material was selected to show an example for the determination of  $p(i)$  in the simple case of an electron multiplier consisting of identical dynode stages.

In front of the first dynode of a 12-stage electron multiplier, an additional stage (dynode) of similar geometry was built from which single electrons (coming from a tungsten filament) were accelerated and injected into the electron multiplier. The over-all voltage of approximately 3000 volts was uniformly distributed over the stages so that the voltage per stage was approximately 230 volts.

The single-electron response of the electron multiplier is shown in curve  $A$  of Figure 2. The scales are in arbitrary units. The background rate was negligible and the curve displays a definite peak. The average multiplication per stage is  $a = 4.0$  and the average

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secondary-electron multiplication, as measured on sister dynodes with full collection, is  $\pi_1 = 4.81$ . Thus the collection efficiency in the dynode stages is  $a/\pi_1 = 0.83$ .

To determine  $\alpha$ , pulse height calibration in the output was made using a mercury pulser. The direct-current gain of the system, related to the cathode current, was measured in successive steps. Because of the preliminary character of the experiments, the pulse height measurements showed a large scatter and an average of  $\alpha \sim 80$  percent is used here for the calculations. (Recently a precise procedure was developed for such pulse height calibrations by Bay and Pearlstein [17] that leads to an accuracy within about 0.1 percent.) With  $\alpha = 0.8$ ,  $A = 0.96$  results. The  $f(x)$  curve calculated from  $\varphi(x)$ , with  $a = 4$ , is shown in curve *B* of Figure 2.

On the basis of the above data, the calculations were carried out with an *IBM 1620* com-

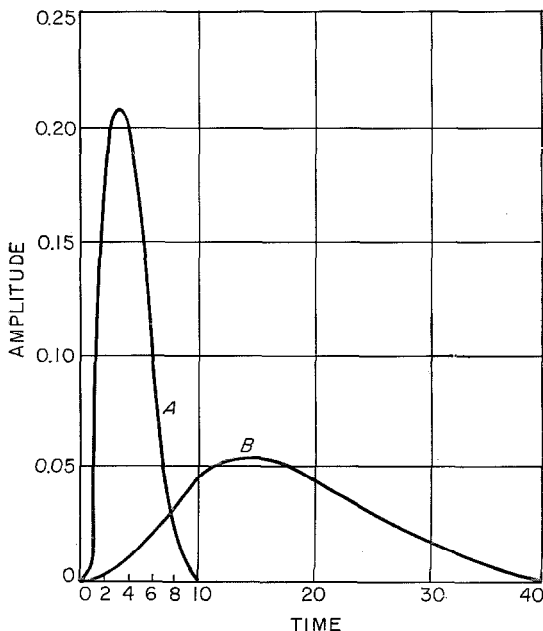


Figure 2—Curve *A* shows the experimental pulse height density distribution curve  $\varphi(x)$ , while curve *B* shows  $f(x)$ , calculated from  $\varphi(x)$ , with the stage gain  $a = 4$ . Both scales are of arbitrary units.

puter at the ITT Industrial Laboratories, Fort Wayne, Indiana.

Table 5 shows the first six  $\pi_k$  moments of the  $p(i)$  distribution, calculated from the moments of  $\varphi(x)$  and  $f(x)$ . The combinatorial moments  $C_k$  are calculated from the  $\pi_k$  moments using Table 3. The procedure of [15] is used to calculate the  $p(i)$  values from the  $C_k$  moments. The approximation by orthogonal polynomials, with  $r = 6$  and with the choice of  $N = 11$  in (11) to (14), allows the calculations of  $p(i)$  up to  $i = 10$ . The corresponding values for a Poisson distribution with the same first moment are included for comparison.

The preliminary character of the measurements limits the precision of the values in Table 5. However, it is felt that the following conclusions are permitted tentatively.

(A) The  $p(i)$  curve is not far from a Poisson distribution.

(B) The variance of the  $p(i)$  curve is slightly "supranormal," in qualitative agreement with earlier results.

(C) The fifth and sixth moments of  $p(i)$  emerge smaller than the Poissonian moments, which may be an indication that large numbers in the secondary-electron emission become less probable for reasons of energy conservation.

Continuation of the experiments promises to obtain information important for understanding the processes of the secondary-electron emission. In such experiments a scintillation counter can also be used instead of the electron multiplier to obtain  $\Phi(x)$  and  $F(x)$  if the electrons are accelerated to an easily detectable level [18-21].

## 5. Conclusions

(A) The probability distribution  $p(i)$  for the release of  $i$  secondary electrons can be determined under deliberately specified conditions, using an electron multiplier for the measurements.

TABLE 5  
COMPARISON OF EXPERIMENTALLY DETERMINED VALUES OF  $\pi_k$ ,  $C_k$ , AND  $p(i)$  WITH CORRESPONDING DATA OF THE POISSON DISTRIBUTION

$i$	$\pi_i$	$C_i$	$p(i)$	$\pi_i$	$C_i$	$p(i)$
	Experimental			Poisson		
0	1.0	1.0	0.028	1.0	1.0	0.008
1	4.8	4.8	0.031	4.80	4.8	0.039
2	28.3	23.5	0.082	27.84	23.04	0.095
3	188.4	113.1	0.146	184.51	110.59	0.152
4	1 373.2	525.3	0.184	1 360.46	530.84	0.182
5	10 704.8	2 267.0	0.178	10 971.58	2 548.03	0.175
6	87 695.8	8 633.5	0.133	95 627.73	12 230.54	0.140
7			0.081			0.096
8			0.054			0.057
9			0.058			0.031
10			0.023			0.015

(B) The moments  $\pi_k$  and factorial moments  $C_k$  of the  $p(i)$  distribution can be calculated from measurable data to any desired degree  $k$ . Extension of the calculations to higher degrees of  $k$  does not change the moments already calculated. Therefore, physical conclusions derived from the behavior of lower degree moments are valid for the entire  $p(i)$  curve.

(C) By introducing the counting efficiencies,  $\alpha$  and  $A$ , the probability  $p(0)$  is included in the treatment and  $p(i)$  with the proper normalization results.

(D) Preliminary experiments with a 12-stage electron multiplier consisting of equivalent silver-magnesium dynodes are presented. The  $\pi_k$  and  $C_k$  moments are calculated up to  $k = 6$ . The  $p(i)$  values are computed from the  $C_k$  moments using an approximation method. The results show that the  $p(i)$  curve is not very different from a Poisson distribution, though indications of departure can be seen by the comparison of moments.

6. Acknowledgments

The authors wish to thank Mr. L. Monostori of the National Bureau of Standards for assistance in making the experimental tubes.

They also thank Messrs. J. Steinhilber and T. Sodano of ITT Industrial Laboratories for making the calculations on the digital computer, and Dr. L. Takacs of Columbia University and Dr. H. Salinger of ITT Industrial Laboratories for valuable discussions.

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**Zoltan Bay** was born in Gyulavari, Hungary, on 24 July 1900. He obtained a doctorate in Physics at Budapest University in 1926.

From 1926 to 1930 he conducted research in gas discharge and active gases at the Physikalisches-Technische Reichsanstalt and at the Institute of Physical Chemistry of the University, in Berlin. In 1930 he became Professor of Theoretical Physics in Szeged, Hungary.

In 1936 Dr. Bay became director of the Industrial Research Laboratories of Tungsram in Ujpest, a suburb of Budapest. Research involved light excitation and detection plus microwave electronics. During this period he also taught atomic physics at the Technical University of Budapest.

In 1948 he left Hungary for the United States, becoming Research Professor at George Washington University, Washington, District of Columbia. Since 1955 he has worked on atomic physics at the National Bureau of Standards.



**George Papp** was born in Szamosujvar, Hungary, on 27 September 1912. He received a teacher's degree in physics in Szeged, Hungary, in 1935, and a doctorate in physics in Budapest in 1937. He taught physics for one year in the L. Eotvos College, Szeged, and later became lecturer in atomic physics at the Technical University of Budapest.

In 1948 Dr. Papp became research associate at George Washington University, Washington, District of Columbia, and worked on

various applications of electron-multiplier tubes for particle counting with Dr. Z. Bay.

In 1952 he joined ITT Industrial Laboratories, then the Capehart-Farnsworth company, where his work included image converters and image storage tubes, tube diodes for microwave detection, and digital methods for electron optics.

Dr. Papp died suddenly on 1 September 1964 from complications following an emergency appendectomy.

# Visual Presentation for Flight Simulators

J. BARADAT

Le Matériel Téléphonique; Paris, France

Flight simulators are training aids designed to help familiarize a crew or part of a crew with the operation and characteristics of a real aircraft. The modern flight simulator [1] is a compact transistor system that assures accurate simulation of aircraft characteristics, tactical system, communication system, et cetera.

Using this type of simulator, the pilot can familiarize himself with cockpit presentation and with the emergency procedures and handling of the aircraft during difficult maneuvers. With practice, the pilot is able to carry out his tasks by reflex action.

However, in this type of simulation, he must take off and land without visual reference and thereby the realism is limited. To overcome this limitation, flight-simulator manufacturers are trying to simulate both these phases by projecting on a screen a view of horizon, runways, and surroundings.

Runway representation was first obtained by means of a light beam projected through a rectangular slit. The beam, having three degrees of freedom with respect to the slit, could give the illusion of distance, altitude, and relative motion by varying the dimensions and geometric shape of the projected trapezium. This beam, moving up and down the

inside of a cylinder, gave a light zone (the sky) and a dark zone (the ground) on which the runway was superimposed. Pitch, roll, and heading were obtained through relative motions of the lamp and the cylinder.

The advantage of this system is that a horizon of 180 degrees is projected and the visible ground reference gives the impression of relative motion. On the other hand, the mechanical and optical system is complex and the projected picture gives little detail.

To improve the detail a landing approach was filmed, then projected in front of the pilot in the flight-simulator. The motion-picture film projection was started by the computer when the correct conditions of distance, altitude, and alignment prevailed. The speed of film transport was proportional to the aircraft speed. Any deviation from the ideal glide path produced corresponding deviations of the picture. This system actually gave the required detail but was abandoned because of the limited ability to present abnormal landing operations.

The closed-loop television system described in this paper avoids this disadvantage. In this system the visual presentation is obtained by relative movement of a television camera and a model of an aircraft carrier, accurately con-

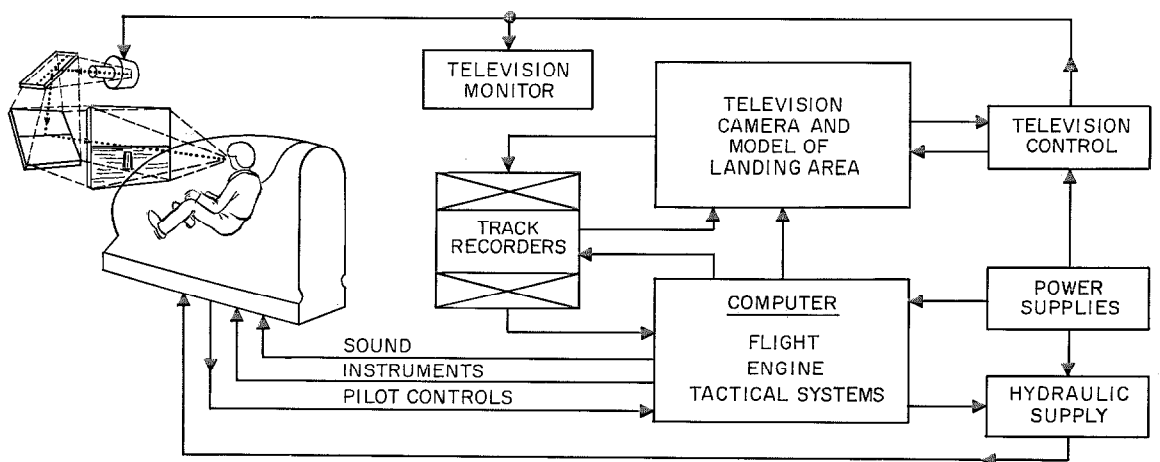


Figure 1—Diagram of a simulator with visual presentation of landing area.

trolled by computer outputs and projection of the corresponding television picture onto a screen in front of the cockpit. It can give a good picture of an airfield, an aircraft carrier, et cetera, depending on model detail and resolution of the television system. Furthermore, the pilot controls the picture, since it is produced by a television camera that is servo driven by the computer, which is programed by data from the pilot controls (see Figure 1). At every moment, the pilot in the simulator "pilots" the camera exactly as he would fly visually to reach his objective. The Étendard IV-M simulator uses this type of visual presentation.

### 1. Technical Data

The Étendard IV-M aircraft is a single-place carrier-based supersonic fighter. The simulator provides for navigational and tactical flight as well as a visual presentation system for carrier-controlled-approach deck landings and catapulted takeoffs on the carrier *Clemenceau*.

Some compromises were made in order that the entire simulator could be housed in a single semitrailer. Still, the basic principles are valid for any visual presentation by television.

### 2. Parameters of Camera System

The television camera has six degrees of freedom as does the aircraft. The computer gives the six corresponding parameters. Three of them characterize the attitude of the aircraft with respect to the ground (see Figure 2).

- $\theta$  = pitch angle
- $\phi$  = roll angle
- $\psi$  = heading

In modern fighters pitch and roll rates are high. Therefore, corresponding rates must be obtained by low-inertia servomechanisms.

The other three parameters define the aircraft position with respect to the runway or carrier deck.

$Z_v$  is the aircraft altitude above ground or sea and  $X_v$  and  $Y_v$  are the relative aircraft and carrier vector components along two perpendicular axes in the horizontal plane.

The glide path is represented by these parameters, their variations being relatively slow and controlled by power servomechanisms that drive the high-inertia camera assembly.

These servomechanisms need not have a dynamic performance as elaborate as servomechanisms  $\phi$  and  $\theta$ . It is essential that they be smooth in operation to avoid any jerkiness of the camera and consequently of the picture on the screen.

### 3. Realization

The size of the equipment was restricted as the simulator was housed in a semitrailer. An acceptable simplification was to assume the carrier to be moving on a smooth sea, detailed information being necessary only for the carrier model. To minimize floor space the carrier model is placed vertically as shown in Figure 3.

Altitude movement  $Z_v$  is obtained by driving

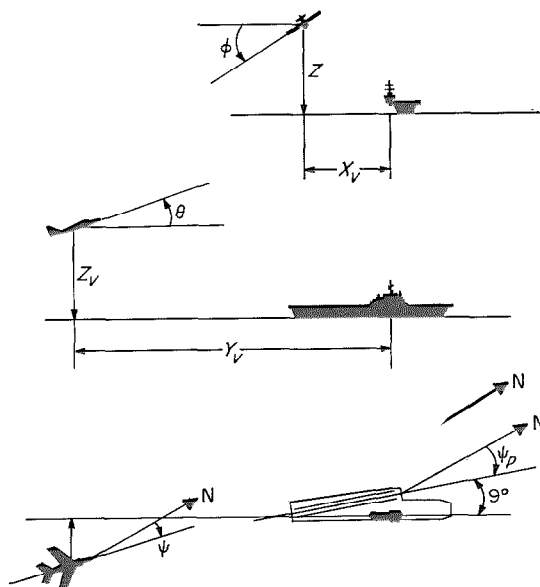


Figure 2—Parameters of camera system.

the optical system of the camera, which corresponds to the aircraft, in the direction perpendicular to the deck of the carrier model to increase or decrease the distance between

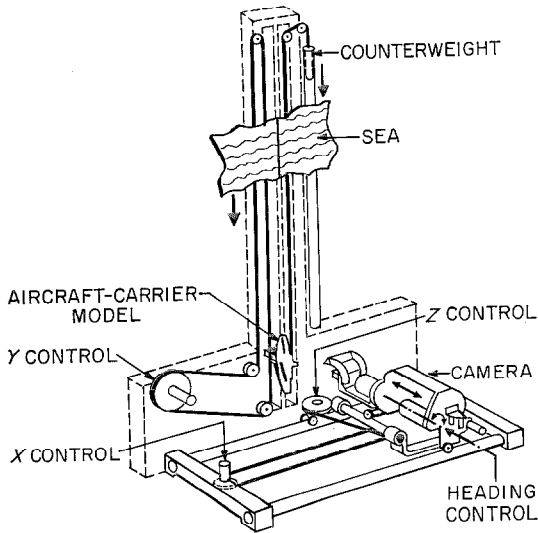


Figure 3—Television camera and model of landing area.

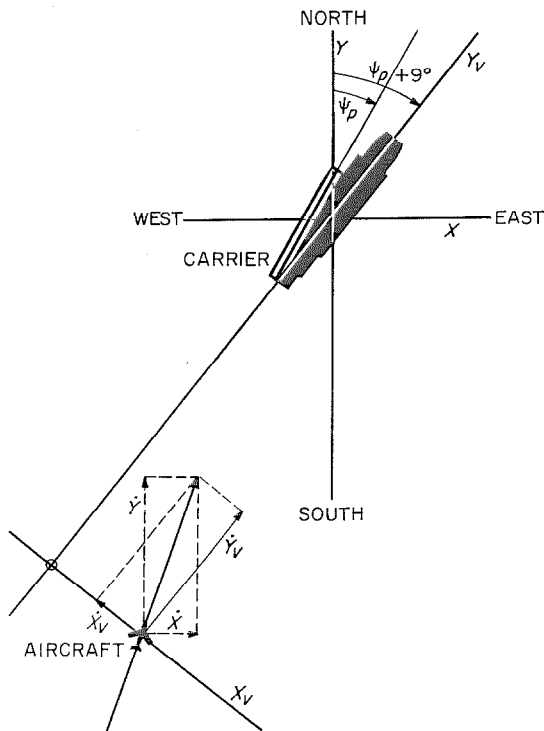


Figure 4—Transformation of axes.

them. By driving the camera assembly sideways on chrome-steel rails in the horizontal plane, the  $X_v$  motion is simulated. The carrier model runs in a groove cut in the center of the vertical surface that represents the sea to correspond to the  $Y_v$  parameter. The computer determines the relative motions of the aircraft and carrier and controls the 3 servomechanisms for the  $X$ ,  $Y$ , and  $Z$  parameters to establish the relative positions of the camera and the carrier model.

The computer controls the track recorders and determines when the aircraft is within prescribed visual limits of the carrier. These limits are 2000 meters (6500 feet) long, 1000 meters (3250 feet) wide, and 250 meters (800 feet) high.

At every moment, the aircraft speeds are computed along the east-west  $\dot{X}$  and north-south  $\dot{Y}$  axes as shown in Figure 4.

The instructor sets up the carrier flight-deck heading  $\psi_p$ . A resolver driven by this control supplies the necessary information to the computer to determine the speeds  $\dot{X}_v$  and  $\dot{Y}_v$ .

$$\dot{X}_v = \dot{X} \cos (\psi_p + 9^\circ) - \dot{Y} \sin (\psi_p + 9^\circ)$$

$$\dot{Y}_v = \dot{X} \sin (\psi_p + 9^\circ) + \dot{Y} \cos (\psi_p + 9^\circ).$$

The axes of the landing deck and the carrier make an angle of 9 degrees.

Pitch movement  $\theta$  of the aircraft is simulated by a low-inertia servo-driven prism in the camera optical system and is limited to a total excursion of 50 degrees. Roll movement  $\phi$  is simulated by a servo-driven Wollaston prism in the camera optical system and is not limited in range or number of revolutions. Heading  $\psi$  is simulated by revolving the camera frame about its optical axis.

These three servomechanisms are critically damped and slaved to the three computed angles.

#### 4. Camera

The image of the carrier model is formed on the camera vidicon through the optical head

shown in Figure 5. The optical system must have the following characteristics.

- (A) High resolution, more than 900 elements per line.
- (B) Low linear distortion.
- (C) Capability of reproducing pitch and roll movements.
- (D) Large depth of field, from 4 centimeters (1.6 inches) to infinity.
- (E) Strength and small dimensions; the head of the optical system must be rigid and narrow enough to "land" on the deck beside the model superstructure.

The model is usually designed to a scale of 1:1000 or 1:5000. In the *Étendard IV-M* simulator, a scale of 1:1000 was chosen and the optics actually "lands" on the carrier

model during deck landings and catapulted takeoffs. Consequently, the model must be strongly as well as accurately built, particularly with regard to beacon, approach lighting, et cetera.

The small scale increases the difficulty in both building the model and in the electronic operation. The camera must have a high resolution to define small bright points against a dark background.

A reasonable level of lighting must be maintained on the televised model. Ordinary systems need several kilowatts of lighting. The resulting heat cannot be accepted in a semi-trailer because of the limited capacity of the air conditioning. In the *Étendard IV-M* simulator 600 watts are sufficient.

To obtain a correct visual presentation, the horizon must remain at the level of the pilot's

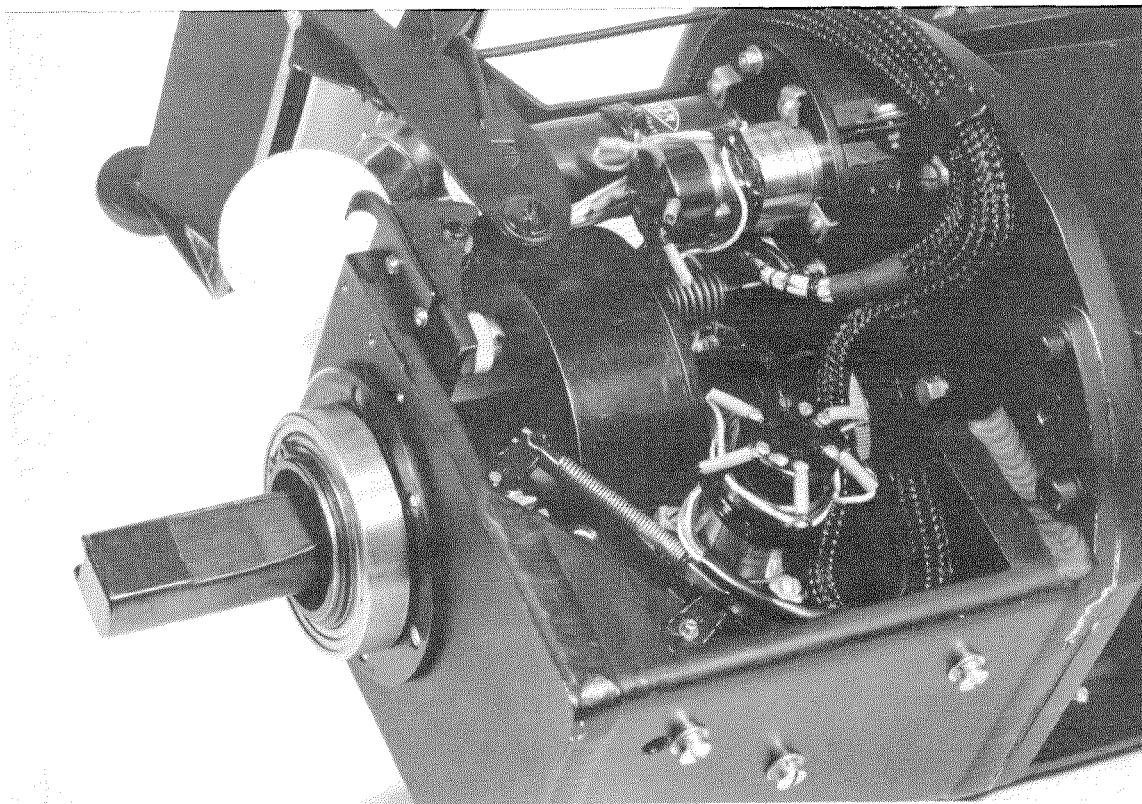
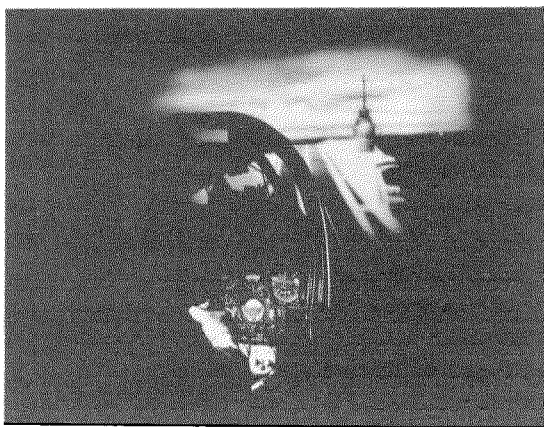


Figure 5—Part of camera optical system.

## Visual Presentation for Flight Simulators

Figure 6—View of the aircraft carrier during simulated landing.



eye. This effect is obtained by mounting a celestial dome on the camera assembly. The inner surface of the dome is essentially white with cloud forms. The dome itself reflects much of the lighting back onto the model, permitting a considerable reduction of the light required and the accompanying heat.

### 5. Projection System

The video signal produced by the camera operates a television monitor and a projector that displays a picture having a peak white brightness of about 8 foot-lamberts. The camera and projector have the same characteristics. In the *Étendard IV-M* simulator the viewing angle is 60 degrees.

Figure 1 schematically shows the projecting system. Two high-quality mirrors silvered on the front surface permit the optical path to

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In 1957 he joined *Le Matériel Téléphonique* and, after working on the simulator for the

be folded. They also correct the image seen by the pilot through a vinyl translucent screen.

Figure 6 shows the projected picture at a particular moment of a simulated approach.

### 6. Conclusion

Although camera and projection geometries were rigorously respected, it has been found that the pilot's subjective impressions would be further enhanced if two main areas of simulation were improved. First, the image is not at infinity, giving an unsatisfactory accommodation as well as parallax effects. These are diminished by placing the screen farther from the pilot, but more-powerful projectors are then needed.

Second, the apparent displacement of the runway—the center of interest during approach—together with the physical sensations given by real piloting, form a coherent whole. Only part of this is conveyed by the picture moving on the screen.

The visual impressions can be complemented by actual physical sensations, produced by cockpit motions and accelerations along two or three axes. Hydraulic systems are being designed to provide the missing sensations to give this visual system complete realism.

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Mirage aircraft, became project manager for the *Étendard* simulator. He is now in charge of a study of a jet digital simulator.

Mr. Baradat is a member of the *Société Française des Électriciens*.

## United States Patents Issued to International Telephone and Telegraph System; August 1963 through January 1964

The United States Patent Office issued 75 patents to the International System between 1 August 1963 and 31 January 1964. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

P. R. Adams, G. B. Speen, and D. E. Brannon, ITT Federal Laboratories, Gyroscope, 3 110 187.

H. H. Adelaar, Bell Telephone Manufacturing Company (Antwerp), Transient Repeater, 3 117 185.

B. Alexander and J. F. Sullivan, Federal Telecommunication Laboratories, Storage Device, 3 104 377.

E. A. Ash, Standard Telephones and Cables (London), Cyclotron Wave Harmonic Generator, 3 118 083.

W. S. Bartky, ITT General Controls, Capacitance Measuring Apparatus, 3 119 267.

A. H. W. Beck, A. T. Starr, and T. H. Walker, Standard Telephones and Cables (London), Decoding Arrangements for Electric Pulse Code Modulation Systems, 3 115 623.

O. Bettinger, Standard Elektrik Lorenz (Stuttgart), Automatic Gain Control Circuit for IF-Amplifiers of a Large Bandwidth, 3 111 631.

A. E. Brewster, Standard Telecommunication Laboratories (London), Coders for Electric Pulse Code Modulation Systems, 3 110 895.

F. Buchwald and K. Hubner, Standard Elektrik Lorenz (Stuttgart), Station for Pneumatic Tube Carrier System, 3 104 078.

K. W. Cattermole and D. R. Barber, Standard Telephones and Cables (London), Coding Arrangements for Electric Pulse Code Modulation Systems, 3 115 624.

J. E. Cox, ITT Kellogg, Four Wire Transistorized Conference Call Telephone System, 3 116 369.

J. A. Deubel, ITT General Controls, Combined Valve and Relay Structure in Burner Control System, 3 100 521.

J. A. Deubel, ITT General Controls, Remote Reset Safety Control for Gaseous Fuel Burners, 3 115 180.

S. J. Erst, ITT Federal Laboratories, Continuous Wave Narrow Recognition Zone Radar System, 3 108 273.

P. T. Farnsworth, Capehart-Farnsworth Corporation, Electron Image-Discharge Device, 3 108 202.

R. C. Ferrar and H. A. French, ITT Laboratories, Diversity Receiving System Using a Low Noise Parametric Amplifier System, 3 118 113.

N. Fries, Mix and Genest Werke (Stuttgart), Selector Circuits, 3 115 617.

H. Fritsch, Sueddeutsche Apparatefabrik (Nürnberg), Electrical Condenser, 3 115 596.

A. G. Gatfield, ITT Laboratories, Amplitude Modulated Carrier Transmission System, 3 118 112.

J. L. Gatto and R. O. Wyckoff, ITT Bell & Gossett, Self-Priming Centrifugal Pump, 3 103 177.

A. W. Gent, C. C. Eaglesfield, R. T. Lawrence, and L. Crampton, Standard Telecommunication Laboratories (London), Waveguides, 3 106 768.

J. C. Gibson and T. L. Bowers, ITT Kellogg, Combined Switching and Adjusting System, 3 110 885.

W. J. Gieffers, ITT Kellogg, Circuit for Maintaining a Load Energized at Decreased Power Following Energization, 3 116 441.

A. F. Giordano, ITT Laboratories, Color Pattern Display System, 3 117 488.

W. L. Glomb, D. R. Campbell, and J. H. Kressman, ITT Laboratories, Signal to Noise Ratio Indicator, 3 101 446.

W. L. Harries, ITT Laboratories, Electronic Fluid Flow Control Valve, 3 117 416.

- M. A. Karpeles, ITT Laboratories, Instrument Landing System, 3 115 634.
- F. S. Kasper and L. Lamin, ITT Kellogg, Electronically Controlled Crosspoint Switches, 3 118 973.
- J. Keyes, E. Oehlerking, and L. J. Smith, ITT Bell & Gossett, Self-Fired Heater and Fan Unit, 3 109 422.
- H. G. King and S. R. Pitkin, Standard Telephones and Cables (London), Modulators for Carrier Communication Systems, 3 118 117.
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- J. Murgio, ITT Laboratories, Digital-to-Analog Converter, 3 110 894.
- C. N. Pagano, ITT Laboratories, Synchronized Gate, 3 115 607.
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R. L. Whittle, J. Luongo, and R. H. Rymer, ITT Laboratories, Data Recording System, 3 104 147.

H. R. Williams, ITT Bell & Gossett, Evaporator with Oil Return Means, 3 111 819.

R. W. Wilmarth, ITT Laboratories, High Power Traveling Wave Tube, 3 104 344.

F. Wolff, Schaub Apparatebau (Pforzheim), Apparatus for Effecting the Automatic Contrast Control in Television Receivers, 3 104 281.

E. P. G. Wright, Standard Telecommunication Laboratories (London), Intelligence Storage Equipment, 3 104 375.

E. P. G. Wright, Standard Telecommunication Laboratories (London), Data Processing Equipment, 3 118 131.

N. H. Young, Jr., Federal Telecommunication Laboratories, Two Data Channel Shaft Positioning System, 3 110 850.

### Station for Pneumatic Tube Carrier System

3 104 078

F. Buchwald and K. Hubner

This is a pneumatic tube station designed particularly for heavy carriers in which deflection of the carriers for ejection presents problems. The station consists of a portion in a straight tube provided with stop members at the forward and rearward ends of this portion. When a carrier is to be stopped for ejection, the forward stop member closes the tube portion at that end. Compression tends to slow down the carrier and when it stops, the rearward stop member seals off the portion containing the carrier, permitting its removal and the insertion of a new carrier. A by-pass line around the station permits continuous air pressure to be maintained in the remainder of the system.

### Waveguides

3 106 768

A. W. Gent, C. C. Eaglesfield, R. T. Lawrence, and L. Crampton

This patent discloses a method of joining two sections of waveguide, each formed of helically wound conductors. The conductors of the two sections are trimmed to precise shapes so that when the ends of the waveguide sections are aligned, the conductors forming the two sections will precisely abut upon relative rotation of the sections to form a substantially continuous helix. The two sections are then mechanically joined to retain the sections in position.

# Maintainability and Reliability Handbooks

Maintainability and reliability of electronic equipment for use on navy vessels are treated in two books prepared by Federal Electric Corporation for the Fleet Electronics Effectiveness Branch of the Bureau of Ships of the United States Navy. Both books are of loose-leaf type with 19-hole plastic ring binders. They are available from Superintendent of Documents, United States Government Printing Office, Washington 25, District of Columbia.

Maintainability Design Criteria Handbook for Designers of Shipboard Electronic Equipment (NAVSHIPS 94324) is about 550 pages, 7.5 by 10.25 inches (19 by 26 centimeters), and is \$6.00 per copy. Its section titles follow.

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