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Modern Research Facilities of Federal Telecommunication Laboratories

By H. H. BUTTNER

Federal Telecommunication Laboratories, Incorporated, Nutley, New Jersey

WITH the opening of the 300-foot aluminum-sheathed microwave research tower on May 19, 1948, at the new Federal Telecommunication Laboratories in Nutley, New Jersey, a unique approach to high-frequency radio propagation experimentation was inaugurated. The new tower constitutes a research laboratory in the sky; its 5 upper levels and roof extend between 200 and 300 feet above the surrounding terrain. It may, therefore, be described as a building on top of a tower, the top level at a height equivalent to that of a 30-story building.

Like light rays, ultra-high-frequency radio waves travel in substantially straight lines making their range virtually limited by the horizon and they are, therefore, most effectively propagated from and received at places located high in space, particularly for communication over any appreciable distance. Heretofore, sites atop mountains and tall buildings have been employed for microwave research, or the antennas have been placed on tall masts. But mountain tops are inconvenient for day-to-day experiments because of their remoteness and inaccessibility as well as their susceptibility to the extremes of weather. Building tops also present many limitations, such as interference caused by the reflection of waves off nearby structures, possible disturbance of existing radio services, and the difficulty of complying with local governmental regulations. Masts, because of their instability, inaccessibility of the structures mounted on top of them, need for supporting wires, and the necessity for long transmission lines between apparatus and antennas, are poor devices for precise measurements.

Tower in Original Plans

When plans for the new laboratories were first drawn up in 1943, a rigid tower for microwave experiments was included. At that time, the laboratories were busily engaged on radar, high-frequency direction finding, and other similar wartime developments. Since then, interest in microwave techniques has increased rapidly, not only for radio navigation with such devices as distance-measuring equipment, assisted radar, and Navar, but also for television, especially ultra-high-frequency color television, frequency and pulse-type modulations, and facsimile systems for broadcast, point-to-point, and relay operation. An extensive microwave program has been adopted by the armed forces of the U.S.A. and during the next decade will involve contracts with private industry of about a thousand million dollars for research and development. It is evident, therefore, that the concept of a tower as an essential unit of a complete electronics laboratory was both correct and foresighted.

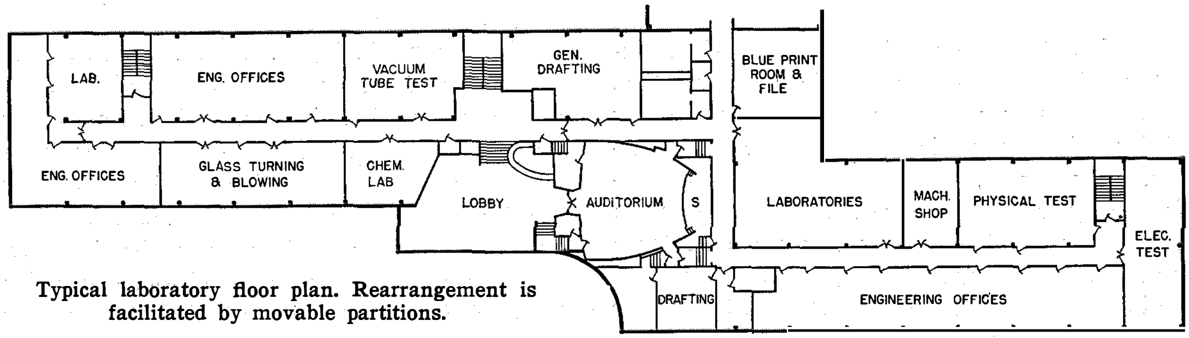
The laboratories as first conceived were to consist of two major divisions, a central part supplying a number of common services and a group of research units. In the common section were to be included technical and administration, maintenance, security and personnel, main incoming power, heating, fire detection and protection, compressed air and gas, and similar services. The first idea was to house these common services in a single building as a center surrounded by the laboratory and research buildings. The tower was to be located on top of the central building.

At this point, architects were consulted and the problem was presented as one of engineering a highly functional group of structures combining extreme flexibility and low maintenance. The first design drawn up by the architect provided for a circular central building three stories high with laboratory wings on either side. The tower was to be an open steel structure with two glass-enclosed floors at the top. This first plan would have permitted a total of seven laboratory wings

New buildings and tower of Federal Telecommunication Laboratories are shown on the opposite page.

to be built radially at 45-degree angles to each other; the eighth radial would have been omitted to provide for the main entrance.

When this initial plan was presented, it became apparent that it had a number of disadvantages. First, as wings were added, the windows on the first floor of the central structure would have been blocked out so that ultimately the whole floor would have been without outside lighting. Secondly, construction of the steel tower on top of the main building would have had to proceed at the time of the erection of the main building. The tower could not have been built afterwards because of the danger and difficulty involved in carrying on construction while the building below was occupied. Thirdly, the appearance of the open structure on top of the building was considered unsatisfactory. Fourthly, the architect recommended against wings at 45-degrees from each other because such construction introduced complications in the steel framework.



Typical laboratory floor plan. Rearrangement is facilitated by movable partitions.

Functional Design

In considering the original design further, it was felt also that the general architectural conception was not modern enough and that, as long as new laboratories were being constructed, they should be as functional as possible and should indicate some degree of independence from the classical method, provided there was justification for such a departure.

After several modifications and revisions were considered, a plan for the buildings was approved. The plan provided for an oblong central building with a group of laboratory wings at either end. In these later plans, provision was made for an independent tower to be erected close enough to the central building for easy access, but far enough away to be constructed independently. However, since the permanent tower could not be built immediately owing to governmental wartime building restrictions, no further designs were considered at the time. Work on the first two buildings was started in November, 1944, following the approved plan. These buildings were occupied the following spring. To provide immediate facilities for microwave research, a 200-foot temporary wooden tower was built nearby.

When the first two buildings neared completion, it was decided to plan for two additional wings. As this construction was to proceed after V-J day, it was possible to include a number of items that could not be considered during the war, that is, an appropriate entrance lobby, an auditorium, and the permanent tower. The four buildings now completed provide 130,000 square feet of gross floor space and comprise the largest group of metal-sheathed buildings in the world. Flexibility has been provided in the building site plan so that additional buildings may be added without impairing the symmetry of the group.

Aluminum for Outer Walls

Although utilizing conventional steel framework, the buildings depart in other ways from normal constructional design. The final plans specified a large amount of glass for the laboratory exterior plus a suitable material in the form of plates for the outside walls. Among the materials considered were an asbestos-cement compound and enamelled steel.

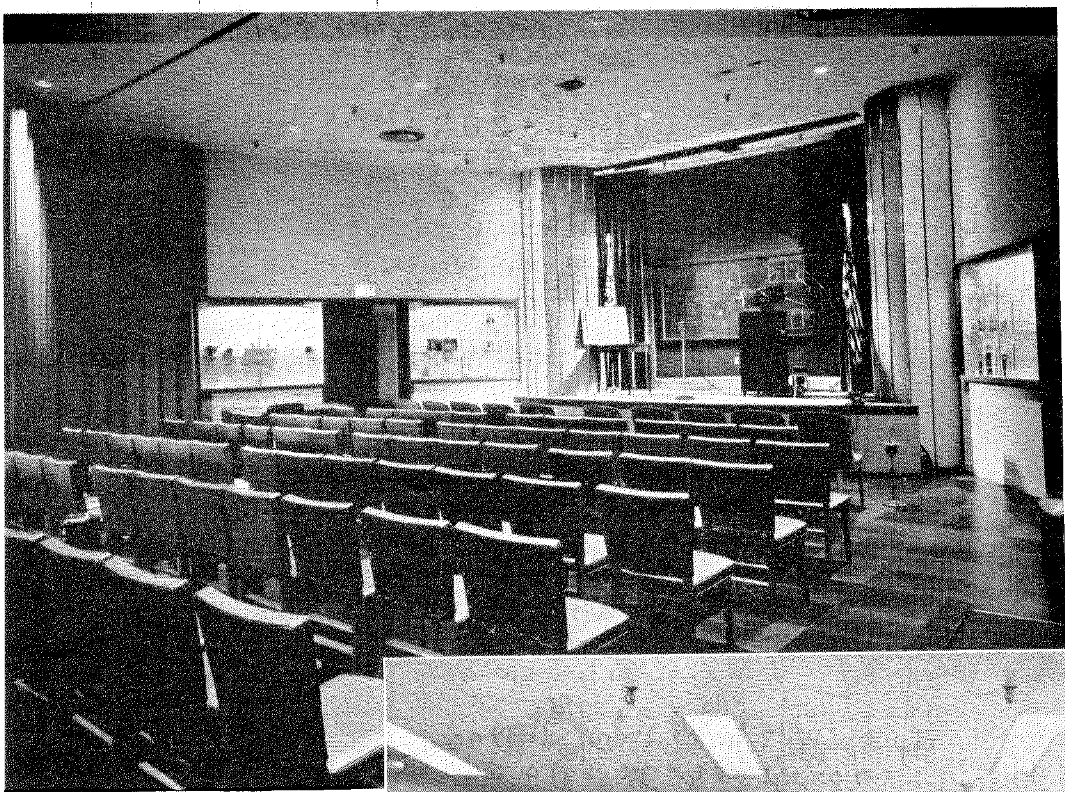
It was found however that at the particular period of the war when the buildings were to be started, an excess of aluminum plates was available. Investigation of aluminum for the outside wall covering revealed that samples of this material submitted to exposure in an industrial area from 10 to 15 years tarnished progressively, but not to objectionable proportions. After this period of time, it is possible to restore the original appearance by application of a suitable finish. Actually, such refinishing may not be necessary since the action of wind and dust on the buildings seems to constitute a continuous polishing agent. Also, it was realized that the aluminum surface would give a fair degree of shielding to the inside rooms against external radio fields produced by nearby radio stations, which measurements showed to be of the order of one-tenth volt per meter. Shielding between laboratories was also effected through the use of metallic partitions. With the use of all-steel flooring of the Robertson type, shielding between floors would also be effected.

The exterior walls, therefore, consist of panels made up of an outer covering or skin of aluminum, an insulation space filled with Fiberglass, and a backing of steel. These panels are two feet wide and are erected vertically, usually as spandrel sections.

The ceilings of the buildings are of the suspended type, utilizing metallic acoustic panels, which may be removed whenever access is desired to the ceiling space. The space between the suspended ceiling and the underside of the floor immediately above is utilized for air ducts, special ventilating equipment, sprinkler pipes, and other service and heating pipes.

Provision is made for distribution of hot and cold water, compressed air, illuminating gas, nitrogen, hydrogen, and oxygen. There are facilities for the detection of the presence of inflammable gases through the use of a detector that samples the air in each area where gasses are used and analyzes the samples several times each minute. In the event of inflammable gases escaping in dangerous proportions, an alarm automatically sounds and a light on the main gas-detector panel indicates the space in which the leak is occurring.

Front view of main building showing the glass-enclosed entrance lobby.



The auditorium may be used for lectures and demonstrations or as a studio for sound and television broadcasting.

Typical laboratory showing the large amount of natural illumination provided.

Typical office area. The wall panels in the rear can be moved to expand or contract the space as may be required.

Flexibility with Six-Foot Module

To obtain maximum flexibility, a system of removable dividing partitions is used. These allow the size of rooms to be changed with relatively little effort and without destroying the wall material. A six-foot space module was established. The first building, constructed during the war, employed Transite wall paneling for interior wall liners, while the later buildings have steel wall liners. The module was respected in designing heating, lighting, and sprinkler systems so that each module is self-sufficient in these respects. In other words, modules can be combined in any desired arrangement without the need of changes in these three basic services.

A maximum of natural lighting is provided through use of large window areas. Artificial lighting, in addition to conforming to the six-foot module, provides complete flexibility within a unit. The basic lighting unit is a fluorescent fixture with two four-foot tubes set flush with the metal-pan acoustic ceiling. The fixtures are of the snap-in type and utilize the same supports that carry the hung ceiling. It is a simple matter to replace two ceiling pan units with a lighting fixture at any location.

Varying from usual practice, the light switches are located in the corridor. At each column, there is a two-foot wall section that is not movable and provides a fixed position for these switches. Thus, partitions may be moved without involving electrical changes. The switches are, however, coordinated with the six-foot module system.

Electrical distribution throughout the laboratories is by means of a four-wire grounded-neutral system supplying 208-volt, three-phase 60-cycle alternating current. Thus, 120-volt, single-phase alternating current may be obtained between any phase wire and neutral. A substation is provided for each of the buildings and for the tower. The primary voltage of each substation is 4150 volts. Facilities are available for supplementary substations should the load require additional power capacity.

Fire Prevention System

The sprinkler system was the subject of special attention, since there are few places where water would cause more loss in both time and money than in an electrical laboratory. The rate-of-rise maximum-temperature system was, therefore, installed to prevent unnecessary water damage. In this system, the rate of temperature rise actuates the controls rather than some predetermined fixed temperature. Any abnormal temperature rise would start the following chain of protective measures.

A. Fire is detected by rate-of-rise heat detectors.

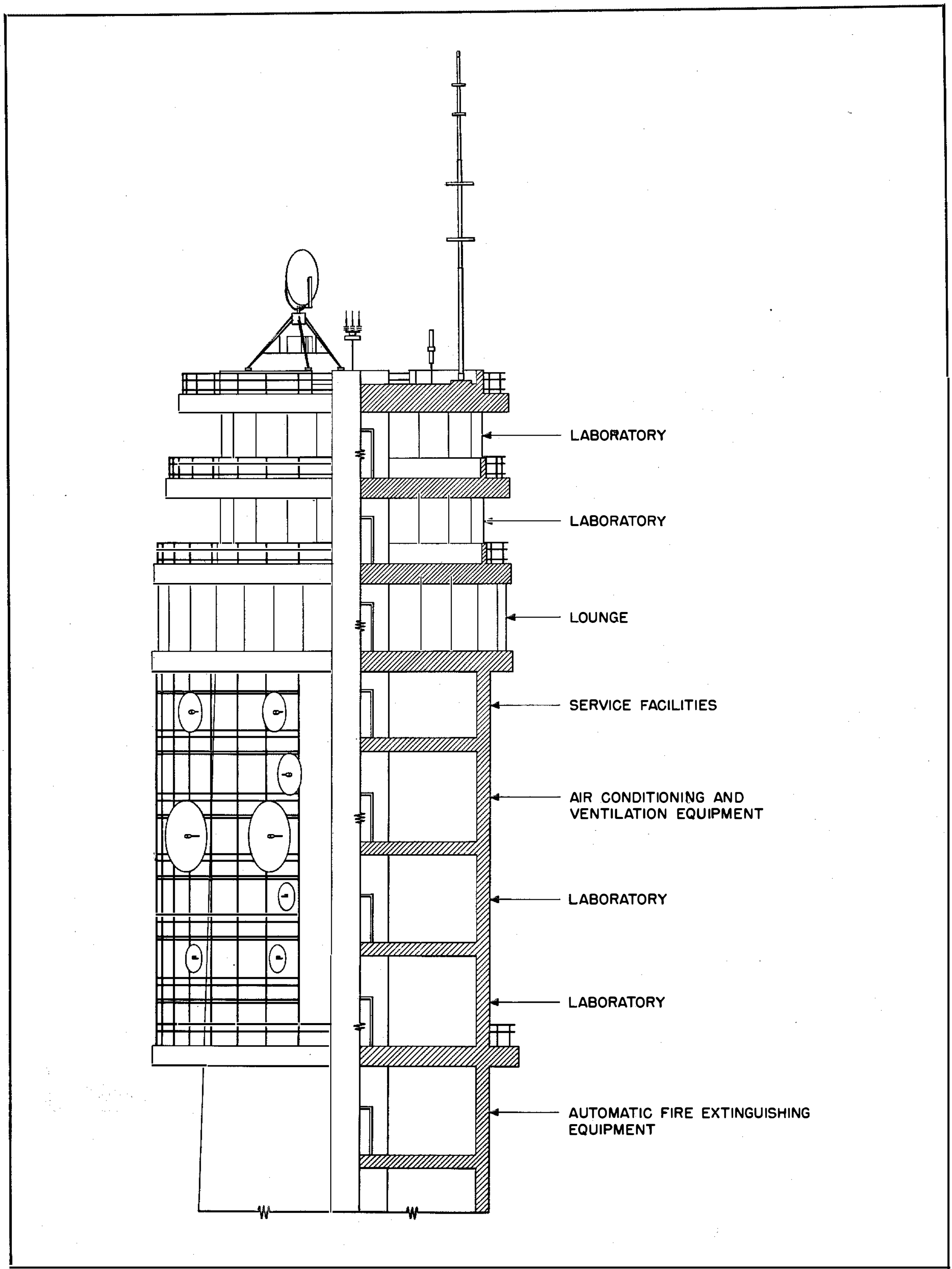
B. An alarm is sounded, indicating the fire zone in which the trouble is located.

C. Water is allowed to enter the sprinkler lines.

D. The water is held back until either
   - a. manual extinguishing efforts succeed, in which case the sprinkler heads do not open and water damage is prevented, or
   - b. the sprinkler links fuse and water under high pressure is sprayed in the affected area.

The heating plant is a steam and high-vacuum system using fuel oil. Controls permit the adjustment of the temperature in each room.

Corridor of one of the laboratory buildings.



Detail and cross section of upper levels of tower.

At the time the lobby and auditorium were being planned, two new basic designs for the tower were also drawn up. One was for a square main shaft with square buttresses and the other was for an oval structure. The towers in both cases were to be totally enclosed providing ample working space in a series of levels. Both designs appeared to have merits, but the oval shape was chosen because it lent itself more readily to experiments in all directions while the square shape might have made it difficult or impossible to operate in certain directions.

Optimum height of the tower for the location was determined through experimentation on the 200-foot structure. These experiments showed that heights between 200 and 300 feet would yield satisfactory results for research in all but one direction. This height would not be great enough for signals to scale the Watchung Mountains to the west. A tower tall enough to do this was considered economically and structurally impractical. Since research was to be carried on chiefly in the southeasterly direction toward the International Telephone and Telegraph Building in lower Manhattan (New York City) and the field station at Telegraph Hill (Hazlett), New Jersey, the 300-foot height was chosen.

Tower Design Unique

The task of designing a high steel tower with a comparatively narrow base presented a number of interesting problems. Foremost among these was that of weight distribution. With 75 percent of the weight concentrated between the 200- and 300-foot levels, the necessity to provide adequate support was a major consideration. For example, architectural engineers estimated that during high winds the uplift stress on the foundation might well run into several hundred tons. As a result of these calculations, a tension anchorage was developed that is probably the most unusual feature of the entire construction.

The main columns of the tower are anchored in a reinforced concrete mat 10 feet thick. Uplift loads are carried by reinforced tension cylinders extending approximately 30 feet below the foundation mat into bedrock. The rock layer in this area is said by geologists to be thousands of feet thick.

To construct the anchorage for the tower, a well driller drove 24 holes each 14 inches in diameter into the ground. Twelve large steel rods were lowered into each hole and a special type of concrete, which expands on hardening, was used to anchor the cylinders in the surrounding rock.

The frame of the tower, including columns and bracing, is made of structural steel of standard rolled shapes. Roof and floor slabs are reinforced concrete on steel beams; the upper levels employ slightly different framing because of depressed floors and overhanging balconies.

The south balcony at the lower landing is supported on a cantilever extending 12 feet beyond the column supports and the resulting uplift on the main floor girder is reacted by an inverted K-frame to the floor above. The south columns above the main landing, having a design loading of over 200 tons, are carried back to the main columns by cantilever girders. Resulting uplift on the main floor girder is counteracted by a tension tie to a K-frame two stories below.

Rigidity of Tower Essential

Because of the exacting nature of the work to be conducted in the elevated laboratory—notably the use of sharply focused beams—rigidity of the supporting structure was of paramount consideration. A primary design requirement, therefore, was limitation of both static deflection and amplitude vibration under a wind velocity of 80 miles per hour. This was dictated primarily to avoid any major interference with focussing operations during stormy periods.

Accordingly, the allowable wind stress in the columns and bracing was so calculated that, with the maximum wind load from any direction, total deflection at the top of the tower would not exceed 10 inches. These calculations, taking into account the unusual weight distribution at the top of the tower and the eccentric loaded projection on the north-south axis, involve both normal and torsional inertia loads as well as actual wind load.

In considering these special conditions, original formulas had to be developed to approximate the amplitude of vibration that would result from periodic and unbalanced wind pressures that would add to the static deflection of the tower under a steady wind load. The period of oscillation of the tower involved calculations based on inertia forces of the elastic center of gravity and the elastic center of oscillation. This was computed to be about 3 seconds, exclusive of the damping effect of the bracing system and the applied wind load. On the basis of these assumptions, it was determined that the maximum static deflection would be about seven inches in addition to an amplitude of vibration of about three inches.

For beam antennas, vertical supports are provided between the lower landing and the main landing, standardized as to spacing and serviced by steel walkways. The pipe supports are attached to the cantilever balcony curb. At present, they are installed only in the southeast quadrant, but provisions have been made for setting them up all around the tower. A cargo boom located on the roof permits a parabola or other type of antenna structure to be hoisted to the point of location. The accessible walkways then permit easy location of the antenna in any chosen position. The boom is also used to haul materials to the roof.

An automatic electric elevator with a speed of 500 feet per minute provides rapid access to the upper levels. The car has a capacity of nine persons or 2500 pounds and will accommodate standard 29-inch bays for transportation to the research levels. Each research floor provides 1000 square feet of laboratory space.

Practical as well as aesthetic considerations dictated the choice of aluminum as the outside covering for the tower. Rolled sheet aluminum sections not only provide the required enclosure for elevator and stairwell, but afford weather protection to the steel frame, thus reducing maintenance to a minimum.

The laboratory space is steam heated on the two upper landings, while the roof has been provided with snow-melting pipes in the concrete. Both electricity and hot and cold water are supplied to these areas. Extensive fire-protection equipment has been provided throughout the tower. The water pump, elevator relay controls and motor generator, flood-light controls, substation, and other service equipment are located in a lower part of the tower. Water is pumped to

Former club house of the Yountakah Country Club now used as a restaurant and recreational center by laboratory personnel.

a pressure distribution tank located at the 230-foot level and distributed from there.

Glass-Enclosed Landing

The main landing is entirely glass enclosed and air conditioned. This area forms an observation room providing a wide view of New Jersey, New York harbor, and the New York City skyscrapers. Decorated in a modern style, in keeping with the impressive functional design of the tower and buildings, this level may be used to demonstrate equipment as well as for research. Included in the decorative scheme is a large mural, symbolizing the progress of electronic science through the centuries, painted on stainless steel by Mrs. Buell Mullen, well-known designer and artist who introduced the technique of painting on stainless steel. A number of her murals are on exhibition in the Library of Congress and in other governmental buildings in the U.S.A. and also Latin America.

A floodlight trench circles the tower at its base to provide projected incandescent illumination, while a blue cold-cathode light strip extends vertically to the top. The tower, then, becomes an impressive beacon at night, its spectacular beauty dramatically mirrored in a large, gracefully curved reflecting pool at its northern edge.

The laboratory buildings and tower are located on the site of the former Yountakah Country Club, whose rolling lawn and tall, stately shade trees have been preserved. The lawn provides auxiliary outdoor areas for field tests and experiments with mobile and portable equipment.

Located several hundred feet to the southeast of the laboratories is the club house of the former country club. A large rambling colonial-style building, it now houses the restaurant and cafeteria for the laboratory employees. Also, there are spacious rooms, which are used for employee recreation. Directly adjoining the club house is an outdoor swimming pool available to laboratory personnel for evening swims during the summer months. An outdoor dance pavilion may be used when picnics are held in the grove. Behind the club house are areas for softball and other games.

Electronic Carillon

A 25-note electronic carillon has its loudspeakers attached to the topmost railing of the tower. With an audible range of approximately 12 miles, its musical tones may be heard in the surrounding community as well as on the laboratory grounds. At hourly intervals the carillon tolls Westminster chimes and musical selections are played on it each noon and evening. So, besides being an efficient facility for research, the tower fulfills the function of the campanile, familiar to old-world communities and now present in some form on almost every college and university campus in the U.S.A.

Less than 20 miles from New York City, surrounded by pleasant and healthful countryside, and in the midst of desirable home communities, the new Federal Telecommunication Laboratories are located in an atmosphere stimulating to scientific development. Since the products of a laboratory are discovery, invention, and design—creations of the intellect—the environment for its scientists and engineers is as important as the tools with which they work. In the new laboratories, the two needs may be said to have been ideally fulfilled, for not only has an advanced, functional, and well-equipped group of buildings been provided, but they have been placed in a setting that makes for a pleasant place to work and live.

Intelex — Automatic Reservations

By J. D. MOUNTAIN
International Standard Trading Corporation, New York, New York
and E. M. S. McWHIRTER
Standard Telephones and Cables, Limited, London, England

COMPARISON of Intelex with existing manual methods of reserving passenger space shows outstanding improvements. While the manual systems may require even hours to confirm a reservation, Intelex will make and confirm a reservation within 10 seconds, and since substantially all operations are performed by circuits using well-tried relays, switches, and tubes, the probability of error is greatly reduced. A brief coded message of reservation, cancellation, or inquiry may be transmitted by teleprinter from any local office. No further manual operations are required and the Intelex machine will reply automatically to the teleprinter in the office originating the order. Information can be obtained at any time on the status of all reservations on any specific journey.

• • •

The growth of transportation in recent years has been accompanied by such a vast multiplication of the complexities of the services, that manual methods of handling many of these are becoming inadequate. A service seriously affected by this phenomenon is the reservation of seats for passengers on airlines and railroads. Diligent efforts by the managements, as well as expenditure of ever-increasing amounts of money, have not enabled the carriers to keep pace with the mushrooming permutations and combinations of space demands brought about by the increasing needs of the traveling public.

Although all forms of transport, including railroads, airlines, busses, and steamships are feeling the pinch of this problem, it is, perhaps, most critical in the airlines. Cost of operation of aircraft is so great that filling of every possible seat on every flight is imperative. At the same time, to sell more seats than are available is disastrous to public relations. The handling of 15,000,000 passengers per year, filling every possible seat but not overselling, is therefore a difficult manual operation.

To accomplish this task, one major airline employs about 700 persons in its reservation service at a cost of about a million and a half dollars per year—nearly 3 percent of the total cost of that airline's operation. Nearly half a million more is spent by this airline for the communications facilities needed to handle these reservations.

To help reduce this huge cost and at the same time improve the reservation service to the passenger, a new system of handling reservations, called Intelex, has been developed. By replacing much of the personnel by electronic and electromechanical devices, it provides great advantages in speed and accuracy, reduces costs, and improves customer relations.

Intelex is essentially an electromechanical "brain" arranged to provide a bookkeeping service, the basic requirement of a reservation system. In its "books," or "ledgers," reservations and cancellations are recorded from many remote points. Information is also provided regarding various totals of the entries. Intelex will record and confirm any reservation or cancellation within 10 seconds. Through the "Have-a-Look" feature, the status of seats on any trip may be determined also within 10 seconds.

In the following paragraphs, a comparison is made of the facilities available in reservation systems as used commonly today, with the features of Intelex. Special attention is given to airlines, which must meet particularly difficult requirements.

1. Reservation Systems in Common Use

1.1 General

An airline system carrying passengers in either direction between two stops once a day (Fig. 1) has a relatively simple job when organizing a reservation system. There are then only two journeys a day, one each way. Space must be provided in the reservation record, or ledger, to enter the sale of, say, 30 seats per day on each

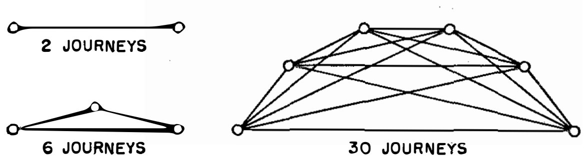


Fig. 1—Number of journeys possible in transportation systems having 2, 3, and 6 stops. Each line joining two stops indicates two journeys, one in each direction.

of two journeys, and up to perhaps 8 days in advance. The number of seats in the ledger is then $2 \times 8 \times 30$, or 480.

If a third stop is added to the route (Fig. 1), the number of possible journeys (between any two stops) per day advances from 2 to 6, and the ledger entries for the 8-day advance booking become $6 \times 8 \times 30$, or 1440 seats. Similarly, if the number of stops is doubled from 3 to 6, 7200 seats are listed for 8 days. It is, therefore, apparent that the complexity of the ledger entries increases tremendously with the number of stops on a particular route; the number of journeys possible in both directions on a route having n stops is $n(n-1)$, indicating that the journeys increase almost as the square of the number of stops.

It will also be apparent that the entries increase directly with the number of flights made each day over the same route, with the number of different routes, with the number of seats on each airplane, and with the number of days of advance booking allowed.

Several domestic airlines of the U.S.A. are each carrying over 1,000,000 passengers a year, and some considerably more. A total of 15,000,000 passengers are carried yearly.

Each of these sales must be recorded, and the number of such entries is complicated by the fact that many reservations are cancelled and the space resold before flight time. Rough estimates, allowing for the fact that during certain days and certain hours the number of transactions are at a peak, show that the average for each 100 scheduled flights with approximately 100,000 passengers per month, involve 1000 messages in the busiest hour. This means that receiving and distributing the messages in a manual centralized office, finding the correct ledgers, and making the notations must be carried out at a speed of one message in every 4 seconds.

Furthermore, the many transactions described must be made from a large number of places. A typical large airline may have a hundred or more district or local reservation bureaus, airport offices, and ticket offices from which reservations are made.

Intelex equipment racks in typical arrangement for a small airline.

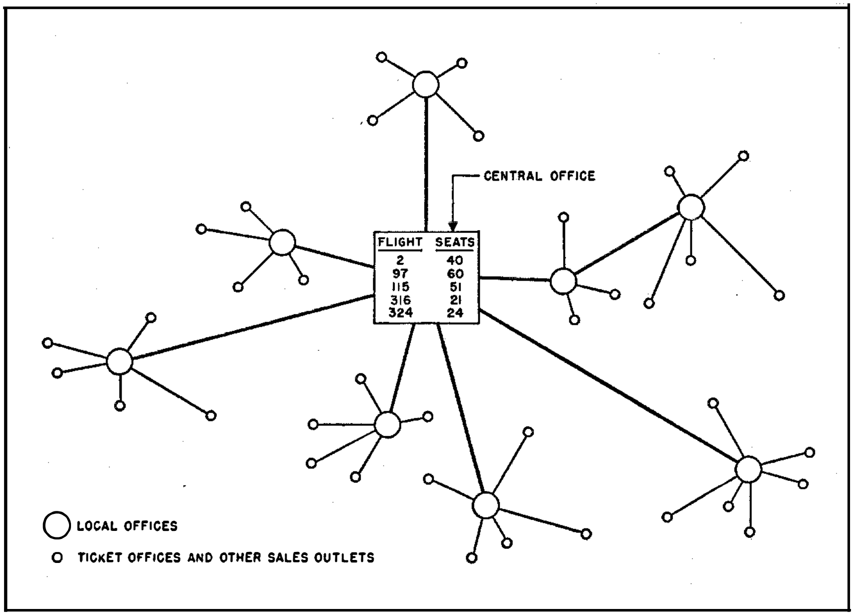


Fig. 2—Typical centralized reservation system. Each local office requests seats from the central office, where the records are kept.

Even with 700 persons handling reservations, it has been found that as long as two hours are often required between the request for a reservation and the confirmation that space is available.

1.2 Request-and-Confirm System

Reservation systems may be classified by the method of handling requests, such as "request and confirm" or "sell and record." Under the first system, the request of the customer is relayed to the headquarters where the ledgers are kept, a search of the ledgers is made, and a message is sent back to the ticket office stating either that the reservation has been made, or that the space is not available. This method, were it not for the time factor and the possibility of errors through the human element, is the most accurate; no space is sold until its availability has been verified. When the traffic becomes heavy, as it is today with nearly 15,000,000 air passengers per year, there is simply not enough time to search the ledgers for each reservation, enter the item, and return a confirmation or denial message. The problem of time is not serious when reservations are requested a week or so in advance, but it becomes more and more acute as flight-time is approached; while this last is to some extent true of any method, it is particularly true here.

Thus, although the request-and-confirm system was the first to be used, and is the most accurate, it has generally been replaced by the sell-and-record method.

1.3 Sell-and-Record Method

Developed primarily to speed up the service to customers, sell-and-record is based on the use of a space-availability board, or chart, in each local reservation office. By reference to this board, clerks can give immediate answers to most of their customers' requests.

Under this system, now in use by most major airlines, local offices inform headquarters each time a reservation is made. Entries are made in ledgers at the headquarters, and the local offices are informed when the flights are almost filled up in order to keep the availability boards up to date. Time is saved since no return confirmation or denial message is used. As flights approach capacity, the facilities again become jammed, since the local office must then, because of possible delay in posting the availability board, call headquarters to see if sufficient space is left, and an answering message is returned. Although a great deal of work has been saved in the long run, mistakes are more likely to occur than with the request-and-confirm method. Selling of the same space twice may occur, or unsold space may be left. Failure to receive a "sold" message in the central office may go unnoticed until it causes oversale. All these difficulties are particularly likely to happen during the last few hours before flight time.

1.4 Centralized Versus Decentralized Systems

Practical reservation systems may be classified as above into sell-and-record, request-and-confirm, or any combination of those two methods, but another useful classification depends on the location of space-control activities. Systems are either "centralized" or "decentralized" under this classification, depending on whether all of the space on a single flight is tabulated and controlled at a single point or is distributed among several points.

1.4.1 Centralized

A diagram of a typical centralized system is given in Fig. 2. A central reservation office, probably near the traffic center of the network, contains the ledgers in which the reservation entries are made for the entire system. This office is connected by teleprinter or telephone lines to each local office in the system. In areas where traffic is relatively light, several local offices may be connected into a single telegraph circuit. As an indication of the number of personnel and the space required, a major airline may use about 200 persons in the central office, and about 25 in each of 20 local offices.

Fig. 3 shows the flow of information in a typical centralized system. In each local reservation office are teleprinter machines connecting to the central office, a large space-availability board, and a number of incoming local telephone lines, some connected to various ticket offices, and some with numbers listed in the local telephone directory for direct calls from customers.

Reservations made by the local offices are sent into the central office until the flights are almost full, perhaps 3 or 5 seats below capacity. The central office then "broadcasts" this fact over a second teleprinter line to each local office. When the flight is actually full, this is also broadcast. On the flight-availability board mentioned above, colored tags are systematically arranged on hooks to indicate the "condition" of the flight, i.e., whether reservations can be confirmed immediately, space has to be requested from the central office, or whether no space can be sold.

To trace the path of a reservation, let us assume that a customer telephones the local office requesting a seat on an airplane traveling between stops *A* and *B* three days hence, leaving at 3:00 P.M.

The clerk who receives this call in the local office will look at the tag that corresponds to this particular date and flight on the availability board (Fig. 3). If the tag indicates that space is available, he will inform the customer that he may have the seat, and asks him when he wishes to pick up the ticket. The information relative to his reservation is noted and placed on file. By means of the teleprinter, the central office is notified of the sale of this seat. In the central office, clerks enter the information in the particular ledger corresponding to the flight and date.

When the customer arrives at a ticket office to pick up his reservation, the ticket clerk telephones to the local reservation office and gives the flight, date, name, and terminals (*A* and *B*). When the proper record is found, i.e., the card that was filed above, the information is checked, the card is marked "Ticketed" and placed on file, and the ticket clerk sells the ticket.

When the customer phones in for a reservation, if the clerk in the local office should find from the

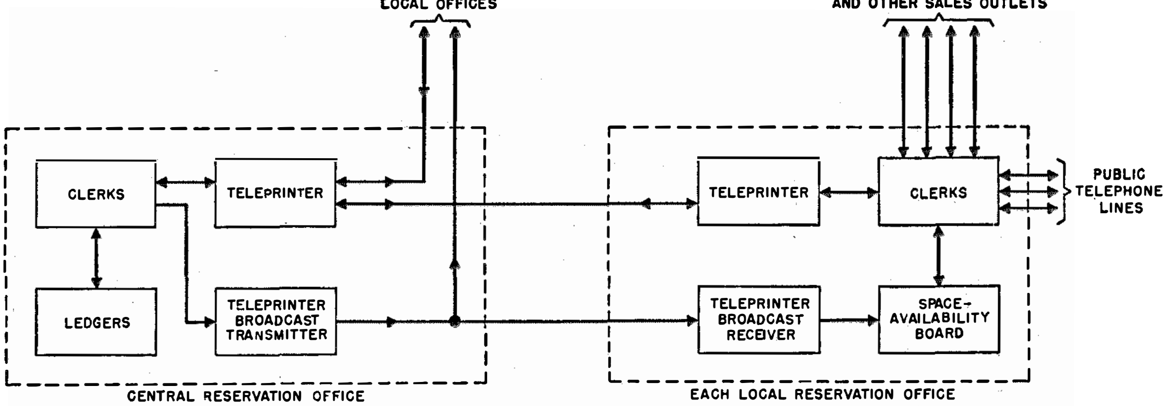


Fig. 3—Reservation network using centralized sell-and-record method, showing flow of information.

availability board that space is not immediately available, he will know that he must check with the central office whether there are any seats left on that flight. The clerk will therefore tell the customer that he will have to confirm the reservation and will call back. After checking by teleprinter with the central office, if the answer states that there is a seat available, the clerk gets in touch with the customer and the procedure is as above. It may be noted here that this follows the request-and-confirm procedure mentioned above.

Should the local-office clerk find a "stop-sale" indication on the availability board, or should the above inquiry to the central office show that there are no seats available for the requested flight-time and date, the clerk will offer the customer alternative flights. That is to say, if there are no seats left on the 3:00 P.M. plane, he will offer seats on the next suitable flight showing on the availability board as "available" or "on request."

All of this checking takes considerable time, and it often occurs that cancellations are not sent into the local office in time for resale of the seats. Such time lags immediately preceding flight departure prevent agents from positive selling, and result in space being available which cannot be sold. Therefore, one may often get a seat by waiting at the airport until departure time. This is a common practice, but is unfortunate from every point of view, since the would-be passenger may be disappointed or, if he does not come to the airport, the unsold space reduces flight revenue.

Again, since a customer's reservation may not

Engineer checking Intelex operation by means of equipment on test-set console. The racks in back of the console include switches, called the ledgers, for the storage of reservation information.

be noted in the ledgers for two hours or so after being approved by a local-office clerk, it is apparent that duplicate sales may occur before the availability board can be brought up to date. This is due to the time-lag occuring before the central-office clerk receives that particular notification (he may have many others to take care of first), finds the ledger, makes the notation, and gives instructions for the flight-condition change to be broadcast.

It must also be remembered that different offices in any other locality may be giving reservations on the same flight between any of the later stops. Thus it is possible that a passenger wishing to fly from New York to San Francisco may be prevented from doing so by previous sale of all space on any one of the intermediate legs of the flight; such as on the Cleveland–Chicago leg of a New York–San Francisco flight. If the fact of such sale is not known in the New York office, it makes possible, again, a duplicate sale.

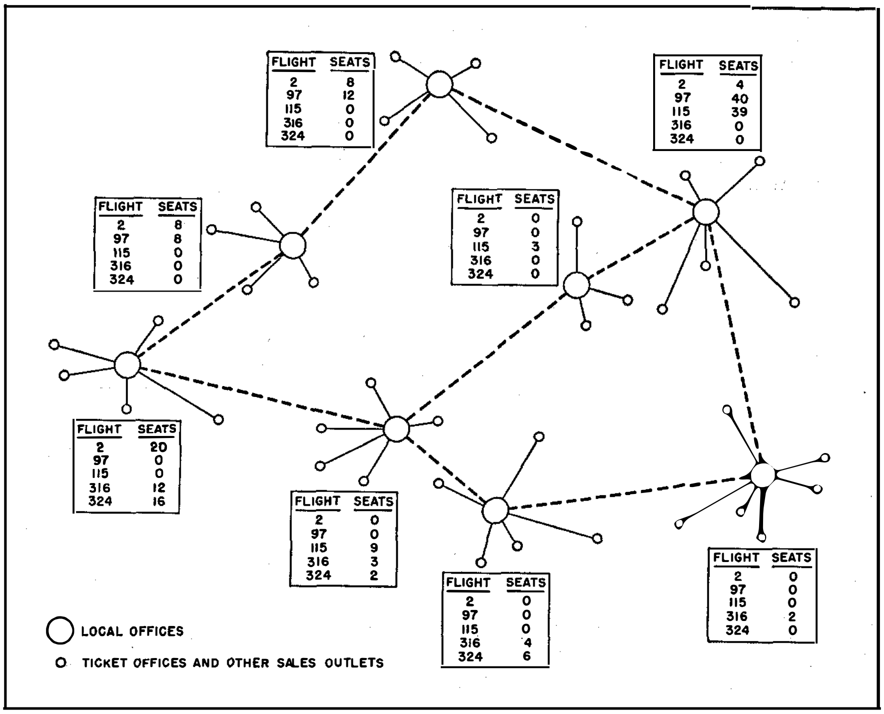


Fig. 4—System having same geographical layout as Fig. 2, but arranged as a decentralized system. Typical allocations of seats among the various offices are shown. Odd-numbered digits travel east to west, and even-numbered go west to east. The dashed lines indicate a communication network necessary for the exchange of reservations among offices having unsold seats and those requiring an excess over their allocation.

1.4.2 Decentralized

Some airlines and nearly all railroads use a method, somewhat similar to the above, that might be called a decentralized, or an allocation system (Fig. 4). Here, the facilities of the central reservation office are divided among the various local offices, the ledgers of the reservations pertinent to the adjacent area being kept in each local office.

Each local office would be authorized to sell a certain number of seats on each trip, based on the average needs of that particular area. The ledgers accounting for the sale of this number of allocated seats are then kept by the local office. The selling procedure is the same as above, except that it is not necessary to send messages to a central office.

However should a local office sell all of the allocated seats, it becomes necessary to get in touch with other local offices to see if they have any to spare. This "shopping" entails considerable long-distance communication between local offices, whereas, with the centralized system, all local offices communicate only with the central office.

If a local office has unsold reservations just before flight time, they are given to a particular office, generally the one at the starting terminal of the flight, for sale there.

Among the basic faults of this system are the duplication of the ledgers in the local offices, since several offices will be handling different numbers of tickets on the same flight (Fig. 4). This may lead either to duplicate sales or to unsold seats. Another fault, mentioned previously, is the great amount of communication between offices in searching for the last few unsold reservations.

2. *Intelex*

The use of Intelex provides a reservation system in which the human element has been reduced to a minimum. A typical system using Intelex is outlined in Fig. 5. This is a *centralized* reservation network that can be operated by the most efficient combinations of request-and-confirm and sell-and-record methods. Adequate protection is designed into this system to prevent most of the difficulties inherent in the manual methods described above. It will be noted, by comparison of Figs. 3 and 5, that the Intelex equipment serves to replace the clerks and ledgers of the central office and most of the teleprinter operators in the central office. In a typical manual centralized system, as many as 30 teleprinters may be required in the central office. From Fig. 5, it will be noted that the operation of the Intelex equipment is performed directly from the teleprinter in the local reservation office. Any printers in the central office are used for monitoring Intelex reservations and for handling "in-the-clear" (uncoded) messages pertaining to reservations or passenger service.

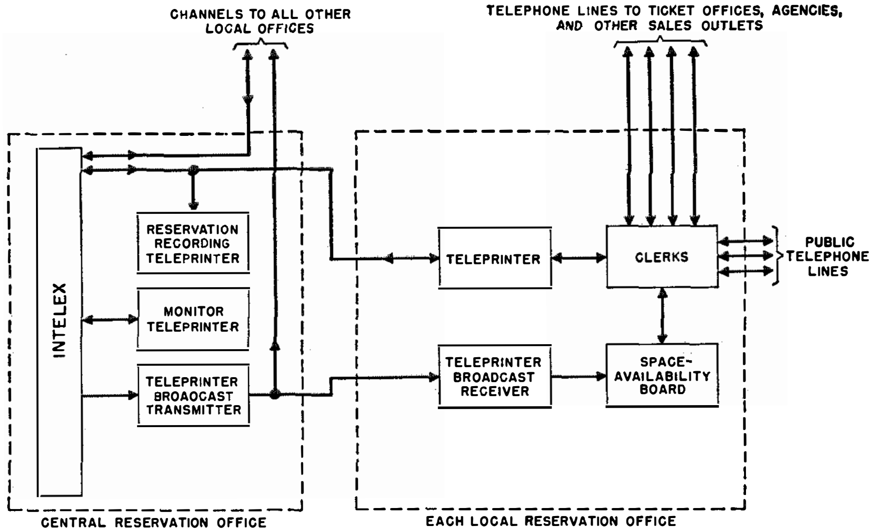


Fig. 5—System of Fig. 3, showing replacement of clerks and ledgers in the central office by Intelex.

The replacement of personnel by automatic equipment (of the type found in automatic telephone exchanges) provides an ultimate in speed and accuracy. It is especially to be noted that when the Intelex system operates on the request-and-confirm basis that was mentioned earlier, it provides the additional advantage that, if no seats are available on the requested flight, the equipment will search other trips to find the best substitute for what was requested and will "offer" this to the requesting office.

The Intelex requires but 10 seconds or less between the start of the requesting message and the end of the answer from the equipment; no human relaying or translation is required between the time when the order message is typed on the keyboard of the local-office teleprinter and when the answer is received on the same machine. A confirmation can be given to a customer within a minute or two from the time that he makes his request.

To handle messages at a speed of one every 4 seconds, or faster as required in the central office of a very large airline, the Intelex equipment is multiplied to provide for the simultaneous handling of a sufficient number of messages to meet the demands of the peak message traffic with a maximum delay of only a few seconds.

2.1 Intelex Central Office

In an Intelex central office, Fig. 5, all of the tabulations of reservations are kept by ledger switches in the equipment (see accompanying illustrations). The additional apparatus in Intelex comprises that used for the choice of the proper ledger switch, and for advancing the switches as each reservation is recorded.

The query from the local-office teleprinter is automatically fed directly into the equipment, and the Intelex answer is automatically sent back to the same teleprinter. Every message to and answer from the Intelex is also printed on a monitor teleprinter that is located in the central office. This teleprinter has two functions: When a query from one of the local offices is unanswerable, being either incorrectly coded or referring to nonexistent flights or impossible dates, the Intelex answer is an *M*, and a signal calls the attention of the monitoring clerk. Also, should an uncoded message be sent, this will not be accepted by the Intelex, but will appear on the teleprinter for the attention of the clerk, who will either give an answer or route the message to the proper office.

In the central office, there is a reservation-recording teleprinter that prints only the Intelex answers in which a reservation was granted or cancelled.

Also in the central office is the teleprinter broadcast transmitter, which automatically originates and transmits the Intelex information necessary to bring the local-office availability board for any flight into the on-request or stop-sale condition; that is, within, say, 3 seats of capacity, or where no sets are left, respectively. This information, when received in the local office, is manually applied to the space-availability board.

2.2 Intelex Local Office

In the reservation offices of an Intelex network, the arrangements are substantially the same as those for the centralized manual system described previously. Only a small change in the type of code used is necessary. Because of the speed with which Intelex will answer any request, the reservation will be confirmed practically at once and while the customer is still on the telephone.

The availability board, which was a prime requisite in the case of the pure sell-and-record system, loses some of its importance here, since Intelex can operate on the request-and-confirm basis. However, in some cases it will be advantageous to retain the board as a means of finding the number of an appropriate flight

Intelex central office. The operator in the foreground is using the monitor teleprinter. The logging teleprinter and the teleprinter broadcast transmitter appear in the left foreground. At the back are the meters and jack panels for monitoring and adjusting the operation of the Intelex equipment.

Typical Intelex local reservation office. The clerks seated around the desk have access to the incoming telephone lines. In the center of the desk is an operator at the teleprinter connecting to the Intelex equipment in the central office. The availability board is in the background, with the teleprinter broadcast receiver (not visible) at its right.

with all possible speed. That is, the availability board here replaces a time table or schedule. By retaining the colored tags on the board, a certain percentage of needless messages will not be sent to the machine, and some time will be saved. The information posted on the board, if it is used, is obtained from the teleprinter broadcast circuit.

2.3 An Intelex Reservation

For the purpose of illustrating the operation of an Intelex reservation system, let us again assume that a customer telephones a local office and requests a seat on a 3:00 P.M. plane traveling three days hence between stops *A* and *B*.

On receipt of the message in the local office, the clerk takes the above information and the customer's name and telephone number. The clerk then looks at the board, and if there is an indication of space available corresponding to the requested flight, he confirms the space to the customer, and obtains such other information as where and when he wishes to pick up the ticket, whether he will take the airline limousine to the airport, etc.

While this is being done, the clerk at the telephone gives a teleprinter operator the following information on a small card:

Clerk's identification number.
Flight number.
Day of the trip.
Journey (start and finish airports).
Number of seats.

The teleprinter operator then punches a tape and sends a message, which may be of the following form, to the Intelex central:

C101 F059 D0518 J12 S01 A3 Z

The first group (*C101*) is the clerk's identification number; the second is the flight number; the third is the date (5th month, 18th day); the fourth is the journey designation (corresponding to airports *A* and *B*); the fifth indicates the one seat requested; the sixth, *A3*, informs the machine that the action to be taken is that of a reservation (as against inquiry, cancellation, or other actions); and the *Z* at the last is the termination signal. The starting signal does not appear as a printed symbol. The above message may be prefaced by the customer's name, which the Intelex will ignore, but which will appear on central-office printers as a record for future reference. Also, the exact form of the message may be modified to meet the requirements of a particular airline.

In about 10 seconds, the Intelex equipment will return an answer as follows:

N1328

The letter and four digits comprise a serial number for the transaction, as assigned automatically by Intelex.

In most cases, even though the clerk has already informed the passenger that his request has been confirmed (on evidence of the availability board), the confirming serial number will be received before the customer hangs up. In case the board had shown the flight to be "on request," the clerk would not inform the customer of confirmation until the serial number was received. This serial number is entered on the reservation card where it becomes proof of a valid, recorded reservation. The card bearing all the information relative to the reservation is then placed on file in the local office until a clerk in one of the ticket offices telephones that the customer has arrived to pick up his ticket. After checking the customer's information against that on the card, the customer will be sold his ticket and the card will be marked "Ticketed" and placed on file.

If no space is available to fill a request on a particular flight, Intelex will search for another suitable flight having a sufficient number of seats available, and will *not* make a reservation, but will return an answer of the following type:

F063 D0518 L16/13/15

Note that the Intelex has not assigned a serial number to this transaction, serial numbers being given only when a reservation or cancellation is recorded. By the above answer, the equipment informs the local-office clerk that there are 16, 13, and 15 seats left on the various legs of flight 063 leaving on May 18. If the alternative appears satisfactory to the customer, another message will be sent requesting a seat.

Should the board indicate that space is unavailable on the requested flight, the clerk will suggest to the customer such other flights as may be suitable before interrogating Intelex.

2.4 Cancellation

One of the great advantages of this automatic equipment is that the ledgers are always up to date. Both reservations and cancellations are immediately reflected in the ledger settings. If a customer cancels his trip through a local office, the clerk there will send a message to the central office, as follows:

C107 F153 D0518 J13 S02 A2 Z

This message has the same significance as a reservation message, except for the *A2*, which indicates Action 2, or cancel. When the cancellation is recorded in the ledgers, the machine will return an answer as follows:

N8678

As in the case of a reservation, a serial number has been assigned. Although the above flight has several sectors, the cancellation referred to only the flight sectors between airports 1 and 3. The machine enters this information and changes the availability only on the legs concerned.

2.5 Inquiry or "Have-a-Look" Feature

It is also possible to send a message to the Intelex for the purpose of determining the number of seats left on any particular flight. This message would be as follows:

F153 D0516 A1 Z

No clerk's number is necessary, since there is to be no reservation or cancellation action by the machine, and hence no office record is required. The *A1* indicates that the message is an inquiry.

The Intelex answer might be

F153 D0516 L07/06/03

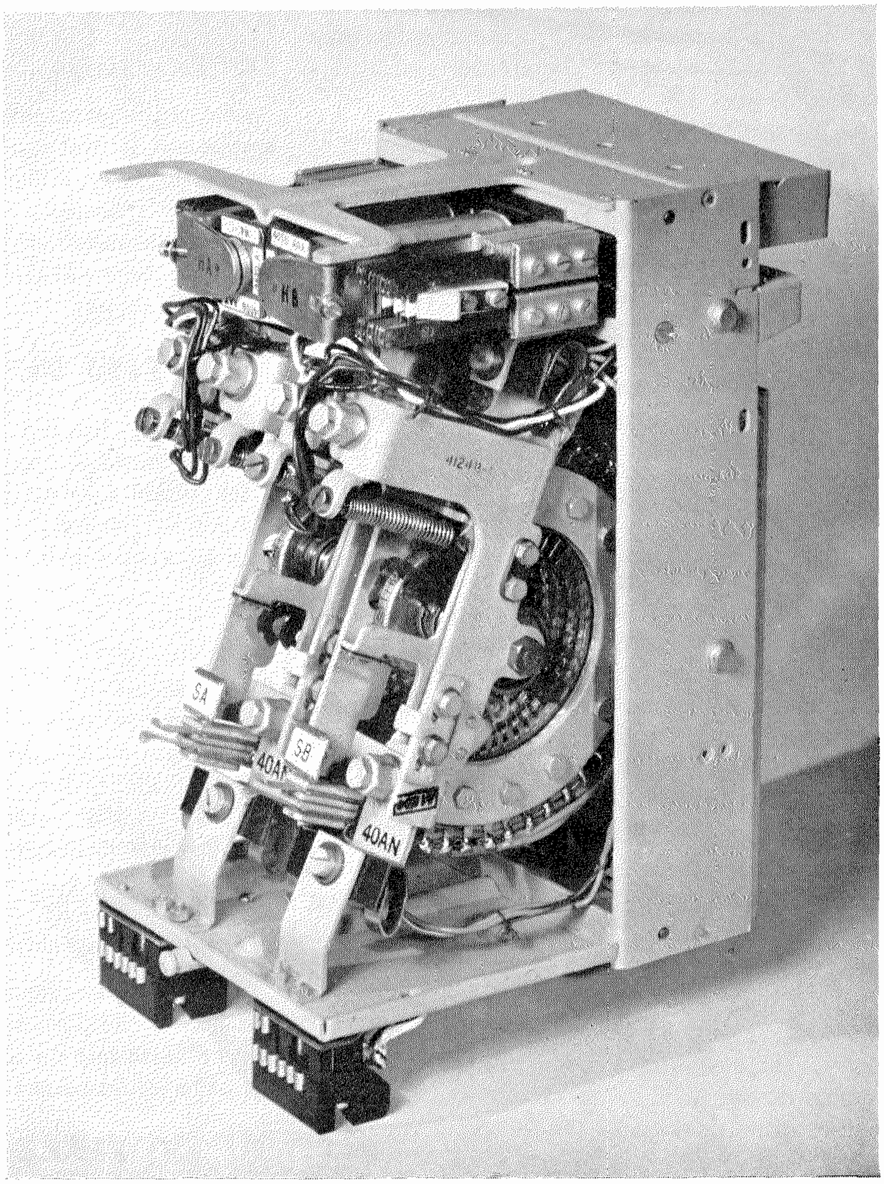
Again no serial number has been assigned. The answer indicates that there are 7, 6, and 3 seats left on the various legs of the flight.

Inquiry messages may be addressed to the machine from any of the offices, local or central. This function is of use for determining the number of passengers on a flight for the purposes of arranging transportation to the terminals, serving meals enroute, determining the weight load, and also where it is desired to see if there is room on a flight for a large party traveling to a single destination. In the last case, it is desirable to determine the seats available on each of several consecutive flights to see if the availability fits the requirements of the party before making the reservations.

2.6 Future Reservations

Intelex, when arranged to handle space reserved up to 8 days in advance, provides storage for 90 percent of all reservations, since only about 10 percent are requested more than 8 days in advance.

When space is requested on flights in advance of this 8 days, the clerk will immediately accept the reservation, since seats are certain to be available on days beyond the storage date. Such reservations can either be held in the local offices until the date of flight falls within the storage time and then passed to the ledgers by normal Intelex methods, or they can be transmitted to the central office at the time of reservation. In the



Ledger switch as used in Intelex. Two switches are mounted on a single jack-in chassis. An advantage of Intelex is that the reservation information may be stored on the contacts of such switches as this. Each switch stores the information for one flight on a given day between two airports. All components in Intelex are mounted on removable chassis for ease in maintenance and for rapid replacement with spares.

latter case, the message will be the same as a normal reservation message (Section 2.3 above), except that the action symbol will be *A4* (future). The Intelex equipment will take no direct action on this message, but will answer with *M*, and operate a signal in the central office. This attracts the attention of the monitoring clerk to the message, which appears on a monitor teleprinter.

The clerk will enter the information in a "Futures" book. When the central-office clerk sets up the Intelex to handle reservations having the requested date of this message, the information in the reservation will be recorded in the machine.

2.7 Waiting List

In the same manner as the above, a waiting list may be set up in the central office for customers who wish to be informed if cancellations occur on certain flights. The action symbol used in this case is *A5*. The signal again attracts the attention of the central-office clerk.

When cancellations are made on flights already completely filled, Intelex reports them to the waiting-list agent. By consulting the compiled waiting list for the system, this agent can authorize use of this space in accordance with the policies of the airline.

2.8 Recording Facilities

Attention may be drawn here to the recording facilities available with the Intelex system. The following services are supplied:

A. Printed records in each ticket office of all messages originating in that office and the answers thereto.

B. Printed records in the central office of all messages transmitted to Intelex and the answers thereto.

C. A selective printed record of all reservations and cancellations on a separate logging teleprinter in the central office.

D. When the reservations on a given flight have brought the total to within, say, 3 seats of capacity, this information is transmitted simultaneously to all ticket offices over the broadcast circuit, and a record of this message is also made in the central office.

3. Conclusions

Intelex is an entirely new means of providing reservation facilities. It is applicable to any system where a limited number of seats are available, and which may be requested, cancelled, or inquired about from any number of different places. It approaches the subject from a modern view using electronic and electromechanical devices. These components have been proven as to stability and long life over a substantial period of time.

The Intelex system is especially noteworthy for its speed and accuracy. These advantages particularly stand out when comparison is made with the manual systems now used by airlines and railroads. Intelex, therefore, permits an efficiency hitherto impossible and hence assists toward the economy of operation that is so important in the transportation business.

Although Intelex is new, the component parts have been tested over the years in automatic telephone exchanges located throughout the world. Many of the operating circuits and features have also been taken from that field, which is noted for its reliability. By concentrating all the equipment in one place, an adequate maintenance program can be followed to prevent failures and interruptions in the operation of the system.

The Intelex equipment is extremely adaptable, since the circuits may be connected to handle any number of flights, for any number of days in advance, and for any number of different airports. The number of possible requesting sources, or local offices, is likewise unlimited. Intelex normally operates from the usual 5-unit start-stop printing-telegraph code.

It may be pointed out here, in conclusion, that the Intelex system, besides its application in industries requiring reservation facilities, such as railroads, airlines, hotels, theatres, and others, has additional possibilities: Intelex is basically a bookkeeping system capable of handling an unlimited number of entries into a great number of different ledgers. Possible additional applications are in the fields of inventory control, credit authorization, chain-store bookkeeping, etc. Intelex would be useful in any system requiring remote-control bookkeeping facilities.

International Telecommunication Convention, Atlantic City, 1947

By P. E. ERIKSON

International Standard Electric Corporation, London, England

THE document that has governed international telecommunication during the last 15 years by agreement between the nations of the world is known as the Madrid Convention of 1932. In July, 1947, plenipotentiaries of 78 nations met at Atlantic City (New Jersey, U.S.A.) for the purpose of revising and bringing up to date that Convention. The new (Atlantic City) Convention is in four parts.

A. Convention proper.

B. General regulations, attached to the Convention.

C. Protocols and resolutions.

D. Agreement with the United Nations Organisation.

These notes are not intended to give a detailed account of the new Convention and its associated documents, but rather to point out important changes or additions to the Madrid Convention.

* * *

1. Convention Proper

The International Telecommunication Union, which will be referred to as the Union, has heretofore had its headquarters at Berne, Switzerland. It has been decided that the Union shall in the future have its seat at Geneva, Switzerland, and the move is to take place by the end of 1948. The former name "Bureau of the Union" will be changed to "General Secretariat."

A rather important article, defining the purposes of the Union, has been introduced into the new Convention. These purposes are:

A. To maintain and extend international co-operation for the improvement and rational use of telecommunication of all kinds.

B. To promote the development of technical facilities and their most efficient operation with a view to improving the efficiency of telecommunication services, increasing their usefulness and making them, so far as possible, generally acceptable to the public.

C. To harmonise the actions of the nations in the attainment of these common ends.

In commenting on the more important changes in the Madrid Convention, the serial numbers of the articles dealt with below are those of the Madrid Convention. The numbering of the articles in the Atlantic City Convention does not correspond to that of the old Convention.

The Madrid Convention (in Article 16) provides for the setting up of international consultative committees and the annexed regulations recognise as existing three such committees (Comité Consultatif International Téléphonique, Comité Consultatif International Télégraphique, and Comité Consultatif International Radio) as part of the Union. The new Convention strengthens the two latter (Article 8), and provides for the headquarters of all three to be at Geneva. It also creates two new permanent organs of the Union, namely, an Administrative Council and an International Frequency Registration Board.

The Administrative Council, which will consist of representatives of 18 member countries of the Union, shall normally meet at Geneva once a year and shall act in behalf of the Plenipotentiary Conference in intervals between its meetings, which are normally every five years, always within the limits of the power delegated to it by the latter. An important duty assigned to this Council is that it shall be responsible for taking all steps to facilitate the implementation by the members of the Union of the dispositions of the Convention, of the regulations, and of the decisions of the Plenipotentiary Conference.

As other duties concern the appointment of the Secretary General (and two assistants), supervision of the administrative functions of the Union, approval of its annual budget, audit of accounts, etc., it may be said that the Administrative Council, in fact, constitutes the management of the organisation of the Union.

The essential duties of the International Frequency Registration Board are to effect an orderly recording of frequency assignments made by different countries and to advise them of the maximum practicable number of radio channels that is workable without harmful interference. Members of the Board, who are all nationals of different countries, shall be elected by each ordinary administrative radio conference according to its procedure. They are to be full-time paid officials of the Union. Perhaps, the most important feature is that members of the Board shall serve, not as representatives of their respective countries or a region, but as custodians of an international public trust. Also, no member of the Board shall request or receive instructions relating to the exercise of his duties from any government, public or private organisation, or person.

The general duties of the Bureau of the Union were dealt with in Article 17 of the Madrid Convention. The corresponding provisions in the new convention (Article 9) lay down similar duties for the Secretary General. He is, however, given additional powers, such as the appointment of staff, and the relations between the Secretariat and the Administrative Council are defined.

A separate article has been provided in the Convention on the subject of Administrative Conferences, which are to be held at the same place and at the same time as the Plenipotentiary Conference, in general, every five years. The primary function of the administrative telegraph, telephone, and radio conferences will be to revise the regulations annexed to the Convention and to deal with all other matters deemed necessary within the terms of the Convention and regulations, or in accordance with any directive given by the Plenipotentiary Conference.

Provision is also made for calling extraordinary conferences during the intervals between normal conferences.

The expenses of the Union are divided into (*a*) general or ordinary expenses, which cover the day-to-day activities of the Union (including the new International Frequency Registration Board and the strengthened consultative committees) and are borne by all members and associate members, and (*b*) extraordinary expenses, which cover the costs of the various conferences and meetings of the consultative committees and are borne by the members and associate members participating. Under the old Convention, private operating agencies and international organisations participating in the work of the consultative committees also contributed to the expenses of their meetings. Under the new Convention, this system is extended to cover Administrative Conferences as well; and in addition scientific or manufacturing organisations contribute to the expenses of the meetings of the consultative committees.

In the past, the Swiss government has advanced funds for the operation of the Union and has been reimbursed when the members' contributions (paid in arrears) were received. Under the new Convention, the Union is financially autonomous, and from the start of 1949 members' contributions will be payable in advance.

French was formerly the official language of the Union, but both French and English were admitted at conferences. The new Convention makes provision for five official languages: Chinese, English, French, Russian, and Spanish. In case of dispute, the French text shall be authentic. There are also now three working languages, Spanish having been added at the instigation of the Latin American countries.

The new Convention is specific in stating that members are bound to abide by the provisions of the Convention and all three sets of regulations (i.e., the Atlantic City radio communication regulations and the telephone and telegraph regulations as amended next year at a conference to be held in Paris). Private operating agencies are likewise bound by the same rule, but military services are exempted from this obligation.

The effective date of the new Convention is January 1, 1949.

There are two annexes to this part of the Convention proper. Annex 1 contains a list of all of the countries represented at the Plenipotentiary Conference. Annex 2 presents a list of definitions of terms used in international telecommunication. Most of the definitions which appeared in an annex to the Madrid Convention have been retained and a few new ones added, due to progress made since the old Convention became effective.

1.2 General Regulations

1.2.1 Conferences

In the Madrid Convention, these provisions are to be found in an appendix, where they are grouped under the heading of rules of procedure. This, in fact, is the subject matter of the regulations. In other words, they lay down the rules to be followed in convening the plenipotentiary and administrative conferences, voting, methods of introducing proposals, order of seating, adoption of proposals, minutes and reports, etc. The regulations also include provisions for a corresponding routine, applicable to the conferences of the international consultative committees. A conference, before entering on its deliberations, adopts its own rules of procedure taking as a basis these regulations, but with such modifications as it thinks fit.

Editorially, the old regulations were listed as *Articles*, of which there were 31 in all. In the new Convention, the regulations are presented as *Rules* in chapter form. The numbers of the rules do not coincide with the former articles and, in commenting on changes or additions to the old text, reference is in all cases made to the number of the *Article.*

Generally speaking, much of the old text has been retained, but has been remodelled to include provisions for the functions of the Administrative Council.

Article 2 of the Madrid regulations specifies the method to be followed in sending out invitations to contracting governments to attend plenary sessions of the Union. In the new Convention, this article is contained in Chapter 1 of the regulations and contains two additional clauses. One states that the United Nations Organisation shall be notified of the date and place of the Plenipotentiary Conference in order that the said Organisation may attend the meeting. The second clause states that any permanent organ of the International Telecommunication Union shall be admitted, as of right, to take part in the conference in an advisory capacity.

Similar rules are laid down with respect to invitation and admission to the Administrative Conferences.

Articles 21 and 22 (Madrid) contain the rules on voting as heretofore used. In the new Convention, these articles are merged into one and a new provision introduced to the effect that each delegation shall present credentials which, in the case of plenipotentiary conferences, must be full powers signed by the head of the government or the minister of foreign affairs.

Article 11 (Madrid) states that the choice of chairmen and vice chairmen of each committee shall be ratified by the plenary assembly. The new Convention retains this clause and adds another, which empowers the chairman of each committee to propose to his committee the nomination of rapporteurs, as well as of the chairmen, vice chairmen, and rapporteurs of subcommittees. In this connection, it is to be observed that in the new rule there is no indication, except in the case of plenipotentiary conferences, that any of these officials must be administration (government) men.

2. International Consultative Committees

As already mentioned, the Madrid Convention proper merely states that international consultative committees may be set up. The reader is referred to the individual sets of regulations for further particulars.

The new Convention lays down general rules for participation in such committees. As these new rules are important, they are summarised below. Administrations as members of the Telecommunication Union are admitted as a right. Recognised private operating agencies are admitted at their own request, which must, however, be approved by the administration of the government recognising it. International organisations, which co-ordinate their work with the Union, may be admitted in an advisory capacity. Scientific or manufacturing organisations engaged in telecommunication are admitted in an advisory capacity to committees of the plenary assembly and to study groups, subject to the approval of the administration of the countries concerned.

Heretofore only the Comité Consultatif International Téléphonique has had a permanent secretariat in charge of a General Secretary. According to the new Convention, the telegraph and radio committees also will have permanent secretariats. All three committees will each have a director, who, in effect, will have much the same status as the Secretary-General of the telephone committee had in the past.

The general regulations conclude with a new clause on the financing of the consultative committees. The salaries of the directors of the consultative committees and the ordinary expenses of their secretariats shall be included in the ordinary expenses of the Union. The expenses of the meetings, plenary and committee, including the extraordinary expenses of the directors and those of their secretariats, shall be borne by the administrations, private operating agencies, and scientific or manufacturing organisations participating. These expenses shall be apportioned among these bodies in proportion to the number of units that the respective governments contribute to the ordinary expenses of the Union. These bodies shall also defray their own personal expenses. All documents are to be purchased.

3. *Protocols and Resolutions*

This part chiefly concerns arrangements for the transitional period, i.e., up to January 1, 1949, when the new Convention comes into force. Thus the Administrative Council was to be set up forthwith and function on a provisional basis until January 1, 1949. In fact, it held its first meeting at Atlantic City, elected its chairman and vice chairmen and arranged for its subsequent sessions. The second session was held in Geneva (January to February, 1948) and resulted in many problems in connection with the operation of the new Convention being clarified. Another meeting will be held in September, 1948, to deal with any further questions that arise before the entry into force of the new Convention. The International Frequency Registration Board has likewise been set up. It held its first meeting at Atlantic City, organised its work, and is operating on a temporary basis until January 1, 1949. The general secretariat will use the present personnel of the Berne Bureau, pending the completion of new staff arrangements.

The protocol gives particulars of the ordinary annual expenses of the Union for 1948 and for the period 1949-1952.

For 1948, the secretary general of the Union is authorised, on approval by the administrative council, to incur ordinary expenses not exceeding 1,500,000 Swiss francs. Two-thirds of this amount is to be allocated to the radio division and one-third to the telephone and telegraph divisions. In addition, the expenses of the International Frequency Registration Board and the Provisional Frequency Board during 1948 amounting to 1,832,000 Swiss francs are authorised.

The administrative council may incur ordinary annual expenses not exceeding 4,000,000 Swiss francs for the period 1949-1952. The prior approval of the majority of members and associate members of the Union is required if this sum is to be exceeded.

The resolutions concern grading of the secretarial staff, pension funds, financial, and other matters.

Regarding the payments of annual dues from member administrations and other recognised members, a resolution was passed instructing the secretary general to show in the annual financial report, beginning 1947, a list of the countries in arrears, together with the sums due.

The section containing the resolutions, concludes with an opinion that is worthy of note. It reads: "The International Telecommunication Conference of Atlantic City recognises the necessity of rendering immediate assistance to the countries (Members of the Union) that were devastated by the second world war, in order to rehabilitate their telecommunication systems, and expresses the hope that the United Nations draw attention of its competent organs to the importance and the urgency of this problem, which is part of the general problem of reconstruction."

4. *Agreement with United Nations Organisation*

This is a formal agreement between the United Nations Organisation and the International Telecommunication Union. The most important article in this agreement is the first one which reads: "The United Nations recognises the International Telecommunication Union as the specialised agency, responsible for taking such action as may be appropriate under its basic instrument for the accomplishment of the purposes set forth therein."

The other articles in the agreement cover methods and means of co-operation between the two bodies.

5. *Historical Note*

As a matter of record, it may be mentioned that the International Telecommunication Union was originally known as the International Telegraph Union, created by the International Telegraph Congress in Vienna, 1868, for the purpose of collecting, arranging, and publishing information of every kind concerning international telegraphy. An office was established in Berne, Switzerland to serve as headquarters and was known as the Bureau of the Union, which was financed by contributions from member countries and from the sale of publications. Plenary meetings of the Union were held at regular intervals of 3 to 5 years, and in Paris in 1890 telephony was for the first time brought in as part of the plenary proceedings. In 1906, the Berlin Radio Telegraphic Conference entrusted to the Bureau the same duties in regard to radiotelegraphy as it already discharged in the field of telegraphy. From January 1, 1929, the international radiotelegraph service was governed by the Washington Convention of November, 1927, and the general regulation annexed thereto.

The International Telecommunication Convention Madrid (1932) and its three annexed sets of service regulations (for international telegraphy, telephony, and radiocommunication, respectively) were the result of the fusion of the Telegraph and Radiotelegraph Conventions. The three sets of service regulations were revised at Cairo (1938).

High-Stability Radio Distance-Measuring Equipment for Aerial Navigation

By H. BUSIGNIES

Federal Telecommunication Laboratories, Incorporated, Nutley, New Jersey

DISTANCE–MEASURING equipment constitutes an important radio aid to aerial navigation. It provides an equipped aircraft with a simple meter indication of its distance from a selected ground beacon. Nonrotating antennas having omnidirectional radiation patterns in the horizontal plane are employed in the aircraft and on the ground. Line-of-sight distances up to 100 nautical miles (185 kilometers) are measured with an accuracy at slant range of ±0.2 mile or 1 percent, whichever is greater.

The crystal-controlled equipment to be described provides 51 clear two-way narrow-band channels in the 960–1215-megacycle-per-second aerial-navigation band. A special detector permits adjacent-channel rejection to exceed 70 decibels with a channel separation of only 2.375 megacycles.

A conservatively rated beacon services 50 aircraft, and several times this number may be accommodated by two or more beacons operating in parallel.

The airborne equipment, exclusive of meter, antenna, and remote control box, is housed in a standard aircraft radio case $15\frac{9}{16}$ by $10\frac{1}{8}$ by $7\frac{5}{8}$ inches (40 by 26 by 19 centimeters) and weighs less than 35 pounds (16 kilograms). The antenna is a simple half-wave element. The standard ground beacon is housed in a cabinet with a maximum height of 76 inches and will deliver 5 kilowatts of peak power. The beacon antenna is a vertical array of nine discone elements.

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The indication in an aircraft of its distance relative to a fixed ground beacon has been stated by various policy-making organizations to be the most urgently needed radio aid to aerial navigation. The combined use of omnirange beacons and distance-measuring equipments allows navigation by the distance-bearing (R-θ) system[1] recommended by the International Civil Aviation Organization. Also, it is contemplated that distance indicators may supplement or replace the marker beacons used with the instrument landing system.[2] As a result of the concentrated effort that has been applied to developing a practical distance-measuring equipment,[3] the major problems have now been solved and several equipments have been put in experimental operation.[4]

1. *Principles of Operation*

In the distance-measuring system to be described, distance is measured by an airborne challenger working in conjunction with a ground beacon. The challenger-responder principle is utilized. Both the airborne challenger and the ground beacon have a pulsed transmitter and a receiver. The transmitter in the aircraft starts the measuring process when it sends out a challenging pulse. This is received at the ground beacon and causes its transmitter to respond with a similar pulse. When the response pulse is received in the aircraft, special circuits measure the time elapsed between the transmission of the challenging pulse and the reception of the response pulse. Other circuits then convert the time difference into a mechanical indication of the distance from the aircraft to the beacon. This sequence of operations is repeated frequently enough to give a smooth and continuous indication.

A beacon does not transmit a response instantaneously when challenged; a standard delay

[1] R. I. Colin, "Survey of Radio Navigational Aids," *Electrical Communication*, v. 24, pp. 219-261; June, 1947.

[2] S. Pickles, "Army Air Forces' Portable Instrument Landing System," *Electrical Communication*, v. 22, n. 3, pp. 262-294; 1945.

[3] H. Busignies, P. R. Adams, and R. I. Colin, "Aerial Navigation and Traffic Control with Navaglobe, Navar, Navaglide, and Navascreen," *Electrical Communication*, v. 23, pp. 113-143; June, 1946.

[4] P. R. Adams, S. H. M. Dodington, and J. A. Herbst, "First Tests on Navar System for Aerial Navigation and Air Traffic Control" (Summary), *Electrical Communication*, v. 24, pp. 263-264; June, 1947.

of 75 microseconds has been adopted and all beacons are adjusted to this value. The airborne distance-indication equipment allows for this delay in its computations.

In order that many aircraft may operate in a given area with a single ground beacon, the beacon responds to all challenges in its assigned channel. Each airborne challenger, therefore, receives the responses of the beacon to other challengers. Thus, the airborne equipment must have some means of finding and abstracting the responses to its own pulses. For this purpose, special circuits called the *strobe* examine in a stroboscopic manner all responses received. Only those response pulses that have the same characteristic timing as the challenging pulses emitted from that aircraft affect its distance indicator.

The number of ground beacons to be employed within a given area will depend on the extent of the area, nature of the terrain, number of airports within it, density of traffic, and accepted flight procedures. It is generally agreed that each beacon will be limited to line-of-sight operation corresponding to a maximum range of about 100 nautical miles (185 kilometers) and approximately 40 nautical miles (74 kilometers) for an airplane at a 1000-foot (305-meter) altitude and a beacon-antenna height of 50 feet (15 meters) above mean elevation. There must be complete coverage of the airways.

2. Channeling System

Each beacon must operate on a separate and well-defined two-way channel, and each airborne challenger must provide for simple selection of any one beacon. The method of channeling used in a distance-measuring equipment to provide a distinct two-way channel for each beacon must satisfy the following basic requirements:

A. Economy in utilization of available frequency spectrum. (In the U.S.A., the number of channels was set at 51 in the frequency band from 960-1215 megacycles.)

B. Separation of channels must be sufficient to eliminate adjacent-channel interference.

C. Each beacon channel must accommodate a large number of aircraft without interference among them.

D. Desired distance range must be obtained with minimum transmitted power.

E. Distance-measuring equipment should not interfere with any other function of a complete aerial-navigation system, such as aircraft identification and altitude reporting, that might share the same channels.

These requirements, which affect the development not only of distance-measuring equipment but other future navigational aids in the 1000-megacycle region, have posed major issues in establishing specifications for a distance-measuring system.

The history of radio provides ample evidence of the continuous trend toward crystal control. Whenever a new band of frequencies is opened, there is always such demand that the most readily available circuits are immediately pressed into service without too much thought of frequency stability. Often, highly ingenious and complicated circuits and techniques are evolved to combat the basic limitations in stability. Sooner or later, however, closer frequency tolerance, with resultant better use of the spectrum and better performance of the equipment, becomes so imperative that the best methods must be adopted, regardless of practical difficulties.

It was felt, therefore, that the future of the proposed aids in the 1000-megacycle region could best be served by a direct attack aimed at the requisite number of crystal-controlled narrow-band channels. Development of such a system presented a distinct technical challenge, but one that would result in a standard type of equipment that could be built by different groups in various countries according to more or less standard production routines.

Some of the specific characteristics of a high-stability, crystal-controlled system may be seen from the following list of characteristics of equipments already constructed.

A. Channel separation of 2.375 megacycles allows 51 two-way clear channels within the allocated band of 960 to 1215 megacycles. The challenging channels cover from 965.375 to 1084.125 megacycles in 2.375-megacycle intervals. The reply channels are always 125.5 megacycles above the challenging channel and extend from 1090.875 megacycles to 1209.625 megacycles.

B. Adjacent-channel rejection is so complete (obtained through the use of a special detector) that in the geographic distribution of beacons, those that are physically adjacent may operate on adjacent channels. Channel selection is simplified and operation is free of interference. Sharing of channels with other services, such as omnirange and localizer beacons, on a geographic basis becomes a simple matter.

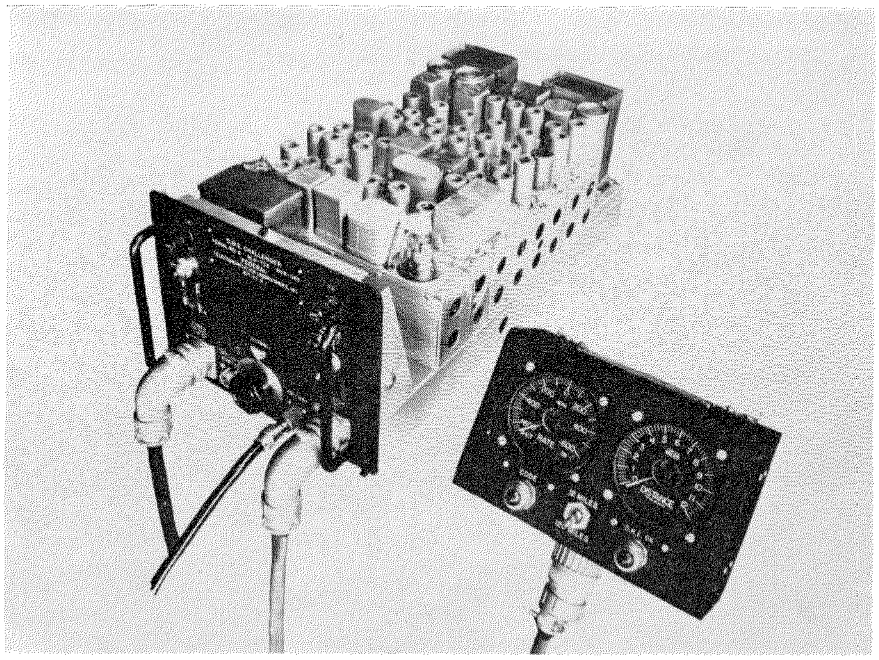

Fig. 1—Airborne distance-measuring equipment flight tested early in 1947. Indicators are provided for distance from the beacon and for the aircraft speed in miles per hour. With the exception of the indicators, all the equipment is mounted on a single chassis.

C. Narrow bandwidth greatly reduces the possibility of interference from harmonics of lower-frequency transmitters.

D. A given ground beacon can service a large number of aircraft, because high stability reduces the total number of pulses required per aircraft.

E. As pulse combinations or codes are not employed for channeling, the use of multiple pulses is reserved for other purposes, including the transmission of additional navigational or traffic-control information over the distance-measuring channels.

3. *High-Stability Distance-Measuring Equipment*

3.1 General

A complete distance-measuring system comprising an airborne challenger and a ground beacon has been developed. In both equipments, the receivers as well as the transmitters are crystal controlled. In each case, the receiver and transmitter, together with the necessary video-frequency, power, and measuring circuits, are housed in a single cabinet. The same antenna is used for both transmission and reception.

3.2 Airborne Challenger

Fig. 1 is a photograph of one of a series of airborne equipments flight tested early in the spring of 1947 to demonstrate system performance. This early series of challengers operates on only the first 6 of the 51 channels and gave distance readings on a 270-degree-scale meter. In this particular instrument, two ranges, 0–12 and 0–120 statute miles (10.4 and 104 nautical miles or 19.3 and 193 kilometers), are provided. Indication of the rate of travel of the aircraft is an optional feature and provision is made for a maximum speed of 600 miles (965 kilometers) per hour inbound and outbound.

A feature of the equipment is the subunit method of construction, with many of the subunits being of the plug-in type.

Fig. 2 is a photograph of a later equipment that operates on 51 channels. In this model, distance information is obtained directly from the rotation of a shaft and can be supplied to the computer of an automatic-flight-control equipment. The distance indicator is a panel-mounting type having a rotating disc and a rotating pointer. The calibration is from 0 to 100 nautical miles (185 kilometers), with the smallest scale division equal to 0.1 mile.

This equipment is mounted in a standard *B1–C1* aircraft radio case measuring $15\frac{9}{16}$ by $10\frac{1}{8}$ by $7\frac{5}{8}$ inches (40 by 26 by 19 centimeters) and weighs less than 35 pounds (16 kilograms). It operates from 115-volt 380–1760-cycle and 28-volt direct-current supplies, requiring 250 watts. It is operable over a range of ambient temperature from -40 to $+60$ degrees centigrade (-40 to $+140$ degrees fahrenheit) at a relative humidity varying between 5 and 95 percent and within the barometric pressure range corresponding to 8.5 and 31 inches of mercury.

A few of the circuit details may be interesting.

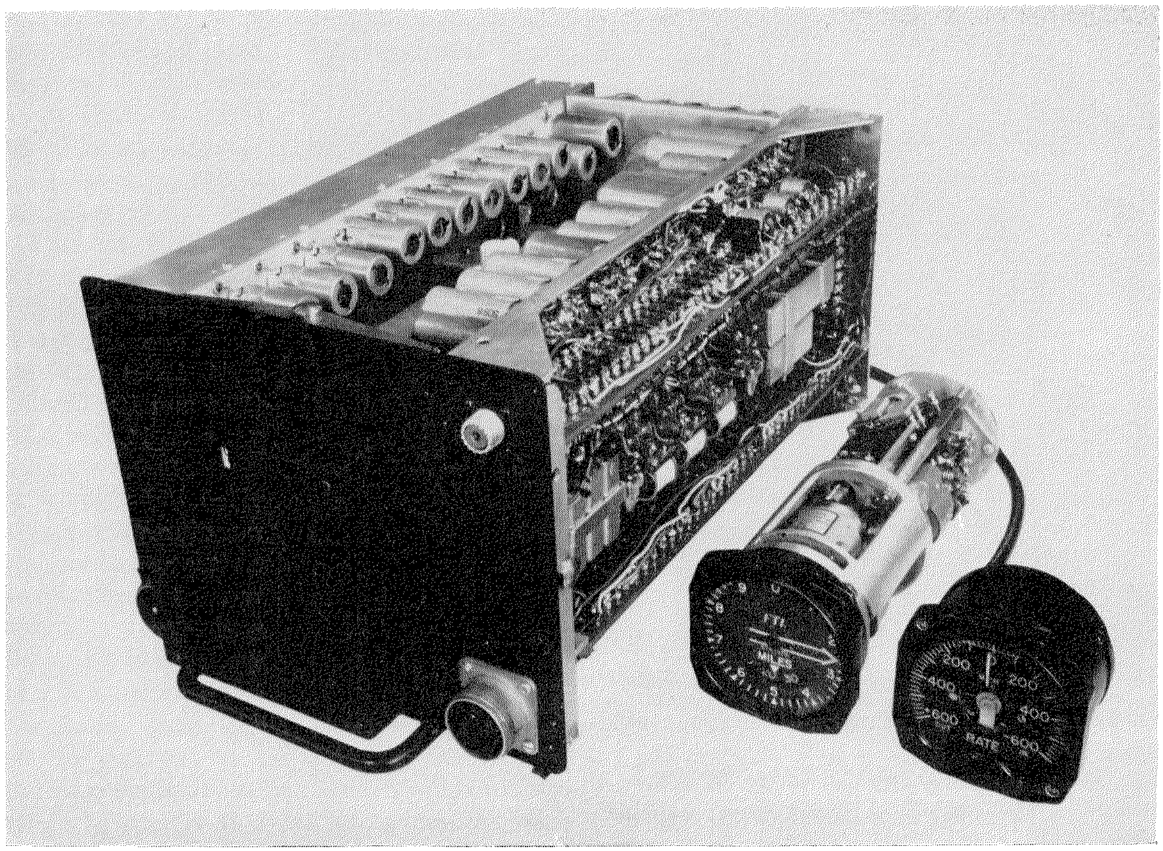

Fig. 2—Latest airborne distance-measuring equipment. Fifty-one crystal-controlled channels are provided. Distance indication is given by the rotation of a shaft. Rate indicator is optional. The remote control box is not shown.

Each of the 51 channels has two clear crystal-controlled frequencies, one for transmission and one for reception, having a constant difference of 125.5 megacycles. The two frequencies of each channel are determined by a single crystal, and 51 crystals in a rotating turret are provided for the 51 channels. The single tuning control of the crystal oscillator, the tuning plunger of the transmitting oscillator, and the tuning plunger of the receiver preselector cavities are linked to the channel-selector mechanism.

The local crystal oscillator and frequency multiplier supply a heterodyning signal to two radio-frequency converters. During transmission, a sample of the transmitting oscillator energy is compared in the automatic-frequency-control converter with the crystal-controlled local-oscillator signal; the difference frequency operates the automatic-frequency-control circuits and the tuning mechanism that brings the transmitter to the correct frequency. It is possible to hold the frequency to within ± 100 kilocycles of the assigned value; but this extreme accuracy does not appear to be necessary and a tolerance of ± 200 kilocycles is satisfactory. During reception, the incoming signal passes through the receiver preselector cavities, receiver radio-frequency converter, intermediate-frequency amplifier, and a special detector that is instrumental in obtaining an adjacent-channel rejection greater than 70 decibels. The video-frequency output of the detector is fed to the distance-measuring circuits and indicators.

For continuous distance indication, the receiver requires an input signal of 15 microvolts across its 50-ohm input terminals. The strobe circuit requires approximately 7 seconds to search through the distance range of zero to 100 nautical miles (185 kilometers) for the response from the beacon. It will continue to search until a response is received and will then lock onto the signal from the beacon and give a steady indication of distance. The accuracy of indication is within ± 0.2 mile or 1 percent, whichever is greater, under normal slant-range conditions.

When a continuous indication of distance is being obtained, the strobe circuits are locked to the responses from the beacon and the airborne challenger emits approximately 30 pulses per second. When no distance indication is being obtained, the strobe circuits search through the distance range for responses from the desired beacon, and the pulse-repetition rate is increased to 150 pulses per second. For a pulse length of 1.5 microseconds, the duty cycles for tracking and searching are $30 \times 1.5 \times 10^{-6}$ and $150 \times 1.5 \times 10^{-6}$, or 0.0045 percent and 0.023 percent, respectively. With a maximum allowable duty cycle of 0.1 percent, the duty cycle during search is only one-fifth of the maximum allowable; and during normal tracking operation there is a much greater reserve of power. In the future, it is planned to utilize this available power to transmit to the ground such information as the identity and altitude of the aircraft.

The antenna serves for both transmission and reception and is mounted on the belly of the airplane. The standard antenna installation employing 35 feet of RG-8/U radio-frequency coaxial cable, has a loss in the cable under matched conditions of 3 decibels in each direction. The peak power of the transmitting oscillator is 2 kilowatts nominal; the peak power actually radiated by the antenna, therefore, is nominally 1 kilowatt.

3.3 Ground Beacon

The function of the ground beacon is to respond to challenges from airborne equipments operating on the frequency assigned to the beacon. However, in a comprehensive system for aerial navigation and traffic control, other functions may be superimposed on the distance-measuring beacon to transmit information to the aircraft.

The ground beacon, shown in Fig. 4, may be tuned to any one of the 51 channels assigned to this service. It has a nominal peak-power output of 5 kilowatts and minimum and maximum outputs of 3.4 and 6 kilowatts, respectively. It requires less than 1000 watts from a 115-volt 50–70-cycle single-phase power source. Using standard 19-inch (48-centimeter) panels, it is 76 inches (193 centimeters) high and weighs less than 500 pounds (227 kilograms). It is designed for operation between −40 and +60 degrees centigrade (−40 and +140 degrees fahrenheit), 5- and 95-percent relative humidity, and atmospheric pressures equivalent to 17 to 31 inches of mercury.

The beacon features simplified construction with subchassis mounted vertically to provide ready access to the wiring and test points from the front of the cabinet and to the tubes and large components from the rear.

Operationally, these beacons may be used for general navigation or for approaching an airport. For navigation, combined use is made of an omnirange beacon and distance-measuring equipment. A maximum range of 100 nautical miles (185 kilometers) has been established as being satisfactory for this purpose. For the next few

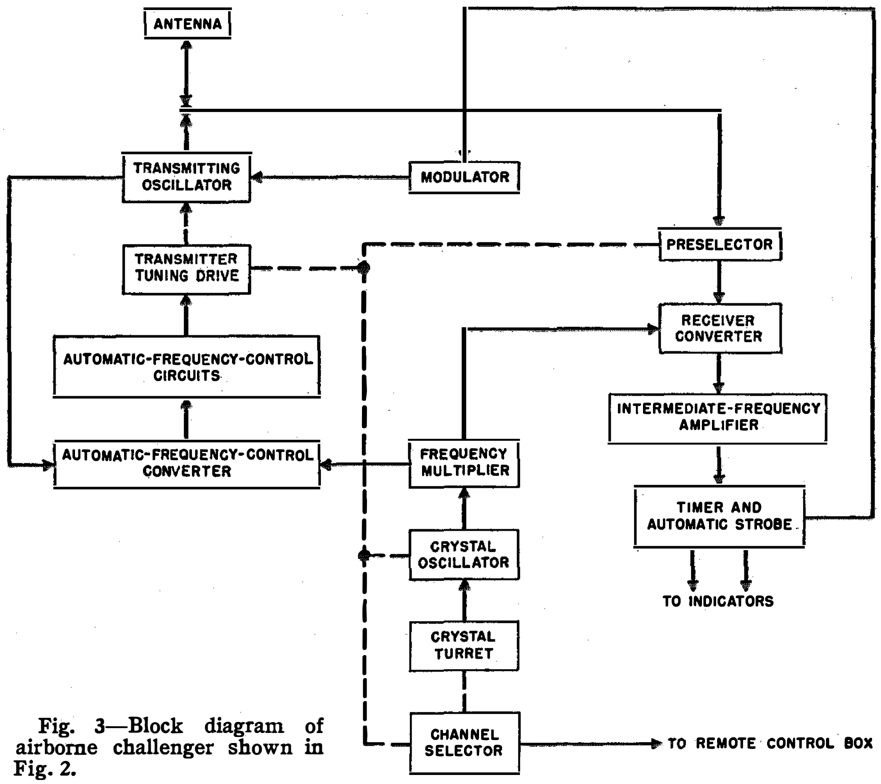

Fig. 3—Block diagram of airborne challenger shown in Fig. 2.

years, the density of air traffic probably will be such that not more than 50 aircraft will be within the service range of a distance-measuring beacon, i.e., within a radius of 100 nautical miles. Accordingly, the present beacon has been designed to handle 50 aircraft with a superior service and up to 80 aircraft with acceptable service.

The traffic-handling capacity of a beacon is determined by the ability of the transmitting tubes to dissipate power appearing in the form of heat. Depending on the tube and circuit employed, the maximum allowable duty cycle may fall somewhere between 0.1 and 1 percent. With a total of 50 aircraft, one of the worst conditions is represented when 5 are searching and 45 are tracking. At this instant, 100-percent replies by the beacon would require a nominal duty cycle of 0.315 percent. However, operation with 80 percent replies by the beacon is considered to be adequate, and the present beacons have a maximum duty cycle rating of 0.25 percent. In the near future, the duty-cycle rating will be increased to 0.4 percent to cover functions other than distance measuring.

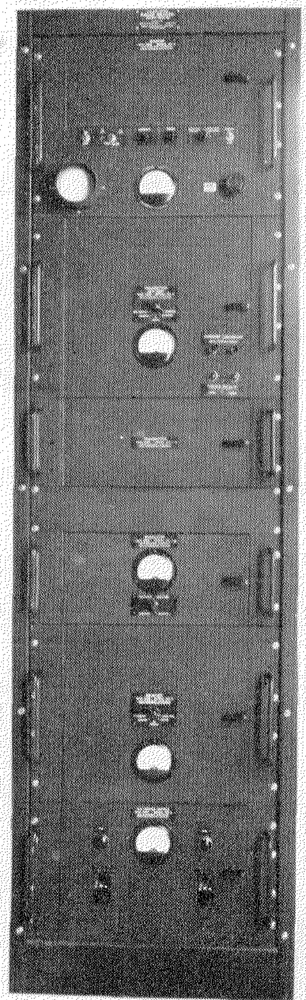

Fig. 4—Ground beacon for distance measuring. The transmitter is rated at 5 kilowatts nominal and 6 kilowatts maximum peak power. It may be adjusted to any of the 51 channels assigned to this service.

The transmitter will be triggered by any input to the 50-ohm receiver terminals exceeding 15 microvolts. The adjacent-channel rejection of the receiver is greater than 75 decibels and the image and intermediate-frequency rejections are greater than 70 and 80 decibels, respectively.

Flight tests have demonstrated that the high-stability distance-measuring equipment performs satisfactorily when less than 2 kilowatts of peak power are radiated from the ground. Therefore, a beacon rated at a peak power of 5 kilowatts is adequate for all practical installations and permits the antenna to be as far as 70 feet from the transmitter-receiver. In this maximum case, slightly more than half the total power is lost in the radio-frequency transmission line.

It should be noted that the beacon requires an antenna having an omnidirectional radiation pattern in the horizontal plane, and a low-angle beam approximately 10 degrees wide in the vertical plane. Thus, aircraft at large angles of elevation receive enough stray radiation for correct operation, but maximum power is radiated near the horizon where it is most needed. The antenna should be at least 50 feet (15 meters) above the mean elevation and should be connected to the equipment by a maximum of 70 feet (21 meters) of RG-14/U cable.

Fig. 5 is a photograph of one of the series of antennas[5] that have been built and operated according to this specification. In this installation, a single 2-kilowatt beacon is housed in a weatherproof case and mounted directly on the mast. This reduces the transmission line to about 15 feet (4.6 meters) and minimizes losses in the cable. The experimental 2-kilowatt beacon has been used for many flight tests and demonstra-

[5] A. G. Kandoian, W. Sichak, and R. A. Felsenheld, "High Gain With Discone Antennas," *Proceedings of the National Electronics Conference, Chicago, Illinois, November 3-5, 1947*, pp. 336-346; 1947: and *Electrical Communication*, v. 25, pp. 139-147; June, 1948.

tions, and the antenna has been used with a remote (60 feet, 18 meters) standard beacon for many other tests.

4. Flight Tests

From June, 1946, to October, 1947, the distance-measuring system was subjected to 130 hours of flight testing and was demonstrated on 94 different flights. The majority of the flights were made in the Laboratories' airplane, a Douglas DC-3, but a few were made in another aircraft of the same type. On many of the flights, azimuth-indicating and distance-measuring equipments were used to illustrate aerial navigation by the R-θ system.

Ground beacon transmitters of three different power output capacities have been used. These transmitters have been rated at peak-power outputs of 8, 5, and 2 kilowatts. The transmission-line losses have reduced the radiated powers to approximately 4, 2.5, and 1.7 kilowatts, respectively. All three transmitters have given equally good service out to maximum range. Therefore, for radiated powers greater than 1.7 kilowatts, the maximum range has been determined by the line-of-sight propagation conditions rather than the power rating of the beacon.

The greater part of the flight time was spent at distances less than 70 nautical miles (130 kilometers), for economy and convenience in operation of the aircraft. However, many flights were made around all beacons to distances between 90 and 120 nautical miles (167 and 223 kilometers), at altitudes near 10,000 feet (3048 meters).

The antenna, the 20-foot (6-meter) mast, and the 2-kilowatt beacon are air transportable and are easily set up for use. The installation shown in Fig. 5 was made at several locations, at distances from 8 to 75 miles (15 to 139 kilometers) from a more powerful beacon operating on the adjacent channel, a separation of 2.375 megacycles. Operation with either beacon was free of interference from the other, even when the aircraft was flying in the immediate vicinity of one of them.

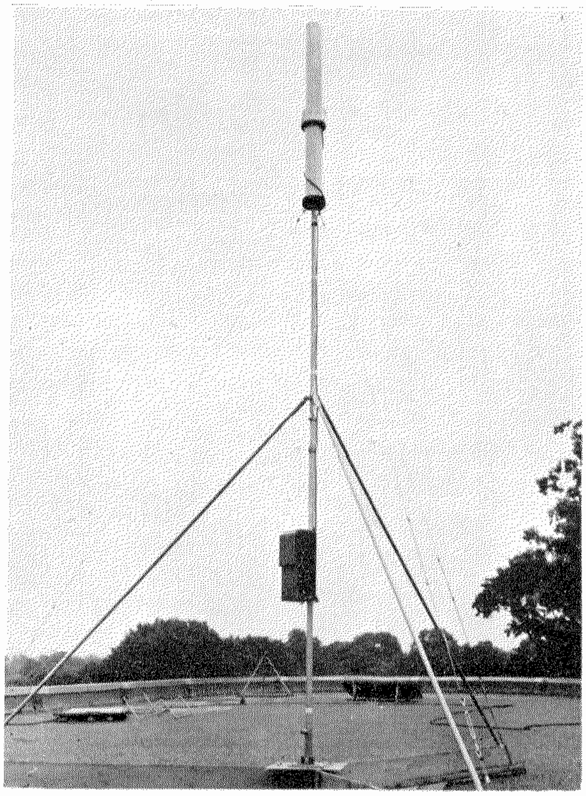

Fig. 5—Omnidirectional horizontal radiation and a narrow vertical pattern about 10 degrees wide are obtained with this stacked discone antenna. Maximum radiation is to the horizon. The air-transportable experimental beacon equipment is mounted on the mast to reduce transmission-line losses.

5. Acknowledgment

This development has occupied a large part of the Laboratories' efforts during the past three years, more than fifty engineers and technicians having at one time or another been involved. The basic system requirements were laid down by Paul R. Adams and the author, and have been modified from time to time by customer requirements. Over-all supervision of equipment design, ground and air, rested with Sven H. Dodington, who also designed the channeling system and the automatic frequency control. The distance-measuring circuits were designed by Gilbert R. Clark and Etienne deFaymoreau, who were greatly assisted by consultations with Norman F. Moody. The beacon antenna was designed by a group headed by A. G. Kandoian. The design of most of the mechanical details was supervised by John A. Herbst. Substantial contributions were made by Edgar W. Blaisdell, mechanical design; Warren A. Anderson, airborne intermediate-frequency amplifier and crystal multiplier; Ben Warriner, transmitters; Alex Hegedus, beacon circuitry; and Sidney Frankel, S- and X-band rejection filters. The manuscript was prepared by Henry D. Scarborough.

Aircraft Radio Communication Set A.R.I. 5272

By E. C. FIELDING

Standard Telephones and Cables, Limited, London, England

VERY-HIGH-FREQUENCY aircraft transmitter-receiver equipment, A.R.I. 5272, was developed during the war for use in naval aircraft, and is noteworthy for the economies effected in weight and dimensions relative to earlier equipments of comparable performance. Information is given regarding the various techniques and special designs used to make these economies possible.

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1. Introduction

The A.R.I. 5272 aircraft radio communication equipment, shown in Fig. 1, was designed primarily for use by naval carrier-based aircraft, and is constructed in accordance with Air Ministry specifications. It is, therefore, also suitable for civil flying under the most severe climatic conditions likely to be encountered, including use at altitudes up to 40,000 feet. The rotary transformer is designed for continuous operation in a horizontal position but may be used in any other attitude for short periods of time. The set is suitable for use under tropical and arctic conditions. A commercial model, designated the S.T.R.-9, has been developed.

The A.R.I. 5272 set comprises a very-high-frequency radio-telephone transmitter-receiver built in the form of a single main unit including power-supply equipment and voltage stabiliser (for valve-heater supplies), and is arranged for rapid selection of any one of four channels by means of a small remote-control unit located at a convenient point in the aircraft. The main unit is 7.9 inches high by 9.0 inches wide by 16.25 inches long (20 by 23 by 41 centimetres); the dimensions of the remote-control unit are 3.5 by 2.2 by 2.6 inches (9 by 6 by 7 centimetres); total weight is 22 pounds (10 kilograms).

Receiver and transmitter operate on the same channel frequencies and use a common aerial. The four crystal-controlled frequencies are in the range of 115 to 145 megacycles per second with frequency stability within ±0.01 per cent. The transmitter power output is 3.5 watts. Total

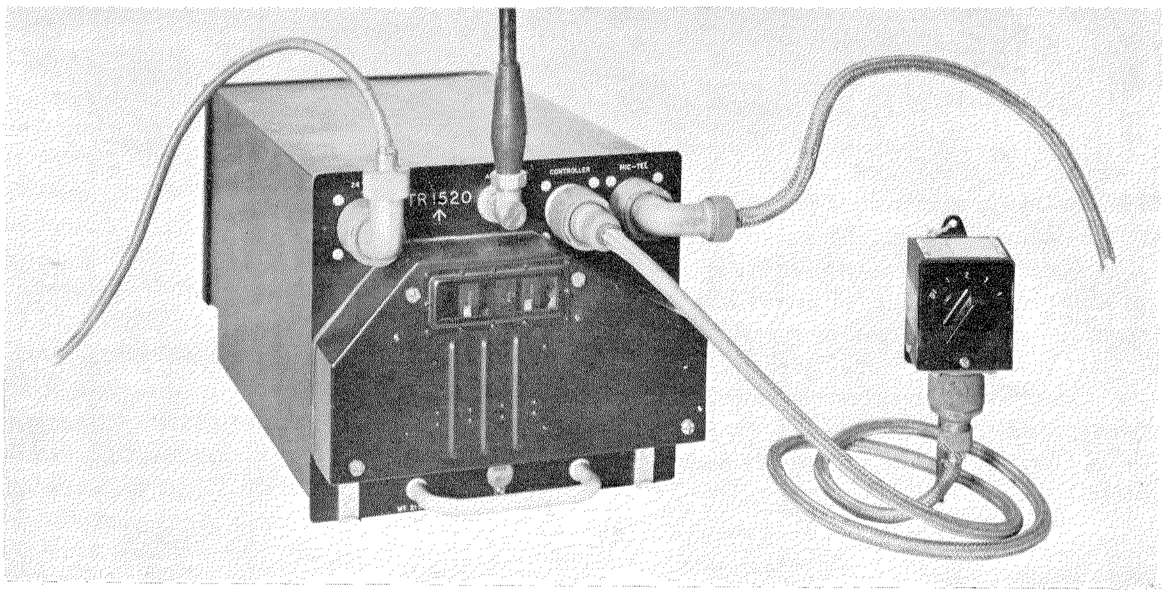

Fig. 1—A.R.I. 5272 aircraft radio communication set. The control unit is at the right. The battery cable is at the left of the main unit, the antenna is central, and the microphone-telephone cable is at the right.

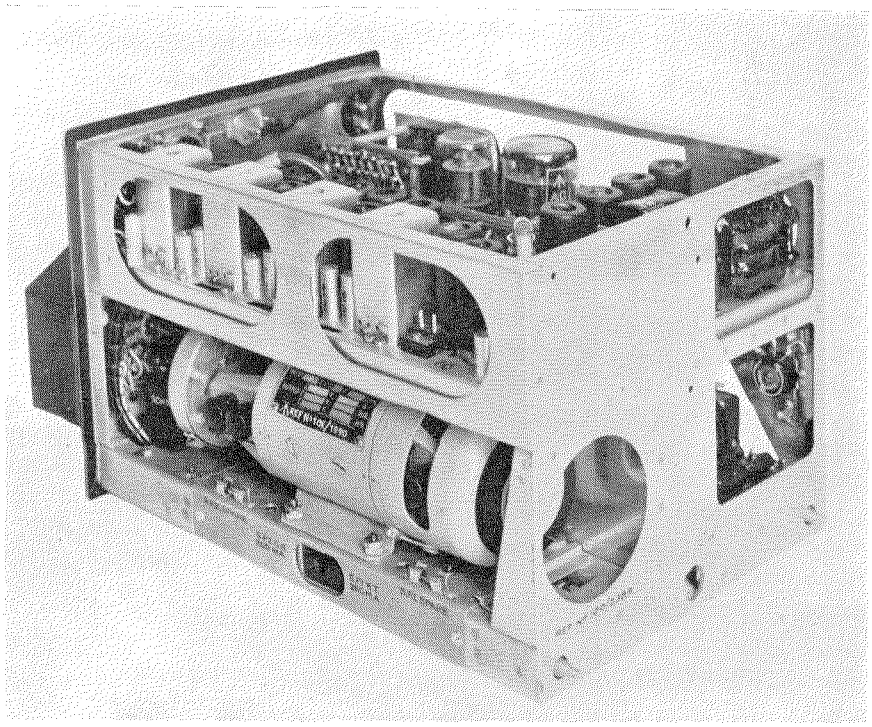

Fig. 2—Main unit showing arrangement of subsidiary assemblies. The transmitter is at the right and the receiver is at the left. The rotary transformer is in the lower left.

power requirements are 150 and 180 watts at 26 volts, the lower value being for receiver operation. The service range of the set for aircraft at a 10,000-foot altitude is approximately 200 miles between aircraft, and 100 miles from aircraft to ground stations.

The entire frequency range is available to each of the four channels, which can be set or reset independently of each other. One crystal per channel is used for both transmitter and receiver, but separate tuning adjustments are provided. During channel-changing operations, the transmitter and receiver tuning circuits are positioned simultaneously, the maximum time for this operation being a little over 3 seconds.

When the receiver is operating, the transmitter is in the standby condition with valve heaters energised; the transmitter is turned on by electrical switching of high-voltage supplies and antenna and other connections, all under control of the remote operator. Aerial switching is internal to the set and is included in the change-over mentioned above.

Gang-tuned circuits are used in the receiver and transmitter for simplicity and speed of operation. This arrangement has the added advantage that there is no risk of valves being damaged during tuning operations as a result of temporary misalignment of the different stages.

The electrical circuits are generally of a straightforward nature except that certain frequency-multiplying stages are common to both receiver and transmitter, as described later.

Valve heaters are wired in a series-parallel network to minimise the effect of the failure of any particular heater on the remainder.

2. *General Description*

The main-unit chassis, which may be seen in Fig. 2, is fitted with a detachable dust cover and is arranged for mounting in a shock-absorbing tray. It is designed fundamentally as a mounting for the subsidiary units comprising transmitter, receiver, intermediate-frequency amplifier, modulator, and power-supply unit, together with such miscellaneous components as relays, carbon-pile voltage regulator, cable form, and channel-selection mechanism. All of these subsidiary units are detachable, and are connected to the main unit by plugs and sockets. The channel-selection mechanism and all external connections are accessible at the front panel, as can be seen from Fig. 3. As might be expected in a naval airborne equipment, the fundamental consideration governing the general design, apart from the electrical requirements, was the necessity of keeping weight and size to an absolute minimum, and it will be of interest to consider in detail some of the means by which the desired results were obtained.

2.1 Unit Construction

One important reduction of size and weight has been obtained by the adoption of unit construction. If this had not been done, it would have been impracticable either to fit initially or to obtain subsequent access to large numbers of components that are completely masked by adjacent units when the chassis is fully equipped, and it would not, therefore, have been possible to make efficient use of the space within the main unit; the set would then have been larger and heavier.

Also, it was known that unit construction would greatly facilitate the manufacturing processes and enable associated groups of circuits to be bench-tested individually before fitting into the complete equipment. Similar considerations in regard to bench-testing also apply to a large extent to maintenance procedures.

2.2 Choice of Materials

Wherever possible throughout the equipment, aluminium alloys have been used in the construction of chassis and mechanisms. Manganese-aluminum alloy is employed mainly for chassis work; this being a material that, in addition to being practical from the forming and welding viewpoints, also possesses good resistance to corrosion by sea air. In cases where rigidity and wear are the deciding factors, duralumin has been used instead of the alternative heavier metals, but the latter could not be avoided in some instances for electrical or other reasons.

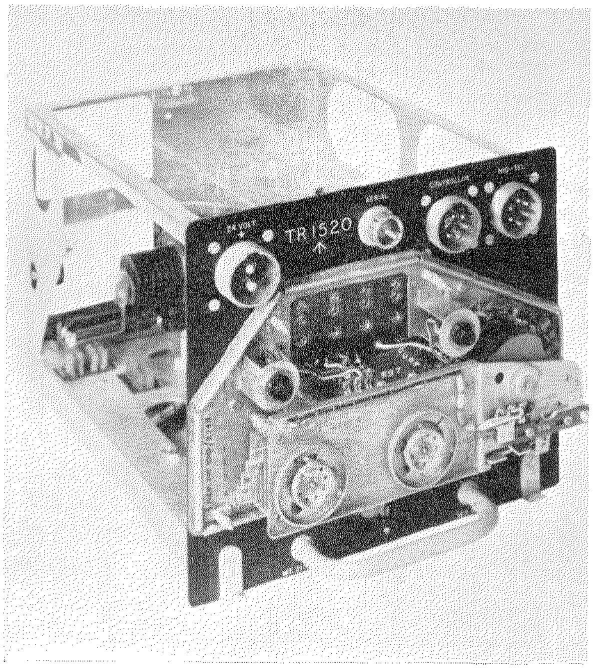

Fig. 3—Main-unit chassis showing channel-selection mechanism.

At the time that the equipment was being developed, the technique of silver-plating aluminium was insufficiently advanced, otherwise further economies could have been made in this direction.

Particular care has been exercised where materials and finishes are concerned, to avoid contacts between dissimilar metals that might lead to electrolytic corrosion.

2.3 Miniaturisation of Components

Practically all components and their mountings—including valves, plugs and sockets, and carbon-pile regulator—are of miniature types, and this represents a considerable contribution to the overall saving in weight and dimensions.

Although it is not possible to give specific figures, it is estimated that the use of miniature components has resulted in a saving of something like 50 per cent in weight and possibly more in volume relative to non-miniature components. In the case of the carbon-pile voltage regulator alone, the saving is substantial, relative figures being 10 ounces against 32, and 6 cubic inches against 26.

It might be mentioned that miniaturisation also introduced certain problems such as congestion of wiring and soldering points, which called for a considerable amount of ingenuity in their solution.

2.4 Midget Relay

The midget relay is of unusual interest, having been designed to meet the requirement for the smallest relay that would operate a maximum of two contacts with complete reliability and a standard of mechanical adjustment similar to that generally adopted on telephone switching systems. The weight of 1.5 ounces (43 grammes) and overall dimensions of 1.38 by 1 by 0.63 inches (3.4 by 2.5 by 1.6 centimetres) are considered to be the minimum possible when the variations in energising voltage and ambient

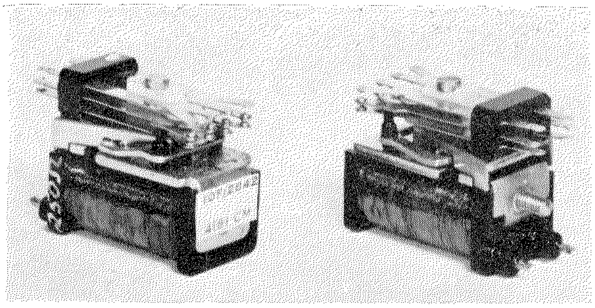

Fig. 4—Miniature relay that weighs only 1.5 ounces.

temperatures experienced in aircraft are considered. In its ordinary form, it is fitted with two sets of armature springs, each fitted with twin platinum contacts capable of handling 2 amperes continuously, or starting currents up to 10 amperes. For the latter use, a heavy-current holding winding is added to the relay to guard against contact burning, which might arise from switching the relay off whilst the rotary transformer is drawing a heavy current during starting. This winding holds the contacts closed until the current value falls to a safe figure.

For heavier duties, up to 100 amperes starting current, this type of relay can be fitted with single heavy-duty molybdenum-silver contacts. The normal winding dissipation is approximately 1.75 watts. Not least of the outstanding features of this relay is its satisfactory operation under severe vibration conditions, this being made possible by its balanced-armature construction.

2.5 Stages Common to Both Receiver and Transmitter

In view of the fact that the receiver and transmitter operate on the same frequencies, and that both are never in actual operation simultaneously, it was decided to take advantage of these conditions by making certain oscillator and frequency-multiplying stages of the receiver serve a similar function for the transmitter, thereby simplifying the circuit arrangements and saving equipment.

This feature is evident from the schematic diagram of Fig. 5 and enables both receiver and transmitter to make use of a single set of four crystals, at the expense of a single auxiliary crystal oscillator in the transmitter.

2.6 Ganged Tuning Capacitors

Similar tuning capacitors are used with slight variations for both transmitter and receiver.

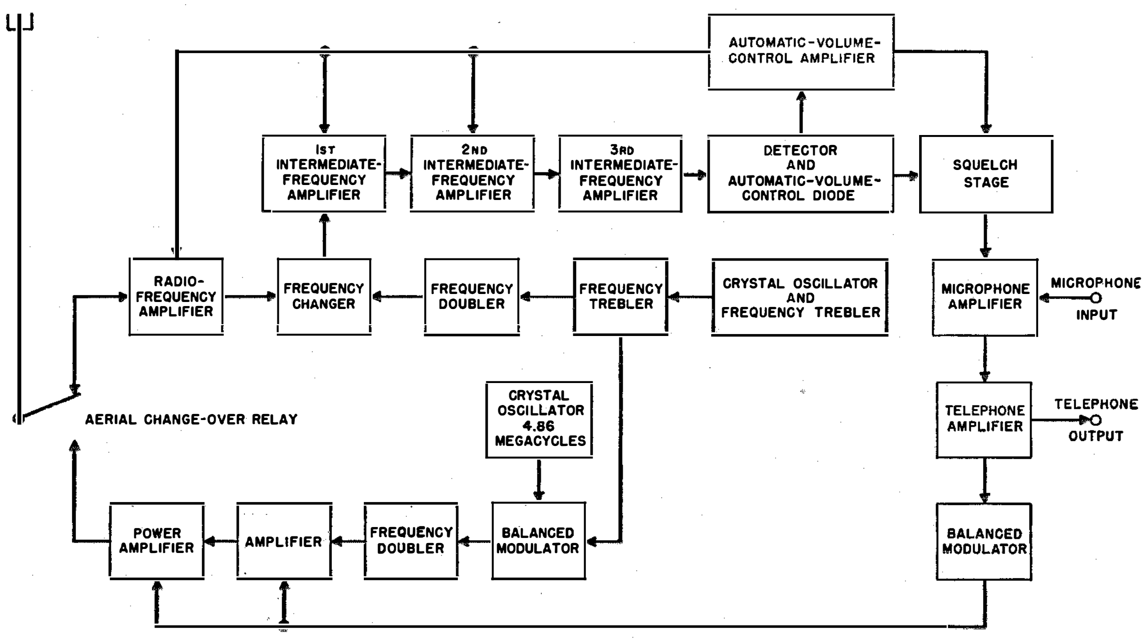

Fig. 5—Schematic diagram of equipment. The crystal oscillator and two trebler stages are common to both transmitter and receiver as are the microphone and telephone amplifiers.

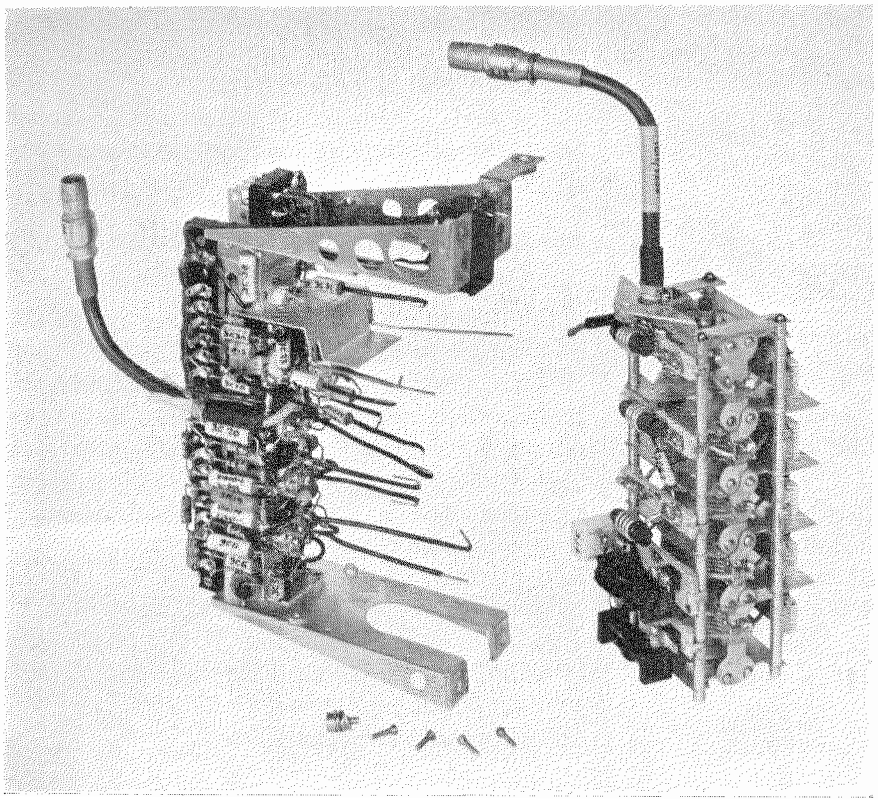

Fig. 6—Receiver input unit with 5-gang capacitors detached. The left-hand cable goes to the intermediate-frequency amplifier and the antenna input is to the coaxial cable connected to the capacitors.

They were specially designed for the equipment and, by means of compact design and silvered-ceramic technique, it has been possible to produce a unit of high electrical efficiency and small dimensions and weight, capable of being jig-assembled on a production basis. The capacitors are fitted with spring-loaded ball bearings, ensuring light action without end play, and are flexibly mounted in their respective units to avoid physical distortion. Provision is made in the design for mounting the tuning coils directly on the capacitors, thus ensuring short leads and minimum stray capacitances. Trimmer capacitors and interstage screens are built in, the latter being subsequently soldered to form integral parts of the associated screens on the unit chassis.

The complete 5-gang capacitor assembly for the receiver is visible in Fig. 6. It is 5.5 inches long by 2 inches wide by 1.75 inches deep overall (14 by 5 by 4.4 centimetres), and weighs 11 ounces (312 grammes) complete with trimmers, coils, and screens.

2.7 Rotary Transformer

It was realised early in the development, that the considerable heat dissipation (120 watts) of the various portions of the equipment within such a comparatively small unit would inevitably require some form of forced-draught cooling system to prevent excessive temperature rise, and it was logical to make use of the rotary transformer of the power-supply unit to accommodate the blower, instead of using a separate motor for this purpose.

The presence of the blower on the rotary transformer naturally suggested the possibility of reducing the size and weight of the machine itself by the expedient of directing a proportion of the air flow through the armature tunnel to cool the winding and commutator, thus enabling a small machine to be run at an output far in excess of its normal rating. Special attention to the design of the machine end-frames and to the provision of maximum airspace in the tunnel made this a practicable proposition, with the result that instead of using an un-cooled machine 3.25 inches in diameter by 8 inches long (8 by 20 centimetres) weighing 7.5 pounds (3.4 kilogrammes), it was possible to use a machine only 2.875 inches in diameter and 8 inches long (7 by 20 centimetres) (including blower), weighing only 5.75 pounds (2.6 kilogrammes). This machine is shown in Fig. 7.

2.8 Drive Unit for Channel-Changing Mechanism

In earlier equipments, it has been usual to provide a separate electromagnetic or motor-driven source of power for operating channel-switching or tuning mechanisms and these have almost invariably been both heavy and bulky.

In developing the mechanical drive unit for the A.R.I. 5272 set, a considerable proportion of the usual bulk and weight was eliminated by making still further use of the rotary transformer as the source of power. A small cam is fitted to an extension of the machine spindle, and this operates a ratchet-type drive unit fixed to the machine end-frame. The unit, whose dimensions are 2.875 inches in diameter by 0.75 inch deep (7.3 by 1.9 centimetres) over its cover, has a rotational stepdown ratio of 480:1 from the machine spindle, and a torque output of 1800 gramme-inches at approximately 15 revolutions per minute, with a total weight of only 4.5 ounces (128 grammes). The end of the machine carrying this mechanism may be seen in Fig. 8.

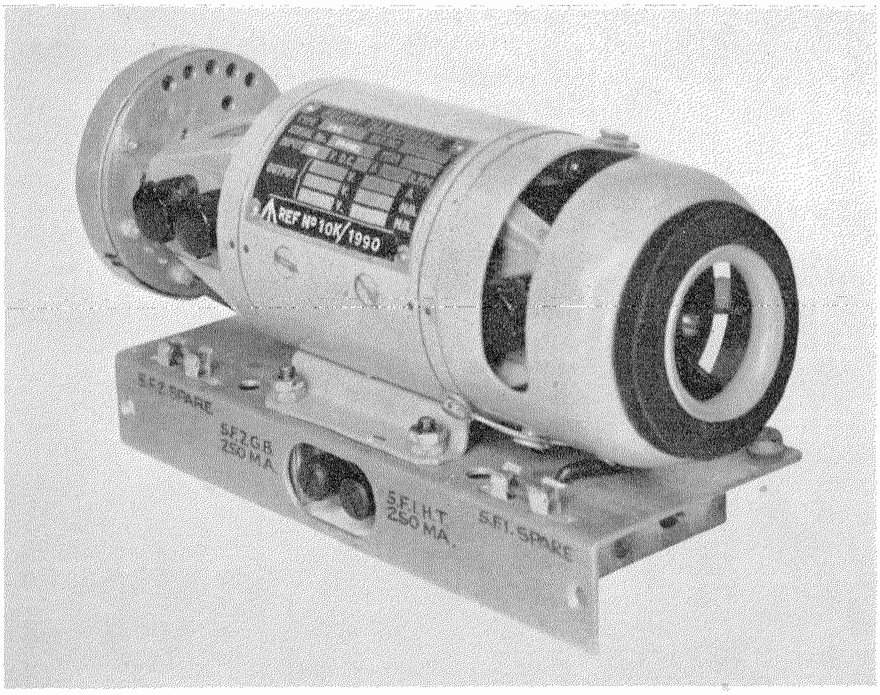

Fig. 7—Power-supply unit consisting of a rotary transformer mounted on a filter box. The drive mechanism for the channel-selecting switches is at the far end. The air blower is at the near end.

Starting and stopping is virtually instantaneous, being controlled by a small electro-magnet built into the unit. The design is such that no load, either electrical or mechanical, is taken by this drive unit except when channel changing is in progress, and the load under these conditions approximates only a 6- or 7-watt input to the set. The majority of this load is taken directly by the magnet coil, and only the relatively small remainder represents load on the rotary transformer, which is in any case operating under light-load conditions during channel-changing.

Stopping accuracy is of the order of 1.5 degrees of rotation of the output shaft, although this is actually of no considerable importance, since the channel-selection mechanism is designed to avoid the necessity for accurate

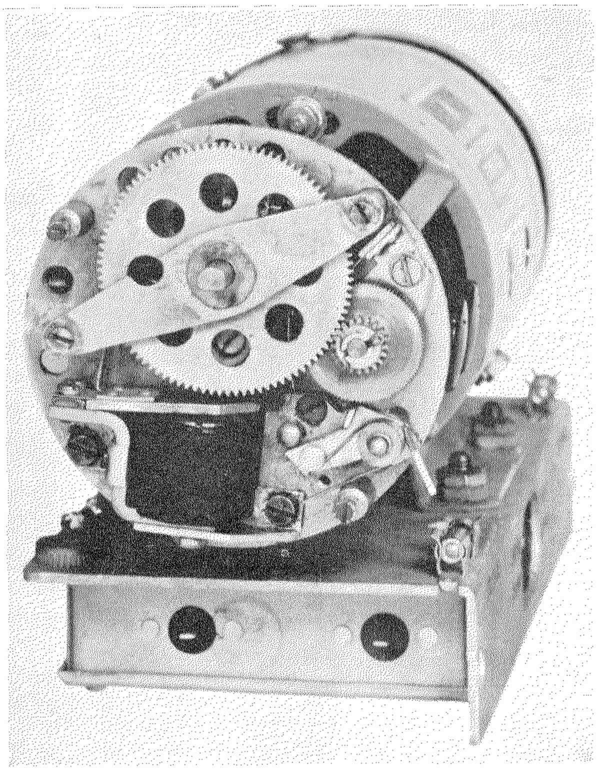

Fig. 8—Drive unit for channel selector with cover removed.

positioning of the driving shaft. When the drive unit is stopped, its output shaft is automatically locked to prevent further movement, but a release lever is provided so that it may be rotated manually f●r assembly and maintenance.

3. *Detailed Description*

3.1 Main Chassis

The main chassis is constructed of formed and welded aluminium alloy and is fitted with a totally enclosing dust cover of the same material.

Where silver-plated subsidiary units mount directly on the aluminium chassis, tinned surfaces are provided over the contact area to avoid undue electrolytic potentials between the metals.

The chassis layout accommodates the several subsidiary units in convenient relation to one another so that all direct interconnections are kept to minimum length. For example, the link between the common frequency-multiplying stages in the receiver and transmitter consists of knife contacts on the receiver unit that engage directly with clips on the adjacent transmitter unit.

A separate compartment is provided for the power-supply unit, with suitably positioned holes in the body of the equipment to direct the airflow to the hot spots of the set. The air blower fitted to the rotary transformer is capable of circulating 20 cubic feet (0.57 cubic metre) of air per minute through the set with a temperature rise between inlet and outlet of only 15 degrees centigrade. Further cooling of the set is assisted by the use of a matt black finish on valve cans and on the dust covers.

To prevent the access of dust and particles of foreign matter to parts of the equipment where it might have deleterious effects, air is taken in through a Vokes dry-type filter, sh●wn in Fig. 9, and is expelled through a similar filter at the outlet. These filters are of high efficiency and low pressure drop, the design offering a large filtering surface permitting low air velocity. Particles of dust are not forced into the filter elements but rest on the surface, whence the majority are dislodged by vibration and shaken to a well at the bottom. Cleaning involves no more than removal of the filters and tapping out of the accumulated dust.

The two filters are fitted in an external compartment at the rear of the chassis dust cover, and are accessible for replacement or cleaning by removing the detachable lid. The latter is louvred for inlet and outlet of the air, and direct circulation of air between the two sets of louvres is minimised by facing them away from one another. An incidental but nevertheless valuable feature associated with the forced-air cooling system is that it promotes rapid drying out of the interior of the set after prolonged exposure to humidity.

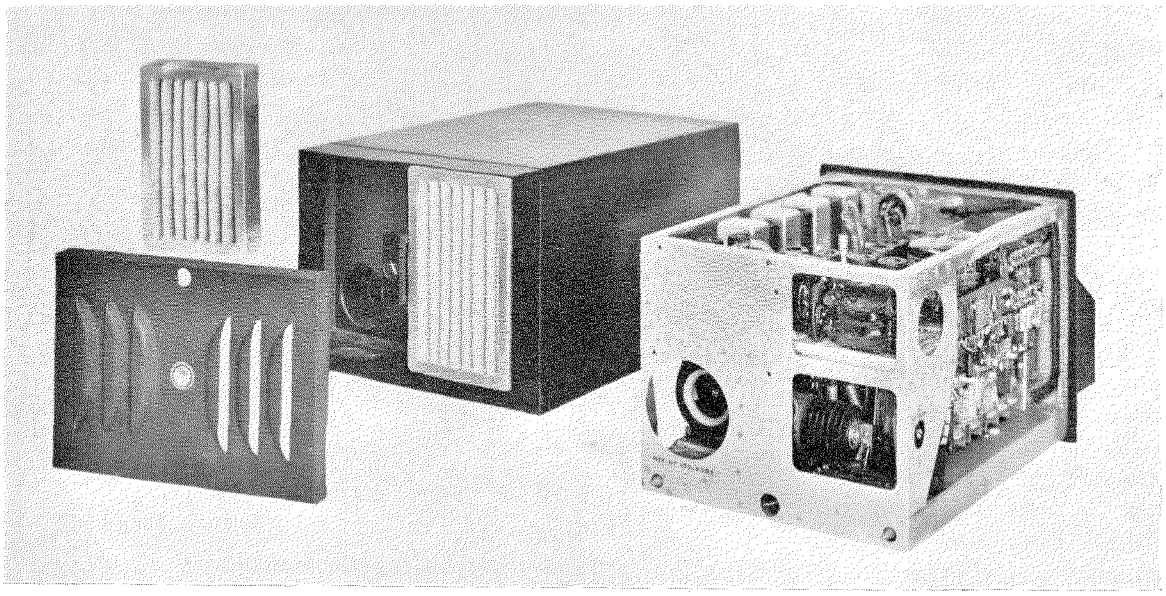

Fig. 9—Rear view of main unit showing dust cover and air intake filters.

3.2 Receiver

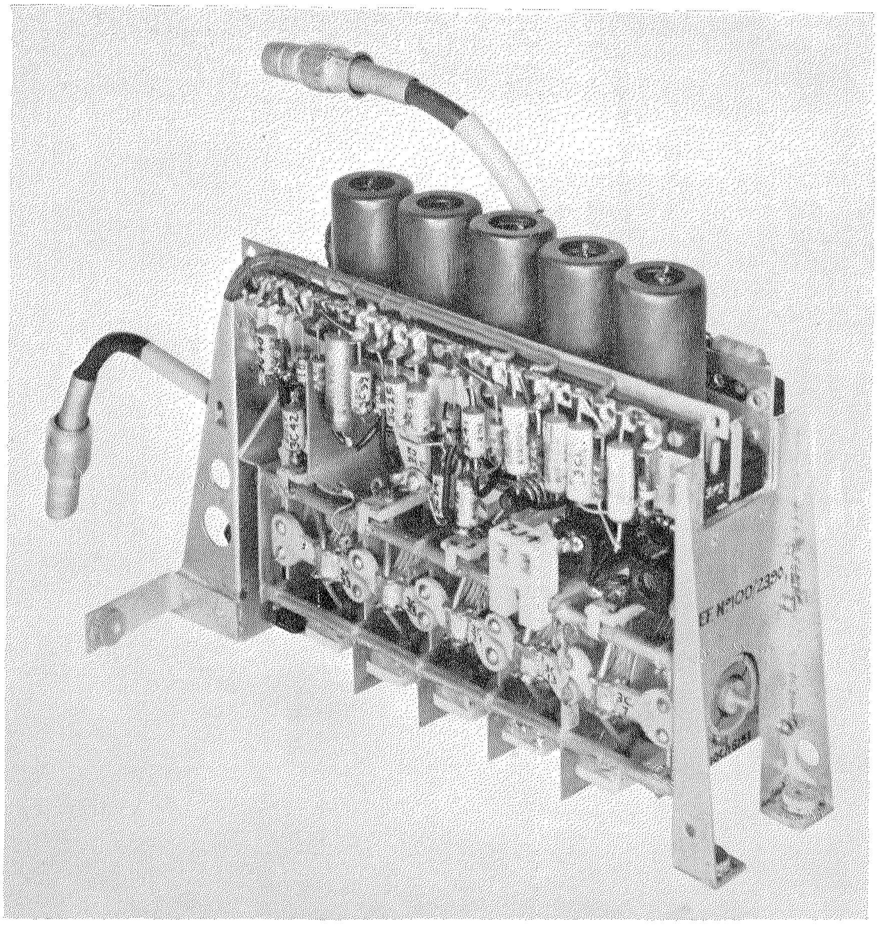

Fig. 10—Receiver input circuits with (upper) coaxial cable to intermediate-frequency amplifier.

The receiver will produce an output of not less than 20 milliwatts into a 50-ohm impedance with an input of 10 microvolts, modulated 30 per cent at 1000 cycles. The signal-to-noise ratio will be at least 10 decibels. The intermediate-frequency amplifier operates at 9.72 megacycles and has a bandwidth of not less than ±40 kilocycles at 6 decibels down from maximum response and not more than ±140 kilocycles at 40 decibels down. Suppression of second-channel signals by the receiver is not less than 35 decibels.

An audio-frequency output of 150 milliwatts will be delivered to three pairs of headphones and the equipment will operate effectively into an impedance between 50 and 150 ohms. The automatic gain control will limit the rise in output to not more than 3 decibels for an increase in input of 80 decibels above 10 microvolts. Relative to response at 1000 cycles, the audio-frequency output is between zero and −6 decibels for 300 cycles and between zero and −8 decibels for 3000 cycles.

The electrical circuit of the receiver comprises an oscillator and a trebler stage (with fundamental input frequencies controlled by four crystals), followed by another trebler and a doubler, the output of which is passed to a frequency changer where it is mixed with the incoming signal from a radio-frequency-amplifier stage. The resulting signal at 9.72 megacycles is passed via a coaxial line to the intermediate-frequency amplifier unit, which includes the detector, and thence via an audio-frequency amplifier in the modulator unit to the telephone output.

The oscillator and the two trebler stages of the receiver are also used to feed the transmitter with an input of nine times the crystal frequency.

The receiver is built in unit form on a silver-plated brass chassis, together with all valves and other components, including the 5-gang capacitor previously described. This capacitor tunes all stages simultaneously and has provision for connection to the channel-selection mechanism by means of a flexible coupling. Coil trimming is effected by dust-iron cores. These input tuning circuits of the receiver are shown in Fig. 10.

3.3 Transmitter

The transmitter will deliver 3.5 watts into a 45-ohm impedance. The carrier may be amplitude

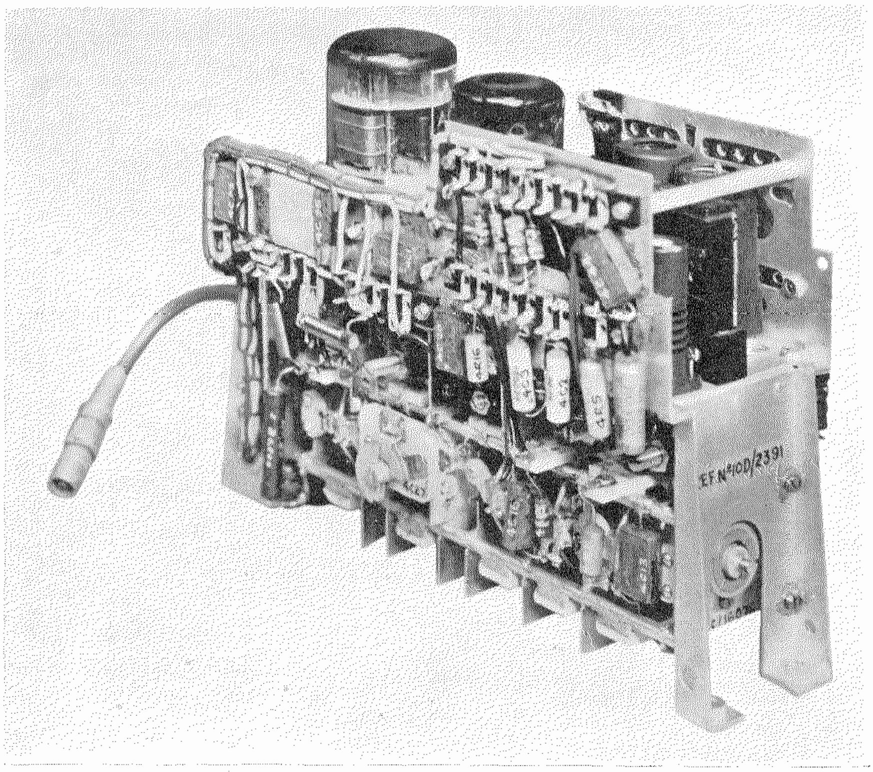

Fig. 11—Transmitter. The coaxial cable goes to the antenna change-over relay. The 5-gang tuning capacitor is at the bottom.

modulated up to 100 per cent. Harmonic output will not exceed 15 per cent for modulation of 80 per cent. The noise level is at least 40 decibels below the level corresponding to 100-per-cent modulation. The audio-frequency response, relative to values obtained at 1000 cycles, will be between −4 and −10 decibels at 300 cycles and between zero and −4 decibels at 3000 cycles.

The transmitter may be seen in Fig. 11 and consists of an auxiliary crystal oscillator at half the intermediate frequency (or 4.86 megacycles), a balanced radio-frequency modu-

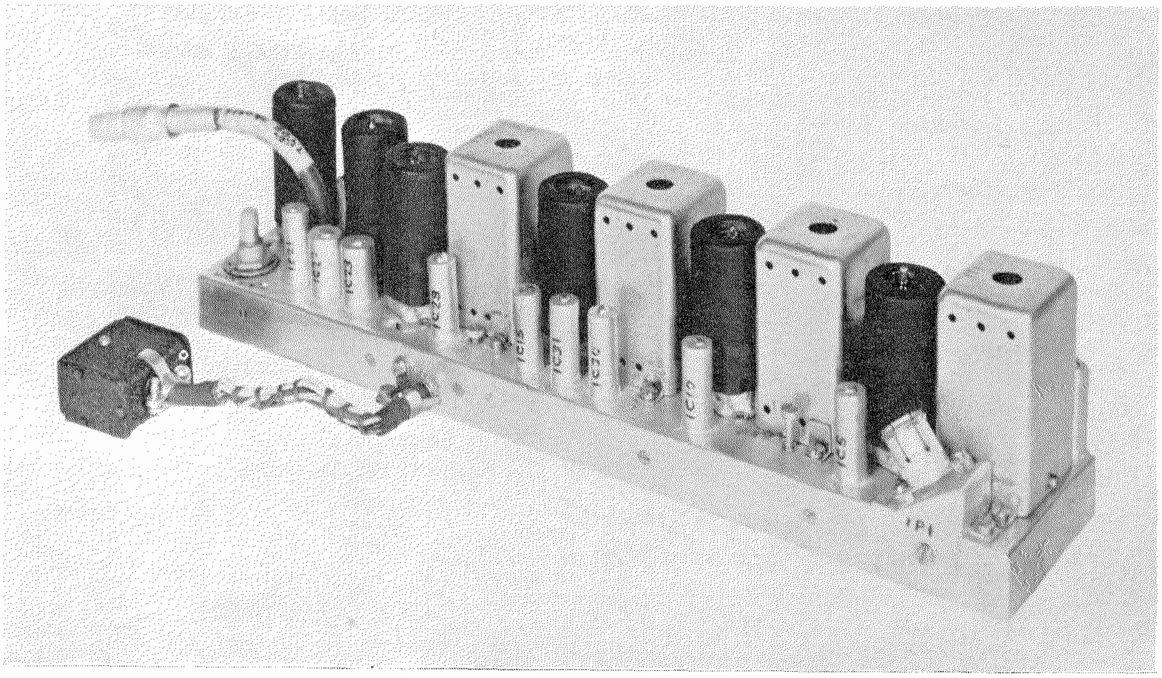

Fig. 12—Intermediate-frequency amplifier. The inter-stage coils are in the rectangular cans and the valves are in the cylindrical shields.

lator, doubler, amplifier, and power-output stages, the latter using a double-tetrode valve. Mixing of the input from the second trebler stage of the receiver (at 9 times the fundamental crystal frequency) with the output from the auxiliary crystal oscillator is effected in the balanced modulator.

Output from the doubler stage is band-pass coupled to the output amplifier where it is modulated by the audio-frequency signals received from the modulator unit.

In physical construction, the transmitter is generally similar to the receiver, being built in the same unit-type construction around a similar 5-gang tuning capacitor together with all valves, coils, screens, trimmer capacitors, test plugs, etc., the capacitor again being connected to the channel-selection mechanism by a flexible coupling.

3.4 Intermediate-Frequency Amplifier

Three stages of intermediate-frequency amplification at 9.72 megacycles are incorporated in this unit, using high-slope variable-mu pentodes, and these are followed by a diode detector with which are associated a squelch stage and an automatic-volume-control amplifier. The squelch circuit feeds an audio-frequency amplifier in the modulator unit for the telephone output from the equipment, whilst the automatic-volume-control amplifier provides a voltage that is applied to the screens of the various intermediate-frequency stages. A portion of this voltage is tapped off and used to control the radio-frequency-amplifier stage in the receiver unit.

The interstage coils are inductively tuned and are provided with convenient trimming devices.

The intermediate-frequency-amplifier chassis, shown in Fig. 12, is of silver-plated brass in the form of a shallow inverted box, with valves, screened-coil units, decoupling capacitors, and coaxial connectors mounted on top. Other components mount below.

3.5 Modulator

This consists of a microphone-amplifier stage, a telephone-amplifier stage, and a push-pull amplifier supplying modulation to the transmitter. Negative feedback is employed between the telephone and microphone amplifiers to avoid distortion and to maintain good regulation.

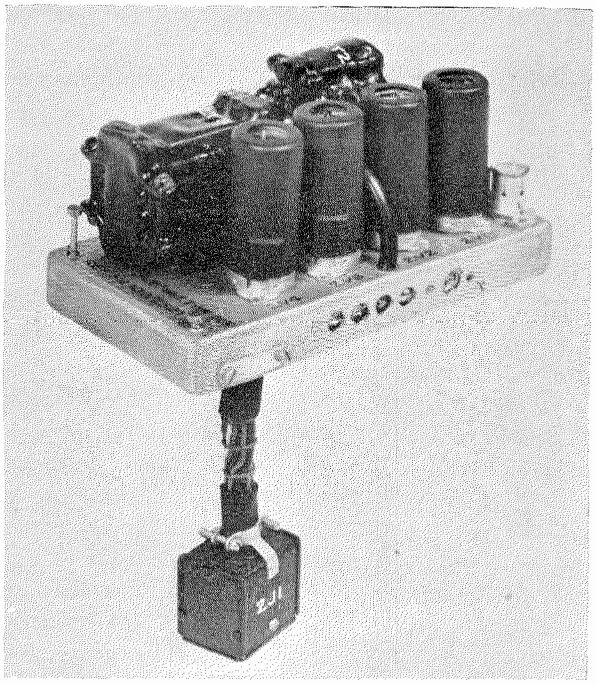

Fig. 13—Modulator. The modulation, driver, and microphone transformers are at the rear.

The chassis is of inverted-box construction in aluminium alloy, with valves and transformers mounted above the deck and other components below. It may be seen in Fig. 13.

3.6 Power Supply

Plate power at 250 volts and grid bias at 50 volts are generated by a rotary transformer mounted on a jack-in-type aluminium-alloy chassis, which also forms a screened box for fuses and input and output electrical filters. The air blower incorporated in the machine consists of a bakelite centrifugal impeller shrouded by an aluminium spinning conforming to the diameter of the machine. A rubber gasket is fitted to engage with the air inlet of the main-chassis dust cover when the power-supply unit is in position.

The mechanical drive unit at the other end of the rotary transformer was also designed to conform to the machine diameter to make a compact overall assembly.

3.7 Channel-Selection Mechanism

The channel-selection mechanism is constructed as a self-contained unit fitted externally to the front panel of the main chassis. It is connected mechanically to the receiver and transmitter tuning-capacitor spindles and to the output shaft of the drive unit on the rotary transformer by double flexible couplings to allow for misalignment of shafts.

Incorporated in the unit, which may be seen in Fig. 14, are a mounting for the four crystals and a bank of four slide switches, which connect them in the circuit as required.

The essential parts of the mechanism are two setting spindles for the receiver and transmitter capacitor drives and four spring-returned slides, which rotate the setting spindles through the medium of cam levers to positions corresponding to the channel selected. Operation of the slides brings the appropriate crystal into the circuit via its slide switch at the same time as the capacitor spindles are positioned. A camshaft, driven from the drive-unit output shaft, operates the slides in sequence until the correct slide has been brought into use, when the camshaft is automatically tripped by the magnet in the drive unit. Positioning of the camshaft is controlled by two switches driven by the camshaft itself. The first is of a conventional rotary type and is used only to discriminate between the electrical markings transmitted from the remote control box for the four channels. The second switch comprises snap-action contact springs operated by four cam-notches in a large-diameter disc on the camshaft. These notches correspond to the stopping positions of the camshaft for correct operation of the four slides and control the drive-unit magnet directly.

Another set of springs actuated by the same four cam-notches enables the cam-shaft to be driven to a "free" position in which all slides are released but can be operated manually for setting and resetting purposes.

Further switches are provided on the mechanism to enable the settings of receiver and transmitter to be checked by meters.

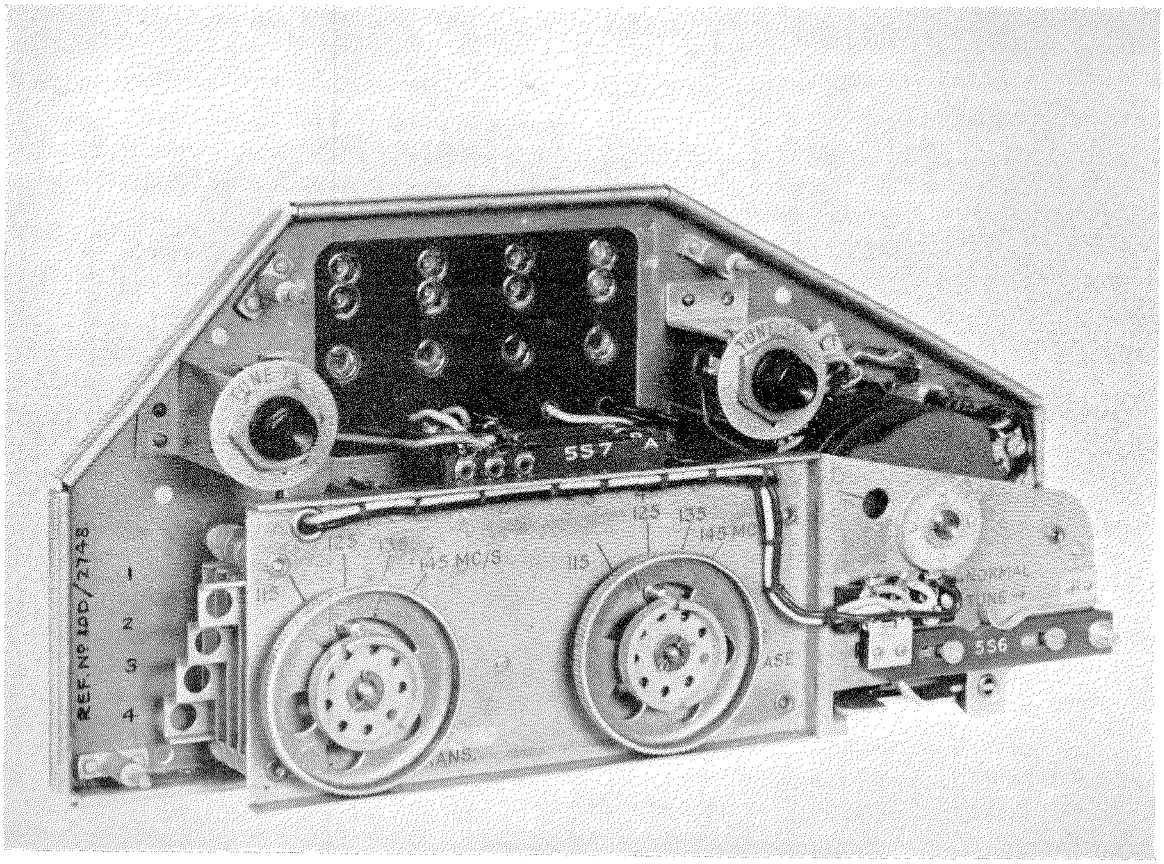

Fig. 14—Channel-selection mechanism. The frequency-setting spindles are at the bottom centre, and above them are the mountings for the 4 crystals.

The mechanism incorporates a compensating cam device that smooths out to a large extent the fluctuating torque imposed on the camshaft by the spring-loaded operating slides.

Although the camshaft stops within approximately 1.5 degrees of its correct position, the need for special accuracy at this point is obviated in the design. Furthermore, the use of spring loading and vee or diamond bearings eliminates setting inaccuracies, which would otherwise occur due to manufacturing tolerances in the various parts, and enables the ganged tuning capacitors to be positioned to an accuracy of ± 0.125 degree.

The mechanism is arranged to permit the unlocking, resetting, and relocking of the setting-spindle positioning for any channel of either receiver or transmitter without disturbing the existing settings for other channels.

Duralumin is used for lightness, rigidity, and wearing properties in the construction of the slides and mounting arrangements.

A detachable aluminium waterproof cover fits over the complete mechanism, with a built-in Perspex window over the crystal mounting for inspection purposes. When the cover has been removed for resetting or similar reasons, any switches inadvertently left in the wrong position are either automatically restored to normal in refitting the cover, or are arranged to foul the cover until restored by hand.

3.8 Remote Control

The remote control unit used with the equipment is a small bracket-mounted aluminium-alloy box fitted with a plug connection for external cabling and a single switch for turning the set on and off and for channel selection.

This unit was purposely kept as simple and small as possible to reduce operating procedure to a minimum and to facilitate installation of the control unit in the congested cockpits of small aircraft.

3.9 Weights and Dimensions

Table I gives the weights and dimensions of the component units of the A.R.I. 5272 set.

TABLE I
WEIGHTS AND DIMENSIONS

Unit	Weight		Dimensions (Height × Width × Depth)	
	Pounds-Ounces	Kilogrammes	Inches	Centimetres
Receiver	1–13	0.8	5.1×2.0×6.9	13×5×18
Transmitter	2–10	1.2	6.0×3.25×8.0	15×8×20
Intermediate-Frequency Amplifier	1–12	0.8	2.9×2.9×10.75	7×7×27
Modulator	1–12	0.8	2.8×3.1×5.7	7×8×14
Chassis, Including Channel-Change Mechanism, Carbon-Pile Regulator and Rotary Transformer	13– 9	6.2	7.9×9.0×16.25	20×23×41
Control Box	0– 8	0.2	3.5×2.2×2.6	9×6×7
Total, Less Cables	22– 0	10.0		

Survey of the Telephone Transmission-Rating Problem*

By L. C. POCOCK

Standard Telephones and Cables, Limited, London, England

THE QUALITY of service provided by a telephone concern is an essential factor in its financial economy. In this relation, it is necessarily the overall quality as experienced by the subscribers. Division into different aspects such as traffic quality and transmission quality is arbitrary; each may be separately measured, but for economic balanced planning there is need of a combined measure of overall quality. The paper deals only with transmission quality. Planning has, in the past, been in terms of circuit attenuation and instrument efficiency, with the object of ensuring an adequate level of received speech, but this conception is no longer adequate or economical.

The direct observation of the number of times a subscriber finds it necessary, in a unit time-interval, to repeat a word or a sentence is the best known indication of transmission quality in service; a complete rating system based upon such observations† and other considerations has been put into operation by the American Telephone and Telegraph Company.

In Europe, the repetition-rate criterion of service quality has been accepted, but application of the practice presents difficulties. Two plans are being investigated: (*a*) attempts are being made to find, under certain restricted conditions, a correlation between repetition rate in service and laboratory articulation tests; and (*b*) a provisional system of rating based on articulation tests (without reference to repetition rate) is being studied.

Both plans are described, and possible correlation procedures are discussed. Reference is made to the economy aspect of rating on the broader basis of transmission quality, but the subject is too large to treat adequately in the present paper.

Brief mention is made of foreign publications.

Appendices include detailed descriptions of the experimental procedure to establish transmission-service ratings.

On account of the fluid condition of the subject of the paper, standardized terminology is not in existence and therefore definitions of the terms used are given as a final appendix.

• • •

1. Introduction

The fundamental economy of industrial concerns comprises cost of production, quantity of production, and selling price. The business of providing telephone service rests upon similar fundamentals, which may be more appropriately described as:

A. The cost of providing service, expressed as total annual charges.

B. The extent to which the service is utilized, evaluated in call units.

C. The charge made to the user per call unit.

These three interdependent elements may restrict the activity of the engineer, but he can receive no positive help from them until there is added a factor directly related to the accounts and susceptible to control by engineering design.

This fourth factor is the quality of the service given to the public; it is the touch-stone of the engineer's contribution to the telephone business and of the business itself as an alloy of finance and engineering.

Fig. 1 illustrates the kind of relation that must exist between the four quantities mentioned. The fundamental importance of such relations is obvious: not only does the measurement of service quality become important, but essentially the quality must be correctly measured, i.e., in terms correlating with the subscriber's experience, because it is the subscriber's satisfaction

* Reprinted from *Journal of the Institution of Electrical Engineers*, v. 95, Part III, pp. 253–265; July, 1948.

† One of the difficulties of obtaining repetition-rate data is the obligation not to infringe the privacy of subscribers' calls. The existence of two large bodies of employees at the Bell Laboratories and in the telephone company's building, with considerable tie-line traffic between them, enables the American Telephone and Telegraph Company to make observations under substantially service conditions without tapping subscribers' lines.

with the service that influences the extent to which he will use it and pay for it.

1.1 Quality of Service

Since it is the purpose of a telephone business to provide a satisfactory quality of service at the lowest cost, there arises at once the searching question, What is a satisfactory service?

At any given epoch, the quality of the service may be improved at a certain increase in cost, and it is common experience[1] that the use of the service increases when the service is improved, so that increased revenue partly offsetting the cost may sometimes be obtained without any increase in charge.

The process of improving the service may be continued with or without aleration in charge until further improvement would result in reduced use on account of the high charges necessary. The quality of service is then theoretically the best economically obtainable; other considerations might, however, dictate a policy of a rather lower standard at lower cost.

According to the principles of cost equilibrium, the annual charges will be least for a given quality of service when the increase in annual charge, due to making a given small improvement by making changes in any one of the parts into which the system may be arbitrarily divided, is the same whichever part is selected for amelioration. From this it follows that the contribution of all parts of the system to the overall service result is determined by economic principles, which enable a choice to be made between the various technical alternatives that might be proposed to provide the grade of service required. It follows that it is necessary to provide means to measure the quality of service and to evaluate the contribution of each part to the quality of service of the whole system.

It must be remembered that service quality thus far discussed is measured by the subscribers' appreciation, which is determined not only by transmission performance but also, amongst other things, by speed, availability, and reliability of service, which may be arbitrarily called "switching quality."

If, therefore, a necessary division is made between transmission quality and switching quality, there is a need to create a new unit of "overall service quality" which will be a function of these two components, combining them in suitable proportions. For example, the units may be so chosen that a unit change in transmission quality in service is equal to a unit change of switching quality, if both produce the same effect on the use of the telephone. It is evident that, if the system is to be so planned that there is economic balance between the expenditures on switching and on transmission with maximum overall satisfaction to the subscriber, some such relation is required to equate switching and transmission quality.

2. *Quality of Transmission*

The paper is concerned with quality of transmission, which is the aspect of overall quality of service perceived when the quality of switching service is disregarded. Transmission quality in service is here called "transmission service" and its numerical values are called "transmission-service ratings." It will be necessary to consider how it is to be assessed (rated) and how the overall rating may be broken down to determine the contribution of every part of the circuit to the total transmission service. It will facilitate the the study, however, to recognize at once that it is more difficult to give good quality over a long circuit than over a short one, and in general that losses in quality or quality impairments relative to some standard are contributed by each part of a circuit. The study of transmission service is

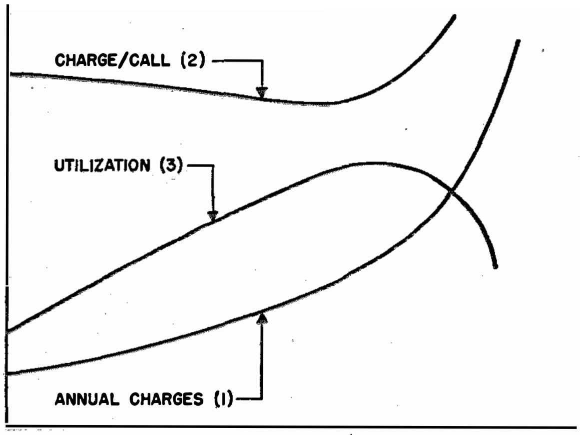

Fig. 1—Fundamental relations.
(1) = (2) × (3).

[1] Bibliographical references will be found on page 272.

therefore to be conducted by the study of the complementary idea of quality impairment in service, and it becomes a further object of study to express quality impairments in such a way that the contributions of the parts of a circuit may be added together or combined in some simple way to give the quality impairment of the whole circuit.

In the past, transmission circuits have been planned to have predetermined overall attenuation with only qualitative attention given to the amount of speech distortion and other factors. The planning of circuits on this basis was a technical matter and the technicians concerned could be sure that the circuits planned would be satisfactory if the subscribers behaved in a prescribed manner. Such a system is unsuited to modern requirements. First, it is not economical to design speech circuits merely to give sufficient loudness because it is not to the advantage of the subscriber and does not tend consistently towards better transmission quality, nor does it provide a required grade of transmission at the lowest cost. Secondly, it is just as true for monopoly services or public utilities as for competitive industry that sales can be increased by studying the consumers' habits and requirements and adapting the service or commodity offered to suit them. Finally, when the subscribers' behaviour is studied, it is found that it is an important factor in the performance of a given physical circuit, and that the average behaviour can be shown to depend at least in part upon some of the characteristics of the circuit. W. H. Martin[1] has discussed in detail the adjustments of behaviour that occur in direct and telephone conversations. The differences between the two cases arise mainly from the differences between the circumstances (e.g., in respect of room noise) of the two persons talking by telephone, as opposed to the close similarity of circumstances for two persons in the same room, and from the ignorance of a speaker on the telephone of the surroundings of his listener.

Apart from these facts, which are external to the telephone, the artificial sidetone introduced by the telephone and the artificial channel of communication itself, which may be unequal in efficiency in the two directions, produce reactions upon the manner of speaking. Some of these reactions may adversely affect transmission quality and it is therefore desirable to eliminate as far as possible those causes which give rise to unsuitable reactions, and to utilize as fully as possible favorable reactions.

To sum up, transmission quality in service is the transmission data that is relevant to the economics of telephony; it is the resultant of objective circuit characteristics and subscribers' actions. Subscribers' actions are, on the average, largely determined by the circuit characteristics and therefore need not be explicitly known if transmission quality is directly measured in service; the results thus obtained may be expressed as a function of circuit characteristics, the subscribers' reactions to the circuit being implicitly included by the measurements. Knowledge of the subscribers' contribution to transmission performance is, however, useful in analysing the results of service observations, in assisting design to eliminate unfavourable subscriber reactions, and in leading to better simulation of direct speech conditions in telephony.

The study of transmission performance in the broad sense of appreciating the quality of transmission obtained in service, leads to the establishment of transmission-service ratings as numerical values for the impairments contributed by parts of a circuit.

3. *Circuit Design on the Basis of Transmission Service*

3.1 Data Required for Circuit Design

The following are the requirements for solving the problem of designing circuits on the basis of their transmission service:

A. The complete technical data of each circuit must be known, i.e., attenuation, distortion, noise, sidetone, etc., must be subjectively or objectively measured. In this way, each circuit can be fully specified in terms of a certain number of parameters, which are preferably chosen and defined in such a way that they are independent of each other.

B. A measurable quantity must be found that is uniquely related to the transmission quality impairment as experienced by subscribers in service.

C. Using *B* as a measure and varying in turn each of the parameters mentioned in *A*, relations must be found between the transmission quality impairment and different values of each circuit parameter.

D. Means must exist for combining into one total the transmission quality impairments attributed to the values of the several parameters. The total result thus obtained must agree with the direct assessment of transmission quality impairment when a circuit having several parameters different from the normal is used in service and measured in terms of the quantity referred to in *B*.

E. For the purpose of practical engineering planning, it must be possible to assign transmission impairments to the separate links of a circuit that may be joined together, in such fashion that the total impairment for a circuit built up from two or more such links can be determined from the impairments assigned to each link.

The above requirements will now be considered in turn.

3.2 Circuit Parameters

The circuit parameters required for the objective description of a circuit have been chosen by the American Telephone and Telegraph Company, as follows:

Attenuation of the circuit.

Attenuation of the sidetone path for speech at the transmitting end.

Attenuation of the sidetone path for noise at the listening end.

Efficiency of the receiving end for line noise.

Circuit distortion.

with the additional quantities:

Amount of line noise.

Amount of room noise.

It does not seem possible to choose a better set of quantities to describe the characteristics of a circuit; all the quantities can be so defined as to be independent and each is capable of subjective or objective measurement. It should be noticed, however, that from the transmission point of view practically all these quantities extend over the range of transmitted frequency, and when they are expressed by a single number, some convention or particular application of the measurement is implied. The tendency is to develop as far as possible objective, rather than subjective, measurements using frequency weightings such that the results agree with subjective measurements. Such methods save time and are more easily repeated.

3.3 Measurable Quantities that Concern a Subscriber

It has been shown that the aspect of transmission quality that is significant can be observed only in service conditions; it is therefore necessary to look for measurable quantities in which the subscriber is concerned. The choice is limited, and the following is believed to be a complete list:

A. Repetition rate. On a monitored circuit, observations may be made of the average frequency of occurrence of requests for words or sentences to be repeated.

B. Unfavourable comments. On a monitored circuit, observations may be made of the average frequency of occurrence of remarks between subscribers criticizing the quality of the transmission.

C. Transmitter output. Observations can be made at the local exchange of the transmission level that, when corrected for local-line loss, depends on the subscriber's voice level and the closeness with which he speaks to the transmitter.

D. Average duration of call. A small amount of evidence has been obtained showing that when circuit conditions are changed the average duration of calls changes (see Section 10).[3]

Of these four manifestations of the subscriber, only the first two seem to be simply and unequivocally related to the subscriber's experience of difficulty or dissatisfaction with the circuit he is using. Observations of transmitter output may provide useful additional data and, in some cases, transmitter output reflects the effort the subscriber has to make, but it is also known to depend on unconscious adjustment of voice level depending upon the amount of sidetone and the amount of room noise. There is no clear evidence at present that subscribers respond to circuit defects due to distortion by speaking more loudly or closer to the transmitter.

Observations of average duration of call can be very easily made automatically; at present insufficient data exist to show whether there is a clear relation between this quantity and circuit parameters.

It has been agreed, internationally,[4] that "repetition rate" indicates the subscriber's degree of dissatisfaction with a circuit; "unfavourable comments" appear to be far less satisfactory because they begin to give an indication only when the circuit is already bad.

Repetition rate is not an absolute measure, but it can be used as a criterion of equality by adopting the rule that circuits having the same repetition rate for a given group of subscribers are equal in performance from the subscribers' point of view.

Repetition rate being adopted of necessity and by agreement as the criterion of equal circuit performance, a sufficient number of subscriber stations must be put under monitored supervision, and repetition-rate counts must be made while the different circuit parameters are successively varied from a typical reference value over a sufficiently wide range, one at a time.

From the results, curves can be drawn showing repetition rate against variations of each parameter from its reference value. All the curves will show the same repetition rate for the reference value of each parameter and therefore at any other value of repetition rate the corresponding values of parameters are equivalent in the sense that they produce the same change in repetition rate. It is convenient by this process to relate parameter values to changes of distortionless attenuation, which are equivalent in the sense described; these attenuation values in decibels are then the transmission impairments brought about by the variation from reference value of the parameters from which they are derived. By this procedure, all impairments are expressed in decibels and repetition rate is used only as a criterion of equality (Section 14.1).

3.4 Assessment of the Quality of a Complete Circuit

When the impairments expressed in decibels are known for all practical values of the circuit parameters, it is a natural step to add together the appropriate impairments for any given combination of circuit parameters. Such addition cannot be pushed too far, but it may be kept within reasonable limits by choosing, for reference, values in the middle of the field of practical variation.

The breaking down of the total impairments of a complete circuit into impairments assigned to each link of the circuit so that the impairments of any such links can subsequently be added to give the total impairment of a new circuit, requires the establishment of a reference circuit. Mention has been made above of reference conditions; the adoption of one particular fully specified circuit as a reference circuit provides a complete standard of comparison. The results of measurements of sidetone, line noise, etc., are expressed relative to the values measured in the selected reference circuit; similarly the impairment of, for example, a complete transmitting system (telephone set, local line, and cord circuit, considered in the talking direction only) is observed relative to the corresponding part of the reference circuit. In effect, any circuit link to which an impairment is to be assigned is substituted in the reference circuit for the corresponding link, and the change in circuit performance expressed as an equivalent change in reference-circuit attenuation is the impairment of the substitute part.

It is an essential requirement that the impairments assigned to the links of a circuit should add up to the impairment of the whole circuit as determined by direct comparison with the reference circuit.

4. *Transmission-Service Rating (U.S.A.)*

The system of transmission-service rating that has been outlined in Section 3 is the system devised and put into operation under the name of "effective transmission rating" by the American Telephone and Telegraph Company. A more detailed account has been published by F. W. McKown and J. W. Emling.[2]

On the subject of repetition rate, W. H. Martin[1] wrote in 1931:

"Different degrees of success in carrying on telephone conversation may be taken as being indicated by the number of failures to understand the ideas transmitted over the telephone and by the amount of effort required on the part of the users to impart and receive these ideas. . . . The repetitions required in a conversation can be noted but a determination of the effort factor presents difficulties."

Martin also advances the following arguments:

A. Circuits which show equal repetition rates are likely to call for equal effort.

B. When the effort appears to the subscriber to be excessive, his opinion of the service will be adversely affected and the "adverse comments" on the transmission, which he will make, can be recorded by the observers and used to supplement the repetition rate in arriving at a better picture of the service.

The subject of effective transmission rating was developed in further detail by F. W. McKown and J. W. Emling[4] in 1933, where the authors state:

"Properly designed, a telephone system should minimize to the degree consistent with costs its inherent differences from direct conversation, and make it easy for the ordinary user to get, without undue effort, results which are satisfactory to him in comparison with direct conversation."

Attention is directed to these two quotations because in concentrating on the repetition-rate aspect of effective transmission the subscriber's effort is apt to be overlooked and forgotten. It is desirable that data should be collected on this subject in so far as it is possible to do so; to give a simple example, it should be possible to determine whether the subscriber's voice effort on circuits that have such high attenuation as to require loud speaking is related to the repetition rate and whether there is a tendency to speak equally loudly on circuits giving a similar repetition rate when the impairment is mainly due to distortion.

5. *Transmission-Service Rating (Countries Other Than the U.S.A.)*

It was only after very considerable discussion that the Comité Consultatif International Téléphonique placed on record[4] in 1938 the inescapable conclusion that repetition-rate observations afford the best known measure of transmission performance.

The spread of the practice of transmission-service rating to other countries from the U.S.A. has been slow. The reasons for such slow development are associated with the geographical and technical magnitude of the task; the extensive series of fundamental observations of repetition rate made in America is of great value as research in fashioning a new tool and indicating the bearing of circuit conditions on transmission performance. The actual results are, however, empirical in character and applicable only to American sets, plant, and conditions, so that they do not provide data directly applicable to other countries. Therefore, in every country a similar extensive programme of fundamental observations would have to be carried out independently.

This would be for each country a big programme of work involving the installation, supervision, and maintenance of a large number of sets with special controllable features, and a very long series of repetition observations. In some countries, more than one type of set is in use, and this would increase proportionally the programme of work. Such an undertaking might be justified by the end in view. The mere accumulation of data in each country, however, would be simple compared with the task of co-ordinating the data, which would be possible only by installing identical transmission systems in every country and making service observations on these.

On quite another plane, the large number of organizations independently engaged in development work have a natural desire to retain within the domain of the laboratory the testing procedure and the criteria that determine what is or is not a significant impairment in transmission. Although two leading countries carried out considerable experimental work on the observation of repetition rate, it was apparent that the full programme of work needed was beyond the present capacity of the majority of administrations, and alternative plans were studied for achieving the same result by simpler methods. The procedure adopted was the outcome of an offer of co-operation from the American Telephone and Telegraph Company.

It was known that laboratory articulation tests, which had long been used for the comparative study of transmission instruments, did not correlate satisfactorily with repetition-rate observations; obvious reasons why correlation could not be expected were the artificial restrictions placed on articulation tests where fixed values of voice intensity and talking distance must be adopted in order to give meaning to results obtained by a small band of testers. In service, on the other hand, very large numbers of speakers and listeners are involved; the voice level and talking distance vary over wide ranges and are statistically stable, though the mean values vary from one set of circuit conditions to another.

It was suggested, therefore, that correlation might be found if articulation scores were compared with repetition rates, the received loudness level in the articulation tests being the same as the average received loudness level in service when repetition rates were observed.

The American Telephone and Telegraph Company placed at the disposal of the Comité Consultatif International Téléphonique some of the special sets with controllable features that had been used for the fundamental series of repetition-rate observations made on calls by employees over tie lines between the Bell Telephone Laboratories and the American Telephone and Telegraph Company building in New York; they undertook to supply full information regarding room noise, line noise, and average voice-level as determined by volume-indicator readings. With this information, it was possible for the Comité Consultatif International Téléphonique laboratory to make articulation tests under conditions closely resembling the average conditions under which repetition rates had been observed.

This programme has been substantially completed, but certain details require further study and the results cannot be made public until they have been carefully analysed; the writer is of the opinion that sufficient evidence of correlation will be found to justify further study.

Should a satisfactory measure of correlation be found between repetition rate and articulation at equal received levels, considerably more work will be required before transmission-service rating based on articulation results and received-level data can be equated to effective rating (repetition-rate basis). It will be necessary to determine whether the particular correlations found for the American sets are valid for different types of European sets and conditions. For this purpose, repetition-rate data will have to be determined in two or three European countries. Further, it will be necessary to establish a considerably higher standard of agreement between articulation results obtained on the same circuits in different laboratories than has hitherto been attained.

6. Possible Relations Between Repetition Rates and Articulation Tests

There seems no reason to doubt that articulation tests and other similar closely allied laboratory tests, carried out under the usual recognized conditions, are a useful measure of the inherent capability of the circuit tested to transmit speech. It is because only a comparatively small number of individuals can be used in such laboratory tests that the wide range of influence on service results exercised by actual subscribers must be excluded by substituting controlled talking and listening conditions.

In seeking for a relation between repetition rate and articulation percentage, the problem is therefore to know and allow for the subscribers' behaviour. Suppose that a particular circuit is considered which is used by a large number of subscribers: some will talk more quietly than others or at a greater distance from the transmitter; some will place the receiver less firmly on the ear, or they may have appreciable hearing deficiency. The same circuit will therefore be used with varying degrees of success by different persons. It is not difficult to imagine that some users will find the circuit satisfactory with low repetition rate, while others will experience a substantially higher repetition rate; the repetition rate recorded in service observations will be a mean value taken over a range of added "personal" impairments.

The personal impairment here referred to is the sum of the subjective and objective losses for which a particular subscriber is responsible by his manner of speaking and listening, and it is reckoned relative to the mean talking intensity, talking distance, and hearing acuity of all the subscribers.

When the same circuit is set up for articulation tests in the laboratory, a standardized talking intensity and talking distance are adopted. In order that the laboratory result may be obtained at the same received level as the speech on which repetition observations were made, the attenuation used in the laboratory test must generally be varied from the real circuit attenuation to allow for the difference between (*a*) the standardized talking level and distance, and (*b*) the average talking level and distance in service; i.e., an allowance must be made for the difference in the transmitter outputs in the articulation tests and in service, the latter being obtainable from service observations and dependent upon the circuit parameters and especially the sidetone.

From various points of view it has been proposed that articulation scores, obtained over substantially longer lines than are used in service, should be considered as significant for assessing transmission performance. Such a procedure leads to correlation being sought with repetition rate, not at the same received level, but with articulation observed at a received level lower by a constant number of decibels; this may be called "correlation with added loss."

This idea may be justified by the consideration that the members of an articulation team are usually selected individuals with good hearing, whereas surveys have shown that a certain deficiency of hearing is widely distributed throughout the telephone population. It is therefore reasonable to add attenuation in the articulation tests to represent the average deficiency of hearing of the population, or, if articulation has been studied as a function of circuit attenuation, correlation may be sought between repetition rate and articulation at a received level lower than that observed in service by a constant number of decibels.

Surveys have indicated[6] a standard deviation of hearing loss of at least 8 decibels, and it is suggested that the "added loss" required for correlation with repetition rate should be at least twice the standard deviation.

It must be mentioned, however, that insertion of added loss in the line is a very imperfect counterpart of hearing loss, since it attenuates the received speech without attenuating the room noise heard by the listener; more properly the added loss should be introduced in series with the telephone receiver, or the room noise should be appropriately reduced in intensity.

While it is undesirable to introduce unnecessary complications, the usefulness of establishing correlation between repetition rate and articulation is so great and the differences between service and laboratory conditions are so considerable that it may be worth while to study a composite function of articulation which takes these differences more explicitly into consideration.

If a series of articulation tests is made on a given circuit producing results illustrated by curve (1), Fig. 2(a), and then further tests are made under conditions of greater noise, the results will be of the kind shown by curve (2). A further series of tests on the circuit as first tested but with a low-pass filter inserted will give results of the kind shown by curve (3).

If the empirical law $N = 50 \log_{10} R/R_0$, which has been quoted as valid for these types of impairment, holds over a sufficient range, the corresponding repetition-rate curves will present the appearance of Fig. 2(b). In these circumstances, consistent correlation between repetition rate and articulation, either direct or with added loss, cannot be obtained over a range of attenuation values.

Since part or most of the subscribers' contribution to overall transmission performance is the introduction of a range of personal impairments over which repetition rate must be averaged, it is more likely that the desired correlation will be found if articulation is similarly averaged over a range of values of attenuation, especially when (as in Fig. 2) different kinds of impairment are

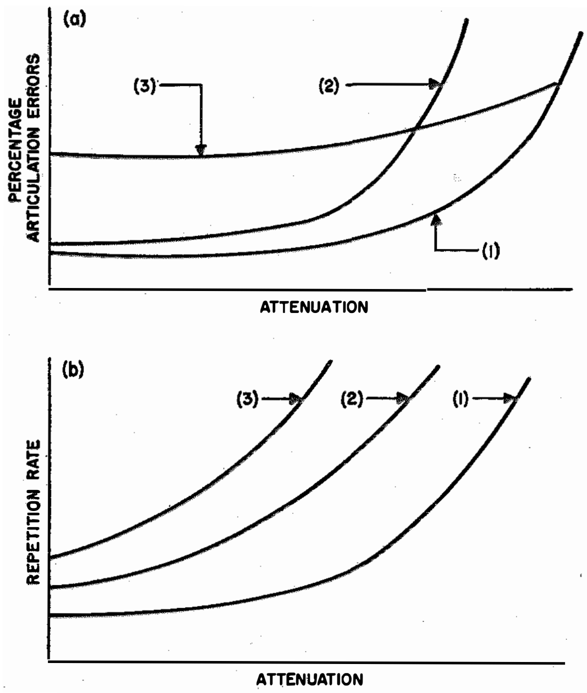

Fig. 2—Variation with attenuation of (a) articulation errors, (b) repetition rate on three different circuits.

considered. This leads to comparison of repetition rate with the weighted average of articulation taken over the range of personal impairments. The combination of this process with "added loss" is illustrated in Fig. 3, where the dotted curve representing the distribution of personal impairments may be taken as Gaussian with a standard deviation of about 10 decibels.*

*This value is obtained from a standard deviation of 6 decibels for observations of transmitter output (Appendix 14.5) combined with a standard deviation of 8 decibels already quoted for hearing loss.

The weighted value of articulation errors $\bar{A}$ is the value to be used for attempted correlation with repetition rate observed at the average received level x_1.

The special significance of this proposal is that it takes into consideration the transmission performance for all the subscribers, as it should do in accordance with the economic principles that have been stated, and is not confined to observations on lines of limiting performance.

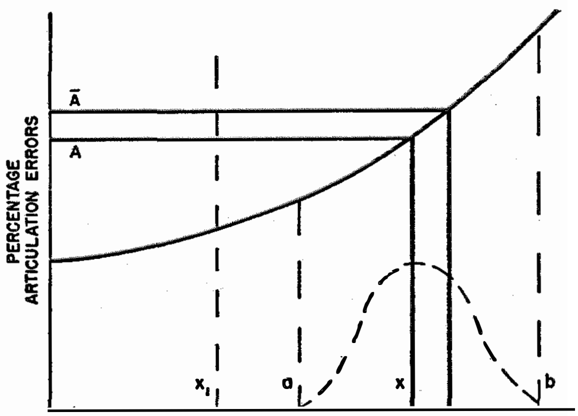

Fig. 3—Illustration of weighted average articulation errors.
$x - x_1$ = **Added loss.**
$b - a$ = **Range of personal impairments.**

There is still one respect in which articulation tests fail to represent service conditions. It is well established that there is a considerable loss of hearing in the upper frequencies with advancing age, and therefore articulation-testing teams should be selected to have age distribution representative of the telephone public, or preferably a range of networks should be used to reproduce the appropriate hearing losses at upper frequencies.

7. *Transmission-Service Rating by Articulation Tests*

In view of the long period that must elapse before European transmission-service ratings uniform with effective ratings can be applied, and the urgent need to introduce an improved system of rating at an early date because of the large amount of telephone development and reconstruction work resulting from the war, the Comité Consultatif International Téléphonique decided[7] in 1946 to attempt the development of a provisional system of transmission-service rating based upon articulation and received level. The proposal is an anticipation of the results of the study of correlation between repetition rate and articulation results, which has been described, because repetition rate does not enter into consideration, and no proof is required that the new ratings are intimately in accordance with the Comité Consultatif International Téléphonique fundamental declaration of the validity of repetition rate for measuring transmission quality in service. The introduction of new ratings on the proposed lines is justified by the consideration that such ratings must inevitably be nearer to the desired results than the volume ratings hitherto used.

The new ratings must, however, fulfil the practical requirement that impairments thus determined for parts of a circuit can be added together and give the same total as can be determined when the circuit is rated as a whole by the same method.

If a successful correlation can be achieved between repetition rates and articulation scores at related levels using one of the correlation techniques that has been described, the dictum "circuits with equal repetition rates are equal in effective transmission," will become "circuits which have equal articulation (reckoned according to the requirements of the successful correlation method) differ in transmission service rating only by the amount of any difference between the transmitter output in service and the transmitter output in the articulation tests."

In the present circumstances, it is not permissible to assume that such extensive correlation exists over a range of articulation values. A simpler and seemingly safer concept has accordingly been set up.

Instead of endeavouring to rate a circuit by its average performance for all subscribers, the proposal is to rate the circuit by its performance under the worst conditions to be encountered in reasonable service. This is equivalent to inspecting a manufactured product to an individual minimum requirement, in contrast to using quality control as a means of maintaining a given standard of production.

It has been seen in Section 6 that the nominal attenuation of any circuit in service is supplemented by a wide range of positive or negative personal impairment. The increase in attenuation due to the effects of noise, hearing deficiency, subscriber's voice level, and speaking distance may amount to 35 decibels or more in extreme cases; making conservative assumptions, 25 decibels may be taken as a limit exceeded by 2½ per cent of subscribers. If, therefore, under the controlled conditions of laboratory articulation tests, additional attenuation, which may be of the order of 25 decibels, is added to the circuit, articulation measurements should indicate the worst results to be experienced among 97½ per cent of subscribers. It remains to decide on the grade of service that should be encountered at this limiting condition and specify it as a fixed articulation percentage X. Then, any circuit that gives the articulation X is, after removal of an amount of attenuation equal to the added loss, a limit circuit to which an articulation rating of a convenient constant number of decibels can be assigned.

This rather cumbersome statement can be made clearer by an example. A commercial transmitting system can be defined as a battery feed circuit, a local line, and a telephone set considered in the transmitting direction; a similar system in the receiving sense is a commercial receiving system. If several different transmitting and receiving systems are connected in pairs through distortionless attenuation, curves of articulation against attenuation can be plotted as in Fig. 4. The transmitting and receiving systems represented by curves (a) and (b) may be connected through N_a decibels and N_b decibels, respectively, before reaching the limiting articulation X. Therefore the transmitting and receiving systems of (b) are together ($N_a - N_b$) decibels worse than the transmitting and receiving systems of (a).

It must be remembered that all circuits giving articulation X are to be regarded, after removal of the added loss, as having equal articulation equivalents, say N_0 decibels; therefore, if $(T + R)_a$ is written for the articulation equivalent of the (a) transmitting and receiving systems, with a similar notation for the (b) systems, it is possible to write

$$(T + R)_a + (N_a - L) = N_0,$$
$$(T + R)_b + (N_b - L) = N_0,$$

where L is the amount of the added loss.

The values of $(T + R)_a$, $(T + R)_b$ obtained from these equations are called articulation reference equivalents because of the method used to determine them; their magnitudes depend upon volume loss as well as distortion. The volume loss is that of the circuit under the controlled conditions of articulation testing and

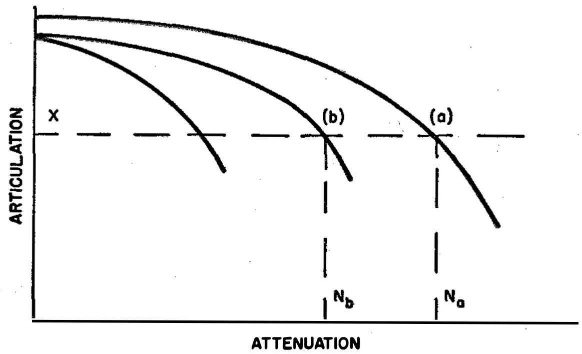

Fig. 4—Articulation equivalent. The circuit represented by (b) has an articulation equivalent $N_a - N_b$ relative to the circuit represented by (a).

therefore the articulation reference equivalents have to be adjusted by an amount equal to the difference between the transmitter output in the articulation tests and in service. When this has been done, the adjusted articulation reference equivalents become transmission-service ratings.

The fixed quantities involved in this plan are a limiting value of articulation X, a value of added loss L, and a convenient number N_0 for the limiting rating. It has already been indicated how L may be arrived at, and N_0 should be selected so that the numerical values representing new ratings will not differ more than is necessary from the old volume ratings for the same circuits.

The value to be assigned to X should be found by articulation tests on commercial types of circuit when L has been fixed. It is proposed, however, that X should be an intermediate quantity and not the formal specification of equal articulation equivalents, because, as is well known, articulation values are not absolute and not exactly reproducible. Instead of specifying X, it will be better to specify an exact physical circuit (articulation reference circuit) so adjusted as to give approximately the required articulation; the conditions of equality as illustrated in Fig. 4 will then be deemed to be satisfied when articulation on a tested circuit is equal to the articulation on the specified reference circuit.

8. *Articulation Reference System*

There has been in Paris for some 20 years a transmission system of known and specified performance, which has been the central standard for the volume ratings hitherto in use.[8] It is convenient to adapt this system for use as the European articulation reference system.

The modifications at present contemplated are the introduction of a 300–3400-cycle-per-second band-pass filter in the line circuit, and the use of a specified amount and kind of room noise at the receiving end. In addition, the particular adjustment of the circuit loss for which the articulation is X has to be specified when X has been determined.

It is not intended that this articulation reference system should be widely duplicated, but rather that the one system should be a means of co-ordinating in one laboratory the national articulation reference systems of all administrations.

Each administration will choose ordinary telephone instruments of its own type and will decide on typical connection circuits and typical (or limiting) local lines. Such an assembly of equipment constitutes a transmitting or receiving system to which transmitting and receiving articulation reference equivalents can be assigned by comparison with the articulation reference system in Paris.

For this purpose, a transmitting system to be tested replaces the transmitting portion of the articulation reference system. A receiving system similarly replaces the receiving portion of the reference system. One of the first requirements that will have to be fulfilled is that the sum of the articulation equivalents for the transmitting and receiving systems determined separately shall be equal to the articulation equivalent determined when both are simultaneously substituted for the reference terminal systems.

When a national articulation reference system has been thus calibrated, the administration to which it belongs will be able to set it up with the appropriate amount of attenuation to reproduce the reference condition X, and other arrangements of local line and connection circuit or other sets can be rated by comparison with the national articulation reference system in the same manner as this itself was rated in Paris.

Proceeding on these lines, substituting any equipment to be rated for the corresponding part in the national articulation reference system and readjusting the attenuation until the articulation is the same over the test system as over the unchanged reference system, it will be possible to build up a complete system of articulation reference equivalents for different combinations of sets, local lines, connection circuits, and inter-office trunks.

Further steps are necessary before these equivalents can be described as transmission-service ratings, which is the form in which they are to be used. It is necessary to determine by associated laboratory and service observations, (*a*) the loudness of sidetone for various combinations of local line and inter-office trunk, (*b*) the dependence of the transmitter output in service upon the loudness of sidetone, and (*c*) the average room noise in service and its influence on transmitter output and received quality if it is different from the room noise used with the reference articulation system.

With this information, corrections can be made to the articulation equivalents to allow for differences between transmitter outputs in service and in the articulation tests, and for differences, if any, between the average effects of room noise at the listening end in service and in the articulation tests. The articulation equivalents thus corrected become transmission-service ratings and can be used for planning purposes provided they approximately fulfil the requirement that addition of the ratings for all the parts of a circuit agrees with the rating determined for each circuit as a whole.

In carrying out such a programme as this there is, of course, much scope for interpolation of results by calculation of relative values of articulation, attenuation, and sidetone; it is to be expected that several subsidiary studies will be made in order to perfect or verify such methods. It may, for example, prove possible to calculate the differences in volume loss, distortion loss, and sidetone attenuation between the national articulation reference circuit and other commercial circuits using the same apparatus, so long as the differences are not too great. It will be necessary, however, in every case to establish the relation between sidetone intensity and transmitter output under service conditions.

8.1 Line Noise

So far, no consideration has been given to line noise. As line noise interferes with received speech by masking the weaker components, it is akin to room noise. The total noise interfering with speech is the resultant of the line noise and the room noise received by leakage and by sidetone; if the line noise and room noise components differ by 5 decibels or more the resultant is practically equal to the greater. It will be necessary, therefore, to introduce corrections for line noise when it is of the same order as, or greater than, the room noise entering the telephone ear. From the nature of the case, it is apparent that the total noise must be ascertained for the purpose of assigning noise impairment and that line-noise impairment cannot be separately assigned as an independent impairment.

Two courses are possible: either a fixed value of line noise must be used in the articulation reference system as part of the reference conditions, or a separate study of line-noise impairments must be made by each administration as part of the programme of establishing transmission-service ratings.

The first alternative has not been adopted, primarily because it was desired to make the Comité Consultatif International Téléphonique laboratory tests as simple as possible. The second alternative has the advantage that each administration will be able to discover the importance of line noise in its own system and direct its efforts towards the reduction either of sidetone or of line noise according to the indications of the results obtained.

In order that all interfering noise may be accounted for, line noise must be understood to include induced noise of all kinds, switching noise, and electrically transmitted noise from the far end.

9. *Application of Transmission-Service Rating*

The impairments that must be taken into consideration in determining the transmission-service rating of a circuit are of three principal types:

A. Those directly affecting received level, namely the overall attenuation (or reference equivalent) and the average transmitter output determined by the subscriber's reaction to sidetone and room noise.

B. Those affecting the useful received level by masking, namely line noise and room noise (direct and via sidetone).

C. Distortion, namely non-linear and amplitude distortion and frequency distortion of apparatus and lines including low-pass filters.

The total effect of these impairments when international and national standards of transmission were fixed on the reference-equivalent basis was considerably greater than it is to-day, and it is because continued planning on the old basis would fail to capitalize these improvements that the new conception of rating has developed.

For example, 25 years ago quite a large number of subscribers' sets were not designed to reduce sidetone as much as possible, the transmitter and receiver characteristics were less satisfactory than is now possible, and many long-distance lines had a cut-off about 2600 cycles per second or lower compared with 3000 cycles per second or higher to-day.

The reduction of impairments attributable to these improvements of the last quarter century is not a fixed amount applicable to all cases, but as an illustration the following figures are typical:

Improvement	*Reduction of Impairment in Decibels*
Anti-sidetone circuit:	
Louder speaking by subscriber[2, 5]	4.0
Reduced effect of room noise[2, 5]	2.0
Better transmitter and receiver frequency characteristics	5.0
Cut-off increased from 2600 to 3000 cycles per second	2.0
Total	13.0

None of these contributions to the transmission performance of the circuit would be taken into consideration if circuit rating continued on the basis of reference equivalents (volume rating). The subscriber would of course benefit from the improvements introduced, but sound economic planning demands that improvements should not automatically and accidentally go to the subscriber as transmission-service improvement but should be properly utilized to give the subscriber the benefit of both cost reduction and progressive improvement in transmission service.

Suppose, then, that economic study indicates that the 13-decibel reduction of impairment ought to be divided as 7.0 decibels improvement in transmission service and 6.0 decibels reduction of cost. The problem is how to design circuits for modern instruments with 6 decibels more attenuation than was allowed for the old instruments, 25 years ago.

The most economical layout of an exchange area network consistent with transmission requirements is obtained when the smallest practicable gauge of cable is used for all lines up to the length at which the permissible transmission loss for the area is reached; longer lines use the the next larger gauge of wire up to its transmission limit and still longer lines use a still larger gauge. In practice many other considerations interfere with this simple plan,[16] and local lines built up with two or more different cable gauges are common. In addition, there may be limitations imposed on the maximum line resistance by signalling requirements.

It is evident that in every exchange area there are a number of lines that have less than the maximum permitted loss. Consequently a revaluation of the permitted loss on the basis of transmission performance, allowing an increase of attenuation loss in the local lines, will permit cable plant economy to be effected only in respect of those lines which on the new assessment are transferred to the zone covered by a smaller gauge of cable.

In a particular case where the allowed transmitting loss for the area is 10 decibels on the volume basis, an increase in the permitted loss to 16 decibels (equivalent to 10 decibels on the new basis) would alter the maximum allowable length of each gauge of conductor as in Table 1.

Corresponding data[10] relating to the instruments used in this country show a similar tendency to increased resistance of subscriber's lines, and in such cases signalling limits may prevent the full realization of transmission gain as cost reduction.

Part or all of the additional loss may, however, be taken up in the inter-office lines, more particularly the loaded lines, because these, having practically flat frequency characterisitcs, have substantially the same rating on the performance basis as on the volume basis. On the other hand, non-loaded lines will on the performance basis (loss at 1600 cycles per second) be assigned worse ratings than on the former basis of loss at 800 cycles per second, and will therefore absorb some of the gain accruing from the lower losses assigned to local lines. In future, loaded lines can be run with lighter gauges of cable. If the local network and junction lines are in cost equilibrium, it is to be expected that the economies to be made by the application of transmission-service rating should be shared between them, but it is also to be expected that the cost-balance conditions will be changed because of the appreciation in performance rating of loaded lines.

The application of transmission-service rating has been studied in this country for some years; the results have been related to a particular system which will no doubt become what has been called in this paper a national articulation reference system.

The methods used and some of the conclusions reached have been recently published[6, 10] and need not be reviewed here. In summary, it appears that for fully exploiting economies in long-term planning, which should result from the introduction of performance rating, it is desirable to do three things:

A. Eliminate instruments with poor performance, which would have disappeared by now, but for the war.

B. Introduce signalling relays capable of working through lines of higher resistance.

C. Develop practical methods of jointing cables of smaller gauge than 6½ pounds.

TABLE 1

	Volume Rating = 10 db		Transmission-Service Rating = 10 db	
Gauge Lb/Mile	Max. Length Miles	Max. Resistance Ohms	Max. Length Miles	Max. Resistance Ohms
20	5.4	475	7.6	670
10	3.6	635	5.4	950
6½	2.6	707	4.0	1090
4	1.6	700	2.8	1230

In other European countries, steps have not yet been taken towards the practical introduction of performance rating; in new or reconstructed areas there will be good opportunities for realizing economy with the new method of rating at an earlier date than in old established areas, but in general the introduction of the new rating method cannot be expected to do more than prepare the way for economies which will mature in 10 to 15 years.

In considering the economic gain to be derived ultimately by the application of transmission-service rating, it is necessary to have a clear conception of the relation between the two main types of impairment, namely distortion impairments, and attenuation or equivalent impairments, which in sum may be called gross attenuation. When circuits are rated by transmission performance, reduction of distortion can be offset by increase of permitted attenuation, but whereas increase of attenuation always implies reduction in cost, reduction of distortion does not necessarily increase the cost. Hence, as distortion is reduced, the permitted (volume) transmission loss tends to be increased; as there is a practical limit to volume loss, distortion impairments (i.e., the decibel equivalents of given distortions) become smaller as the volume-loss limit is approached. The economic gain to be secured by the introduction of telephone instruments with less distortion is therefore smaller in systems designed for a relatively high toll terminal loss (volume basis) than in those planned for a lower loss.

10. *Other Methods of Assessing Circuits*

Space does not permit discussion of the various laboratory methods that are used for estimating the transmission quality of communication circuits; most of these have been studied with a view to their possible use to measure transmission performance.

Apart from various forms of articulation test, special interest attaches to "immediate-appreciation tests" introduced by W. H. Grinsted[11, 12] in 1937. In this test, listeners are merely asked to report whether they have clearly and immediately grasped the meaning of sentences read to them; herein seems to be contained the essential element that determines whether repetitions will be required in service. The test has many advantages especially as regards simplicity, but there are concomitant disadvantages in greater difficulty of standardizing the procedure and of unifying results.

Amongst other contributions[14] to the subject of quality rating, mention can be made only of those not published in English. K. Braun[14] has deduced, on the assumption that repetition rate is intimately related to sentence articulation, that small repetition rates are linearly related to sound or sentence articulation. He then defines a quality loss as $\Delta A/A$, a fractional loss in sound articulation which he finds can be related to a real or equivalent attenuation value b (nepers) by a formula of the type $\Delta A/A = \exp K(b - p)$, where K is a constant, b is attenuation and p is a constant for the circuit, depending upon the location along the attenuation axis of the falling part of the articulation curve.

On these foundations it is shown that quality losses can be combined as exponential functions of the attenuations, a conclusion that is useful mainly for indicating that the resultant quality loss in a given case is very largely determined by the factor individually responsible for the greatest loss.

Braun concludes that variations of line attenuation are so far from being a dominating variation in transmission quality that it is questionable whether it is justifiable to place such close limits on line attenuation as is usual.

Applying Braun's conclusion in another way it may be concluded, as already remarked, that circuits having high attenuation cannot be substantially improved in performance by correction of distortion.

A rather different approach to the rating of circuits was described in 1942 by Strecker and Von Susani,[15] who used judgment tests to determine the most favourable conditions for communication circuits. Two teams, each consisting of five persons, were used, and each listener was asked to adjust the line attenuation of a circuit under test (*a*) to the best value, (*b*) to give the loudest bearable reception, and (*c*) to give the quietest reception that was adequate without causing effort to the listener. The results of the tests were presented as statistical distribution curves, from which, by a sweeping generalization, it was concluded that the best value for the reference equivalent of a telephone circuit was one neper and that two nepers should not be exceeded. (The maximum value for international calls is fixed at present at 4.6 nepers.) The authors then proceeded to study the effect of noise and sidetone on the judgments of quietest acceptable reception and found that, by suitably choosing the reference condition in each case, the impairments due to room noise, line noise, or sidetone could be approximately expressed by a common curve corresponding to Table 2, which has been compiled from the curves in the original paper.

TABLE 2

Room Noise,* Sidetone Level† or Line Noise‡ in Phons or Decibels	Impairment in Decibels
−20	−0.9
−10	−0.9
0	0
15	8.7
23	17.4
30	26.1

* Room noise in phons relative to 40 phons.

† Sidetone level in decibels relative to a reference equivalent of 2 nepers (17.4 decibels).

‡ Line noise in decibels relative to 1.5 millivolts.

Such a generalization as this is not unreasonable since the impairments concerned are all due to noise interference.

An interesting conclusion reached by Strecker and Von Susani is that improvement of the frequency characteristic of a telephone set by eliminating resonant peaks does not, other things being equal, appreciably change the maximum permitted attenuation; it does, however, reduce the tolerated minimum attenuation.

One other suggestion that has been put forward must be mentioned: in 1938, the German administration presented results of simultaneous observations of repetition rate and average duration of call for varying amounts of circuit attenuation; they found that as the attenuation increased the repetition rate rose and the average duration of call decreased.

The author of the present paper made similar observations on factory calls in service and found a very regular reduction of call duration with decreasing sidetone. The dependence of call duration upon circuit conditions is, if it exists, important for traffic studies, and because it is easy to observe it might be of some assistance for transmission-service rating. The reality of the effect has yet to be established, the author's own results requiring further confirmation for the following reason, which is recorded to illustrate the type of pitfall in the path of those who make service observations.

The calls observed were trapped at random and put through the experimental equipment where the sidetone was adjusted; the subscriber therefore had no opportunity of becoming familiar with the abnormal condition presented, but on the contrary noticed when his call had been trapped that his set was working abnormally. It is thought that the observed reduction of call duration might have been due to a high proportion of calls in which the subscriber considered he had "a bad line" and either broke down the call to dial again or shortened the call because he was too much aware of its abnormality. This suspicion is based upon the fact that observations at the lowest possible level of sidetone had had to be discontinued because of subscribers' complaints.

11. Conclusion

The facts and circumstances relating to the solution of a problem, which is at present in a fluid state, have been presented. In the United States, effective ratings have been in use for 15 years or more; the keystone of the system there used is the dictum that circuits which give rise to equal repetition rate with the same group of subscribers are equal in effective rating.

In Europe, the keystone has been cut to the American pattern but the arch has not been built; the principle has been accepted without the practice. The reason for this state of affairs is the variety of conditions to be found in the different countries, making it necessary for each country to carry out a very extensive and difficult programme of tests; in each country independent data would have to be collected with very little mutual assistance from the data of another country, and finally the co-ordination of all the data into a homogeneous international system would be a formidable task, especially considering the difficulty of centralizing comparative tests under a single authority such as the Comité Consultatif International Téléphonique laboratory.

The American Telephone and Telegraph Company are in the happy position of the designers of a new car who have been able to gauge the public requirements by extensive trial sales to their employees of cars presenting many different features.

Other car designers must proceed without so much assurance of success, but they are well aware that the consumer public will be their judge in the long run and that the sales index is the measure of their success in service. How then will the designer proceed? He will estimate without exact knowledge what the customer requires, and how the customer will use his machine; he will allow margins or factors of safety in the components that may receive rough usage; he will consider the sales value of different features in relation to the cost, and, in general, his design tools will be laboratory, engineering, and cost data.

The planner of telephone networks must proceed on analogous lines; his transmission-service ratings must be based on laboratory data, illuminated by the knowledge of those factors that repetition-rate observations have shown to be important, and reasonable margins or factors of safety must be allowed in recognition of the imperfection of the methods used. A procedure such as this cannot be regarded as the final development of planning methods, because it does not give full recognition to the place awarded by the world's technical telephone conscience to repetition rate as the best known measure of transmission service.

More research is needed; to repeat the fundamental research in each country presents difficulties and might well be a misdirection of research effort. Effort directed towards elucidating the connections between repetition rate, objective design factors, and subscriber behaviour may add more to basic knowledge of transmission service than can be acquired by repeating the initial research in different countries each with its appropriate objective circuit elements. The former course aims at analysis of a fundamental nature, the latter at the piling up of data which would be difficult to co-ordinate and which in view of their empirical nature would have to be redetermined from time to time.

Nevertheless, the observation of repetition rate is so far the last word in measuring transmission quality in service, but, like other primary standards, recourse to it will be less frequent as experience and knowledge perfect the appropriate laboratory techniques and increase confidence in the results they yield. It is, however, impossible to avoid the conclusion that repetition-rate observations will have to be made on a certain scale in several countries if transmission-service rating is to be established on firm foundations.

Finally, the author wishes to emphasize the view that, in harmony with the economic principles stated at the beginning of the paper, it is the quality of the service given to all the subscribers that should be measured and controlled in the ultimate plan; designing the transmission network for the worst condition and evaluating performance in this worst condition should be regarded as a provisional step. It is not unknown for a telephone instrument with a peaky characteristic to give better performance through high attenuation than an instrument with a smoother characteristic which is superior on shorter circuits. In general, it is doubtful whether transmission-service rating will show advantages over volume rating where the system has been designed for the greatest possible volume loss; it is only when a good grade of service in terms of volume rating is given that the economic value of improved quality can become apparent. Extending the argument, transmission-service ratings based on limiting transmission conditions are likely to show smaller advantages than those which assess the average service given to all the subscribers.

The values of transmission-service ratings will always be, not only relative to, but dependent upon the reference conditions.

12. Acknowledgments

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14. Appendices

14.1 Relation Between Impairments and Repetition Rate

Let x, y, z.... be circuit parameters which define the transmission properties of a circuit. Let R stand for repetition rate, which by hypothesis is a function of the circuit parameters.

$$R = F(x,y,z\ldots.). \qquad (1)$$

Proceeding by variation of one variable at a time, it is possible to find experimentally

$$R_x = F(x,y_0,z_0\ldots.) = F_x(x), \qquad (2)$$
$$R_y = F(x_0,y,z_0\ldots.) = F_y(y), \qquad (3)$$
$$R_z = F(x_0,y_0,z\ldots.) = F_z(z), \qquad (4)$$

where x, y, z are variable and measured from fixed reference values x_0, y_0, z_0.

If x stands for circuit attenuation, (2) represents a graph of repetition rate against attenuation, which may be used to evaluate as an equivalent attenuation the impairment due to variation of any other parameter from its reference value, e.g., the impairment for the value y is the value of x in (2) for which $R_x = R_y$, or if F_x^{-1} is the inverse function of F_x so that $F_x^{-1}(R) = x$, the impairments I_x, I_y, I_z due to the values x, y, z are in decibels:

$$\left.\begin{aligned} I_x &= x, \text{ by definition} \\ I_y &= F_x^{-1}(R_y) \\ I_z &= F_x^{-1}(R_z), \end{aligned}\right\} \qquad (5)$$

which is a formal statement that I_y, for example, is the number of attenuation units by which x_0 must be changed to produce the same repetition rate as is observed when y_0 is changed to y.

In order that the impairments thus obtained, in decibels, may be useful, they must possess additive properties. If x_0, y_0, z_0 are changed to x, y, z in one circuit so that

$$R_{xyz} = F(x,y,z), \qquad (6)$$

then it is necessary that the relation

$$F_{xyz} = F_x(x + I_y + I_z) \qquad (7)$$

shall be satisfied.

When this relation holds $(x + I_y + I_z)$ is the impairment due to x, y, z relative to the reference conditions.

14.2 Distortion Parameter

In Section 3.1, it has been noted that the circuit parameters used to describe the physical characteristics of a circuit should be so defined that they are independent of each other. No difficulty occurs in defining and measuring the first four parameters listed in Section 3.2, but distortion is in a different class. It is necessary to include in this one parameter the effects of amplitude and non-linear distortion, for which no appropriate objective measurements have yet been found, as well as frequency distortion, which presents difficulties in objective measurement, and which when so measured is not expressed as a significant single figure.

The natural course is to seek a statement of distortion in terms of articulation, but articulation is considerably affected by received level and noise so that it requires a special definition to secure independence of the other parameters.

Such a definition can be made (at least in principle) if the distortion of a circuit is defined as the articulation measured when all the other parameters of the circuit have fixed reference values and the speaking level is standardized at the level appropriate to such a circuit. As a consequence of this definition, circuits which give the same articulation under these special conditions have the same distortion factors.[2]

Let D be the value of the distortion parameter for a circuit, and let D_0 be the reference value; let x and x_0 stand for variable and reference values of attenuation with the notation of Section 14.1, omitting explicit reference to parameters other than x and D, which are to be held at their reference values

$$R_d = F(x_0, D). \tag{8}$$

The impairment equivalent to D is

$$I_d = F_x^{-1}(R_d) \tag{9}$$

or $I_d = x$, when $F(x, D_0) = F(x_0, D)$.

This provides the data for fixing the impairments to be ascribed to different values of distortion studied by repetition-rate counts.

14.3 Calibration of a National Articulation Reference System Under the Interim Plan

When the master articulation reference system has been fully defined, it will consist of a transmitting system, a fixed distortionless line with specified attenuation (with filter) and a receiving system. At the transmitting end, voice level and talking distance will be specified; at the receiving end, room noise will be specified.

In order to retain appropriate numerical continuity with reference equivalents (volume ratings) used in the past, numerical values of articulation reference equivalent (not necessarily zero) will be attributed to the transmitting and receiving ends of the articulation reference system, and an overall articulation equivalent in decibels will be assigned to the whole system.*

Thus there will be values of reference fixed as follows:

T_0 = convenient figure attributed to the transmitting system of the European articulation reference system and chosen so that transmitting-service ratings of commercial systems are comparable in magnitude with their reference equivalents.

R_0 = convenient figure attributed to the receiving system of the European articulation reference system chosen on the same grounds as T_0 *mutatis mutandis*.

N_0 = convenient figure for the articulation equivalent of the European articulation reference system such that transmission-service ratings of existing systems are comparable in magnitude with reference equivalents.

Careful choice of references as described seems absolutely essential especially during the period (necessarily rather long) in which the old system of ratings is in use simultaneously with the new system.

There will also be fixed a certain amount of attenuation for the line of the European articulation reference system; this will be denoted by N_k,

* It is important to decide which particular transmission system shall have the same numerical value of transmission-service rating as its volume rating or reference equivalent.

and, since the basis of articulation equivalents is the "added loss" method, it will include an amount of attenuation L for this loss. Then,

$$T_0 + (N_k - L) + R_0 = N_0. \quad (10)$$

The set-up for the calibration of a national transmitting system is shown schematically in Fig. 5.

The value of $(N'_N - L)$ is to be determined by trial so that the articulation is the same over the two circuits. Then the national articulation reference transmitting system is worse than the European articulation reference transmitting system by $(N_k - N'_N)$ decibels, and is to be assigned the articulation equivalent

$$T_N = T_0 + N_k - N'_N. \quad (11)$$

The arrangements for calibrating a national receiving system and for making the overall check are shown in Figs. 6 and 7, it being understood that N''_N and N'''_N, respectively, are adjusted until the articulation is the same on the two systems compared.

The articulation equivalent of the national articulation reference receiving

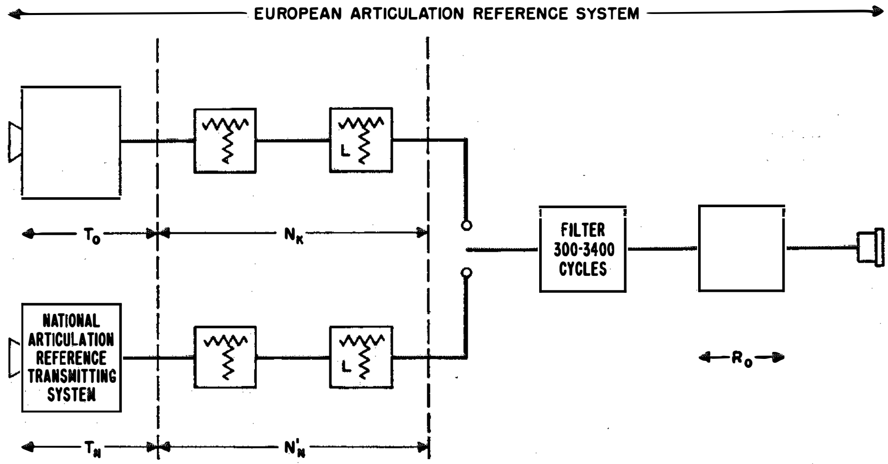

Fig. 5—Calibration of a national articulation reference transmitting system.

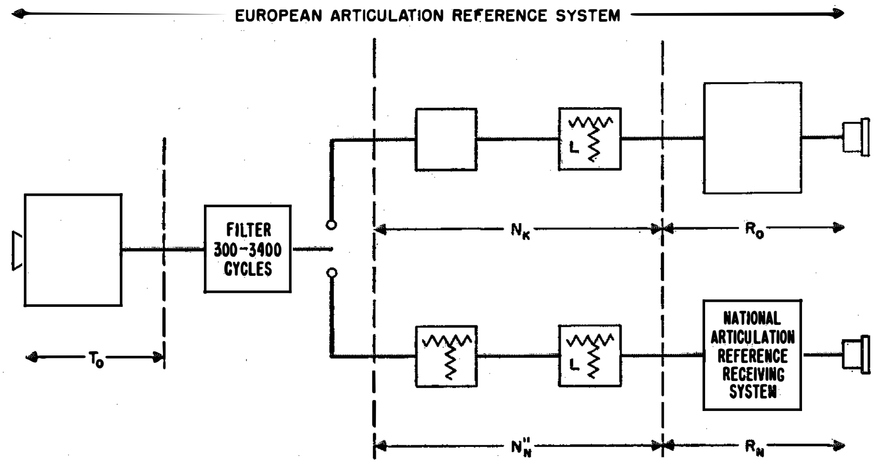

Fig. 6—Calibration of a national articulation reference receiving system.

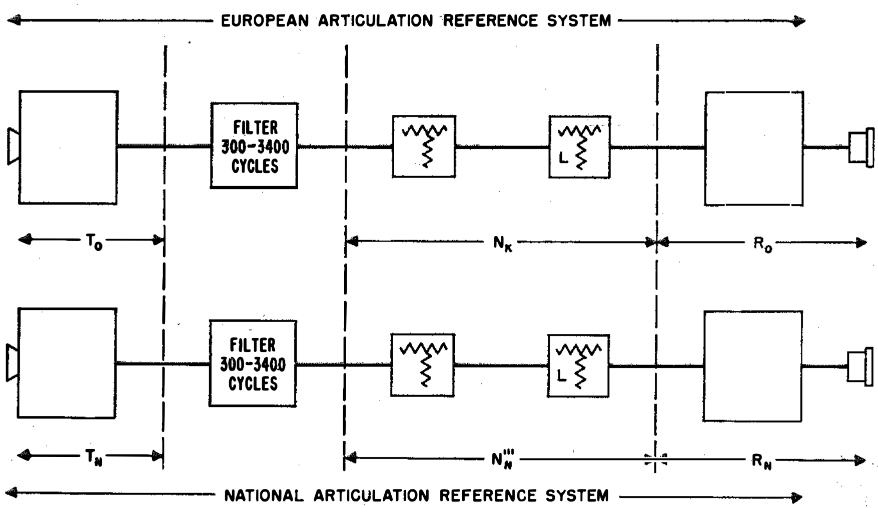

Fig. 7—Adjustment of complete national articulation reference system.

system is

$$R_N = R_0 + N_k - N_N''. \qquad (12)$$

The articulation equivalent of the national articulation reference system (combined transmitting and receiving system) is

$$T_N + R_N = N_0 - (N_N''' - L) \qquad (13)$$

or, by direct addition of (11) and (12),

$$T_N + R_N = T_0 + R_0 + 2N_k - N_N' - N_N''. \qquad (14)$$

From (13) and (14), substituting for N_0 from (10),

$$N_k = N_N' + N_N'' - N_N''', \qquad (15)$$

which condition must be satisfied if addition of the articulation reference equivalents of transmitting and receiving systems is to be valid.

The fixed amount of attenuation to be used as the line of the national articulation reference system when set up for use is, of course, N_N'''.

If (15) is not satisfied, better agreement must be sought by using a different reference adjustment of the articulation reference system, or a more complicated criterion of equality such as equal average articulation over a range of attenuations with or without weightings.

14.4 Determination of Transmission-Service Ratings under the Interim Plan

When a national articulation reference system has been calibrated in accordance with Section 14.3, it can be used to evaluate the articulation reference equivalents of other transmitting and receiving systems, in which different lengths or gauges of local lines are used. For this purpose the national system is set up and the system to be tested is compared with it in the same way as the national system was compared with the European articulation reference system. The appropriate values T_N and R_N are, of course, used instead of the articulation equivalents T_0 and R_0 of the European reference system.

For purely national purposes the amount of work to be done will be reduced by two-thirds if planning is done on the $T + R$ basis, i.e., the sum of the transmitting and receiving impairments is determined without evaluating them separately. In this case, the requirement of (15) will not arise, though it should nevertheless be met. For this procedure the only tests required are those analogous to Fig. 7. For international purposes, when the sets at the two ends are different, the necessity to determine T_N and R_N separately remains.

When the articulation equivalents have been determined for the local lines and gauges that are of interest, they have to be adjusted to transmission-service ratings by taking into consideration the differences between the articulation testing conditions and average service conditions.

The main considerations are sidetone and transmitter output. The national articulation reference system has necessarily some particular amount of sidetone which can be taken as the national reference sidetone. As the local line is varied, or the junction line-impedance is varied, the sidetone will change. It is necessary to establish by voice test or calculation, or by a mixture of both, how the attenuation of the sidetone path for speech changes from the reference sidetone value as the local line and trunk change. It is also necessary to determine, preferably by observations in service, the actual voice intensity at the transmitter for different amounts of sidetone attenuation, so that a curve can be drawn for voice level at the transmitter against sidetone attenuation relative to reference sidetone; the origin of the voice-level ordinates should be the value used in the national reference system under the conditions of articulation testing.

When this curve has been constructed, the transmitting articulation equivalent for any particular local line must be adjusted by the amount of the ordinate of the curve corresponding to the relative sidetone attenuation for that particular local line. When this has been done, the result becomes a transmitting-service rating.

Receiving articulation equivalents obtained by the procedure described will include the impairment due to reference room noise acting through the direct and sidetone paths, for the value of sidetone appropriate to a 600-ohm inter-office trunk. For other kinds of trunk and other values of room noise, the sidetone and the room-noise impairment will be different and appropriate corrections will be required.

When necessary, additional impairments due to line noise must be taken into consideration.

To complete the system of transmission-service ratings, it is necessary to have ratings for the different types of junction line.

Ratings can be found by substitution in the national articulation reference system, but the changes in reflection coefficients thus introduced make this a matter of some difficulty; however, studies already made indicate that the impairment per mile of junction can be evaluated as the attenuation per mile measured at a particular frequency in the neighbourhood of 1600 cycles per second. Reflection and interaction impairments can also be determined in theory by tests in the articulation reference system, but it is probably a sufficiently good approximation to treat these as purely volume losses, their values generally being of the order 1–3 decibels.

The effect of the junction impedance on sidetone, and hence on talking level and room-noise impairment, cannot be neglected, and must be taken into consideration as described above.

14.5 Field Data Relevant to Transmission-Service Rating

14.5.1 Variation of Transmitter Output for a Large Number of Subscribers

A series of observations was made in Bucharest on lines connected to public call boxes (see Table 3). Volume indicators were connected at the exchange end of the lines and additional lengths of cable were connected as required.

Another series of observations (see Table 4) was made on calls at Standard Telephones and Cables, Limited, at New Southgate, where the local lines were not altered but a range of variation of sidetone was secured by alteration of transmitter current and terminal impedance, with compensating amplification to avoid alteration of the transmission equivalent.

About 600 calls were observed for each condition.

Tables 3 and 4 both show that the spread of transmitter outputs or personal impairments at the transmitting end is not constant but tends to diminish, in the first case as the local line lengthens, in the second case as sidetone diminishes. As lengthening of the local line causes reduction of transmitter current and sidetone, the direct controlling cause may be the amount of sidetone

14.5.2 Speech Intensity at the Transmitter in Relation to Sidetone

The second series of observations, shown in Table 4, was made for the purpose of relating sidetone to speech intensity at the transmitter. Average readings of the volume indicator for

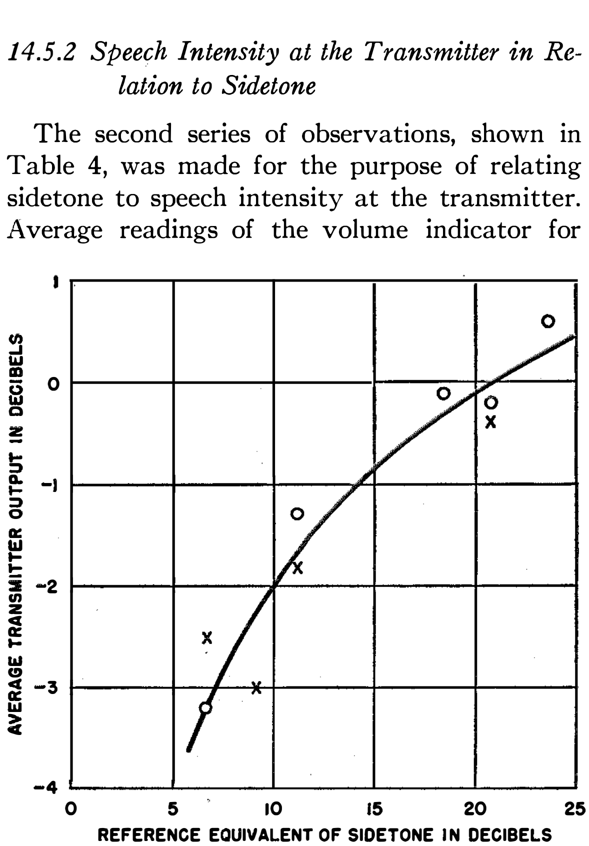

Fig. 8—Dependence of voice intensity upon sidetone.

TABLE 3

Added Local Line, 4-Pound Cable in Kilometers	Number of Observations	Standard Deviation of Volume-Indicator Readings in Decibels	Skewness
0	4000	7.96	−0.384
1	7200	7.56	−0.236
2	3200	7.45	−0.157
4	8000	6.77	−0.146
5	8000	6.47	−0.16

TABLE 4

Approximate Reference Equivalent of Sidetone in Decibels	Standard Deviation of Volume-Indicator Readings in Decibels	Skewness	Type of Connection
6.6	6.70	−0.28	Tie Line
6.6	5.56	−0.18	Internal
9.1	5.80	−0.05	Tie Line
11.2	5.16	+0.14	Tie Line
11.2	5.12	−0.29	Internal
18.5	4.56	+0.02	Internal
20.7	5.60	+0.06	Tie Line
20.7	4.66	−0.08	Internal
23.8	4.35	−0.13	Internal

each line condition were compared with the reading obtained for a standard speech intensity at a fixed distance. The results are plotted in Fig. 8.

It should be noted that the results in this Section are for the purpose of illustration, particularly of the range and variation in range of personal impairment. The telephone sets used were not the standard sets used in Great Britain.

14.6 Abbreviations, Terms, and Definitions

A. C.C.I.F.—the consulting international organization concerned with all aspects of international telephony.

B. A.T.&T.—the American Telephone and Telegraph Company, incorporating the Bell Telephone Laboratories.

C. A.E.N. in C.C.I.F. documents—see *H*.

D. Transmission performance—a general term for the degree of satisfaction with which a circuit fulfils its transmission function in service.

E. Effective transmission—transmission performance when considered in connection with repetition rate as the criterion.

F. Effective transmission rating—a numerical assessment (in decibels) of effective transmission, derived through the application of the criterion that circuits with equal repetition rate have equal effective transmission.

G. Transmission-service rating—a numerical assessment of transmission performance derived in any way understood or described.

(In earlier publications transmission service (rating) has been called effective transmission (rating); it has been decided by the Comité Consultatif International Téléphonique (in 1946) that the term "effective transmission" should be reserved for use as defined in *E* and *F*.)

H. Articulation reference equivalent (French A.E.N.—*affaiblissement équivalent de la point de vue de la netteté*) of a transmitting or receiving system or both together, is the difference between the attenuation of the line of the European or a national reference system, and the line of the system tested when both systems have the same specified articulation *X*.

(A distinction has been arbitrarily made between "equivalent" and "rating," the former is used in connection with laboratory articulation tests and the latter for final values to be used in planning as representative of service results.)

I. European articulation reference system—The European reference system modified by the inclusion of a 300–3400-cycle-per-second filter, and with room noise at the receiving end and a fixed specified attenuation in the line; used to determine the articulation reference equivalents of national articulation reference systems.

J. National articulation reference systems—commercial transmitting and receiving systems completed by a line containing a 300–3400-cycle-per-second cut-off filter and distortionless attenuation of such an amount that the articulation of the system is the same as that of the European articulation reference system.

K. Articulation reference value (*X* in the text)—the particular articulation value observed on the European articulation reference system or on a national articulation reference system; see *H*.

L. Transmitter output—used in the paper to express relative values of the subscriber's speech intensity at the transmitter, depending on his speaking intensity and the distance between his mouth and the transmitter; where necessary it is to be understood that corrections have been applied to eliminate the influence on the actual transmitter output of feeding current and line loss.

(Under service conditions "transmitter output" can be observed; the subscriber's voice intensity and speaking distance cannot be observed.)

M. Repetition rate—in principle, the average number of repetitions of words or phrases asked for in 100 seconds of actual conversation time; it is calculated from the total number of repetitions and the total time observed over a large number of calls. A more precise definition includes the detailed instruction given to observers as to what is a repetition and how the conversations are timed. Adverse comments are similarly counted per 100 seconds of conversation.

Position-Finding by Radio: First Thoughts on the Classification of Systems*

By C. E. STRONG

Standard Telephones and Cables, Limited, London, England

I WISH, first, to thank you very much indeed for the honour you have done me in electing me as your Chairman for this coming session. It is a great privilege to be the Chairman of the Radio Section, and certainly I shall be proud and happy to serve the Section to the best of my ability.

During the last two sessions, under the able guidance of the retiring Chairman, Professor Willis Jackson, and his predecessor, Mr. Mumford, we completed the task of committing to record the great store of new knowledge and technique which was an outcome of the war effort. That record is now in the pages of the *Journal;* it is not only a record of great scientific and engineering achievements, but also, we may well say, a monument to the skill and perseverance of many workers in the radio field.

In particular, we see how outstanding were the contributions made by the physicists, the mathematicians, and the chemists, who, coming in newly from other fields of work, applied themselves to our subject during the war. They brought in a fresh outlook and the latest scientific knowledge, and certainly also they made their mark in judgment and leadership. Being myself an engineer, it is not inappropriate for me, I think, to speak of the vitalizing effect of the new blood they introduced and to pay a high tribute to their valuable and important work.

The most spectacular achievements were in the fields of radar and radio aids to navigation, or, perhaps I should say more generally, in the whole art of position determination by radio. Here the widest new vistas were opened up and the most alluring prospects for the future were revealed. It remains to us now to apply this new knowledge to the needs of the day, and certainly it is a task to inspire interest and to fire enthusiasm.

But first, I believe that, to facilitate the orderly application of this knowledge, there is a need for us to rearrange our material and perhaps to overhaul our terminology. The art has moved so fast that we are almost overwhelmed by the flood of systems, and there has been little chance to sort them out in an orderly fashion and to see them in their proper relationships one to another. Some of the newer methods appear more fundamental than those with which we have previously been familiar, and that would seem to require some readjustment of our past ideas.

Now, however, with the completion of the record of war-time activity, to which I have just referred, we have the opportunity to stand back and survey the entire scene so that things may be viewed in their true perspective.

If, as a result, it appears that, in order to blend the new systems with the old, we shall require a new pattern of classification and some new terms, that will, of course, be a matter for consideration and agreement. It could not be carried far in an address such as this, yet it has seemed to me that I might venture to go a little way in that direction on a sort of preliminary reconnaissance.

I propose, therefore, to glance over the field of position determination by radio to obtain a first impression as to how systems are related to each other and, having in mind the table of classification given by Whelpton and Redgment in their paper at the Radiocommunication Convention, to consider some of the factors by which systems are distinguished.

First I will ask, What is the status of this art of position determination, or whatever it should be called, in relation to radio generally? Is it a part of radio or is it something different? Is it proper to use an expression such as "radio and radar devices," or would that suggest confusion of thought between the particular and the general? It is certainly a matter of the transmission of intelligence by radiation, and surely therefore it is a branch of radio. It involves techniques very

* Chairman's address to the Radio Section, Institution of Electrical Engineers, London, October 15, 1947. Reprinted from *Journal of the Institution of Electrical Engineers,* v. 95, Part I, pp. 31–35; January, 1948.

similar to those employed in radiocommunication but it differs from communication in that the intelligence conveyed is restricted to geometrical information in contrast to the unlimited scope of intelligence conveyed in communication. It appears, indeed, to be on a par with communication as a main branch of the tree of which radio is the root and trunk. If that is so, what should it be called? The name must cover the whole field of direction and range determination. It must embrace direction-finding and radar, and much else. We speak of "radio aids to navigation," but that is cumbersome and not sufficiently general. I believe the title "radiolocation" would be ideal, though it has been used before in a different sense and it is perhaps somewhat awkward to borrow a term with such important historical associations. But it would be hard to find a name which could more aptly be applied as the comprehensive term to cover the whole of the field. The main branches of radio would then be radiocommunication and radiolocation, and we could speak of systems as communication systems or location systems.

Accepting that for the time being, how should we proceed to divide up radiolocation itself? In view of the rapid development which has taken place, existing divisions are inadequate or ill-defined. Thus, while we have the term "direction-finding" to define parts of the field concerned with reception, we have no equivalent term to denote the process of transmitting azimuth information by means of appropriate beacon systems; and, while we make common use of the title "radar," its present meaning is far from clear. There is a lack, I think, of general terms to define main sections of the field, and in consequence we are often obliged to describe the general in terms of the particular by means of the code names of specific systems. There appears to be a need to examine the subject anew, starting from the firm ground of the common basic principles.

It might be well to look first to see if there is any lead to be obtained from what has occurred in the communication field. Here the first division is on the basis of purpose of application. We have telegraphy, telephony, broadcasting, television, and so on. Thereafter there can be further classification by the principal technical methods employed, such as modulation, whether variable-amplitude or constant-amplitude, or channel separation, whether by frequency separation or by time-sharing. But the various technical methods are common to the several functional categories, and so the division by function had to come first. The same will apply, I think, in radiolocation, and before drawing distinctions by technique we should first achieve some segregation of systems on a broader basis. It is more important, for instance, to see Gee and Decca first as closely related by function before dismissing them into widely separated camps because one is pulse technique and the other continuous-wave technique.

To make a start, we must go back to first principles and work from the general towards the more particular. The A.B.C. of the whole art is that by measuring the difference of the distances of an object from two fixed points we can find that the object is situated on a particular hyperbola, that being a locus of points of constant difference of distance from the fixed points: and by measuring the sum of the distances from the fixed points we can state that the object lies on a particular ellipse, being a locus of constant sum of the distances. In the first way I would say, taking some liberties with words, we obtain an idea of sideways displacement or direction and in the second an idea of outwards displacement or range. A single system of two spaced elements, with provision for measuring both the sum and the difference of the distances, could yield a fix by intersection of the hyperbolic and elliptic loci.

The distance relationships have, of course, to be found in terms of time of wave propagation. Let A and B (Fig. 1) be our two fixed points and C the mobile object. Then first, if we suppose there is a master transmitter at A, a repeater or slave transmitter at B and a receiver at C, by observing at C the difference in the arrival times of signals transmitted over the paths AC and ABC, and knowing the delay in AB, we can obtain the difference of the distances AC and BC and hence derive knowledge of the hyperbolic position line of C. This, of course, is the basis of such direction-giving systems as Gee and Decca. We could also reverse the process and transmit from the mobile C and have repeat and master receivers at B and A, respectively, so obtaining a hyperbolic direction-finding system as distinct from a direction-giving system.

Secondly, suppose we had a transmitter at A, a repeater at B, another repeater at C and a receiver at A; we could then measure at A the total propagation time round the loop AB, BC, CA, and knowing the delay AB, derive the sum of the

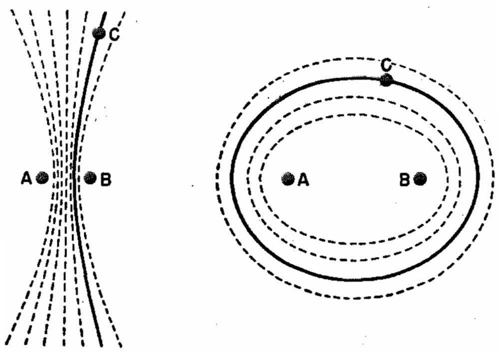

Fig. 1—Basic principles of radiolocation. (*Left*) Measurement of the differences of the distances *AC* and *BC* determines the hyperbolic position line of *C*. This is the general case of "direction" determination. (*Right*) Measurement of the sum of the distances *AC* and *BC* determines the elliptic position line of *C*. This is the general case of "range" determination.

transit times of the paths BC and CA, so finding the elliptic position line, or locus of constant time sums, on which C lies.

These, as I see it, are the fundamental principles of radiolocation on which the whole art is based. They are not peculiar to hyperbolic and elliptic systems, as, in the special cases arising when the separation between the fixed points is small compared with the distance of the mobile object, they apply also to the classical direction-finding systems and beacon systems and to the usual methods of range measurements. Thus in elliptic systems, as the spacing is reduced the ellipses merge into circles, and when A and B coincide (Fig. 2) we have the normal conditions of range measurement when the distance measured is $AC + CA$, which is twice the range; and in hyperbolic systems, as the spacing is reduced the loci of constant difference of distance merge into straight radial lines.

The point I am making, therefore, is that all radiolocation systems are either hyperbolic or elliptic position-line systems, these including radial and circular position-line systems as special cases. The hyperbolic and radial systems are concerned with direction in a manner of speaking, and the elliptic and circular systems with "range."

From this it appears that the first division of radiolocation might be into two parts (Fig. 3), including on the one hand all time-sum methods giving "range," and on the other hand all time-difference methods giving "direction." If so, we should require eventually to coin new terms to denote these two main divisions of application, "X-dar" and "Y-dar," so to speak. For the present I shall refer to them by the terms "direction determination" and "range determination." These two categories would together cover the whole of the field, and subsequent steps would be a matter of further division within these categories.

Pursuing that, we must evidently provide, in the category of "direction determination," for transmitting and receiving systems. In general, the main methods can be applied in either way. Thus the Adcock direction-finding system has a transmitting counterpart in the omni-range beacon system, and, as has been mentioned, the principle of Gee could be applied to reception as well as to transmission. For the present, I shall use the terms "direction-giving" and "direction-finding" to denote these two functional divisions. The former would include Gee, Decca, omni-range beacons, overlapping beam course beacons, and all systems transmitting azimuth information, while the latter would embrace all the receiving counterparts of the above.

Then in both of the main categories it would be convenient to distinguish between broad-based systems and narrow-based systems. There is a considerable contrast in application between these two. In direction determination, for in-

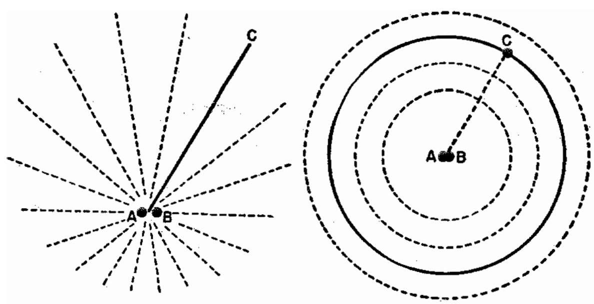

Fig. 2—Radial and circular systems are special cases of hyperbolic and elliptic systems. (*Left*) In the special case when the spacing *AB* is small compared with the distance *AC*, the difference of distances is *AB* cos θ and the loci of constant difference of distance are straight lines. (*Right*) When the spacing *AB* is very small the loci of constant sum of the distances *AC* and *CB* are circles.

stance, the broad-based hyperbolic systems are applicable where it is important to carry as far out as possible the accuracy of position-line determination obtainable near in, while the narrow-based radial systems, on the other hand, are applicable when it is essential to obtain uniformity of indication all round, as in ordinary direction-finding and omni-range systems.

So far, we have not introduced radar into the family tree; but if, conforming, I think, to Sir Edward Appleton's definition, we mean by radar the radiolocation of objects without their active co-operation, then it is clear that in the categories of range determination and direction-finding there could be sub-division into radar and non-radar groups to differentiate between systems which do and those which do not require co-operation.

I have now, I hope, indicated a line of thought in the matter of a first division of systems by application or function. We are still left, however, with systems falling in the same categories which clearly require further differentiation. For example, while Gee and Decca would so far be classed together as broad-based direction-giving systems, there is a marked difference between them in technique. We have in fact reached the stage where further differentiation must be done according to the technical methods used. This is a large subject, and I shall not aim to do more than introduce it by some observations on three of the factors which I think would be relevant. These are, first, the method by which transmissions are marked so that differences in times of arrival can be observed; secondly, the method of modulation; and, thirdly, the method of channel separation.

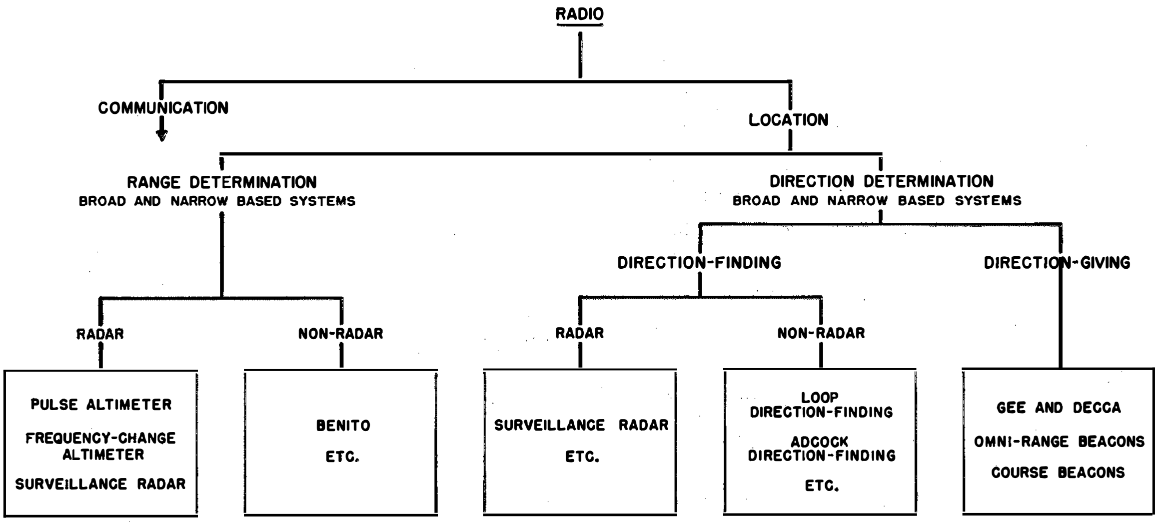

Fig. 3—Division of radio on a broad basis of function.

Consider first the method of marking (Fig. 4); this is a question of the calibration of the yardsticks of radiation sent out. The method which, it seems to me, springs most naturally to mind is to start the transmission suddenly and observe the times of arrival of the sharp fronts. In practice, the transmission is marked by a succession of pips. This, of course, is the pulse method as used in Gee and primary radar. The transmission is in the form, we might say, of a "comb carrier," and time intervals are observed as the displacement between the teeth of the interlaced combs received over circuits of different delay.

Secondly, the transmission can be marked by the peaks and valleys of low-frequency sine-wave variation impressed on the radio-frequency wave. (I am trying to avoid using the word "modulation" in this connection, as no geometrical information is conveyed by this continuously repetitive variation.) Differences of distance are observed by phase comparison of the low-frequency envelopes, and the method can be referred to as the "tone-phase comparison method." It is exemplified in the Benito ranging system and in certain proposed course beacon systems.

Thirdly, we have the radio-frequency phase-comparison method in which the wavelength of the radiation itself is the unit of graduation, and differences of distance are found in terms of the number of whole wavelengths and the fraction of a wavelength by which one path is longer than another. This is exemplified in direction-finding omni-range beacons and in Decca.

There is a sharp distinction between the pulse method and the two phase-comparison methods, in that in the former the transmission is discontinuous and the method is therefore inherently appropriate to time-sharing methods of multiplex and to time discrimination between signals, while in the latter the transmission is continuous and separation of signals must be by difference of frequency.

I pass on now to remark on the second factor of technical method I mentioned, namely modulation. This term as applied to radiolocation should, I think, be taken as referring to the characterization of signals whereby geometrical information is conveyed. In that sense, it is the signal characteristic which changes with a change in the position of the mobile object. We have, as in communication, the two main kinds of modulation, namely variable-amplitude modulation and constant-amplitude time modulation, of which frequency modulation and phase modulation are varieties (Fig. 5).

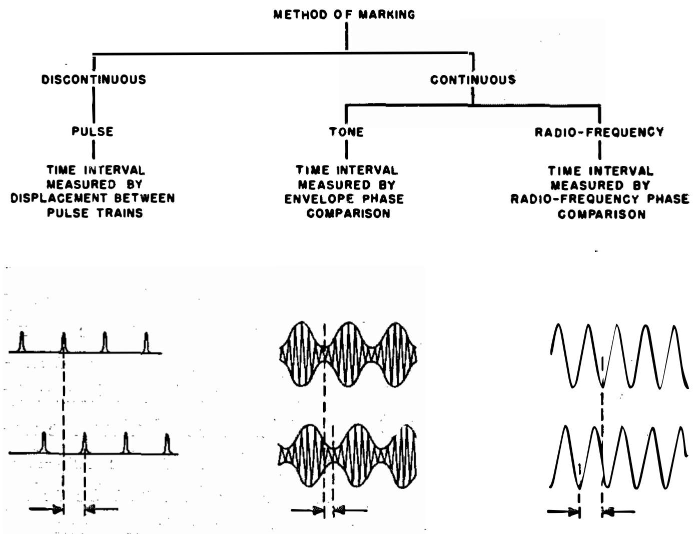

Fig. 4—Division of radiolocation according to method of marking. Transmissions are marked to enable differences in times of arrival to be observed.

To take some examples, in overlapping beam systems the modulation is amplitude modulation, and the degree of modulation is the ratio of the amplitudes of the patterns. This changes with direction, and position lines are indicated accordingly. In Gee and in pulse-ranging systems the modulation is pulse-time modulation, i.e., the displacement in time of one train of pulses with respect to another train serving as a reference. It is a form of envelope phase modulation and is exactly the same kind of modulation as is used in some multi-channel pulse-communication systems. In the Benito ranging system the modulation is tone-envelope phase modulation, being the variation of the relative phases of two tone envelopes, and finally in Decca the modulation is radio-frequency phase modulation, being the change of phase of one radio-frequency signal with respect to another serving as a reference of phase.

While we have the same kinds of modulation as in communication, there is a very distinct difference in the way the modulation is impressed. Modulation of the signal with geometrical information in radiolocation can be effected only by virtue of the spacing of antennae. We might possibly use the expression "space modulation" in that connection.

To illustrate this point, consider a system of Gee character in which interlaced pulse trains of "comb carriers" with a certain fixed delay between them are fed to two radiators *A* and *B*. Imagine first that the radiators are brought together. Then a mobile receiver circulating round the system would receive the two carriers constantly with the initial fixed delay between them. The signal is unmodulated in the sense applying in radiolocation, and no position information is radiated. Now suppose we begin to move *B* away from *A*. We commence thereby to apply space modulation, and we have the situation that as the receiver rotates the *B* pulses received are cyclically advanced and retarded about their mean occurrence time with relation to the occurrence time of the *A* pulses. This is precisely what happens in a pulse-time-modulated communication system when a channel is modulated, the channel pulses being advanced and retarded cyclically with relation to the train of synchronizing pulses. If the receiver is arrested in its circulation round the system a direct-current value of the modulation is observed which is indicative of the position line of the receiver.

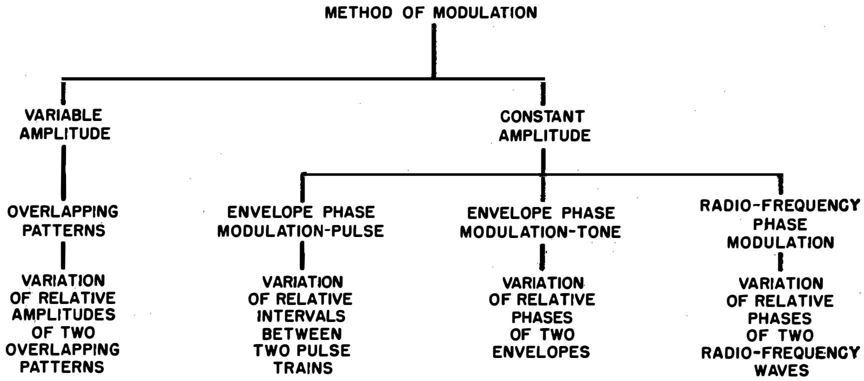

Fig. 5—Division of radiolocation according to method of modulation. In radiolocation, modulation is "space modulation," applied by the spacing of antennae.

The third point I mentioned is the method of channel separation. I think it can be said that radiolocation is fundamentally a multiplex proposition in that, in "range" systems it is required to transmit and receive simultaneously on the same site without interference, and in "direction" systems it is required to transmit simultaneously over multiple paths without interference, or, in the case of amplitude-modulated systems, to lay down separate overlapping patterns.

Two methods exist, namely "frequency multiplex" in which channels are separated in frequency, and "time-sharing multiplex" in which channels are separated in time (Fig. 6).

The distinction can be illustrated by comparisons between Gee and Decca and between pulse-ranging systems and tone-phase comparison-ranging systems.

In Gee, the transmissions from the spaced points are on the same frequency, but, being in the form of interlaced pulse trains, they are kept distinct by time-sharing. The signals pass through the same receiver, but because of the separation in time there is no interference. In Decca, on the other hand, the transmissions from the spaced points are on different frequencies and they are separated at the receiver by frequency-selective circuits (actually two receivers). The point is that in Gee the channels are kept distinct by time-sharing, exactly as they are in a multi-channel pulse-communication system, while in Decca they are kept distinct in the familiar way by frequency separation.

As between pulse- and tone-phase comparison ranging systems, the same distinction applies. In the pulse method, simultaneous (if we may call it so) transmission and reception on the same site is possible by virtue of the fact that the outgoing and incoming trains of pulses are interlaced in time. In the tone-phase comparison method, on the other hand, there has to be a frequency conversion at the responder at the remote point so that the incoming signals can be separated from the outgoing signals by being on a different frequency.

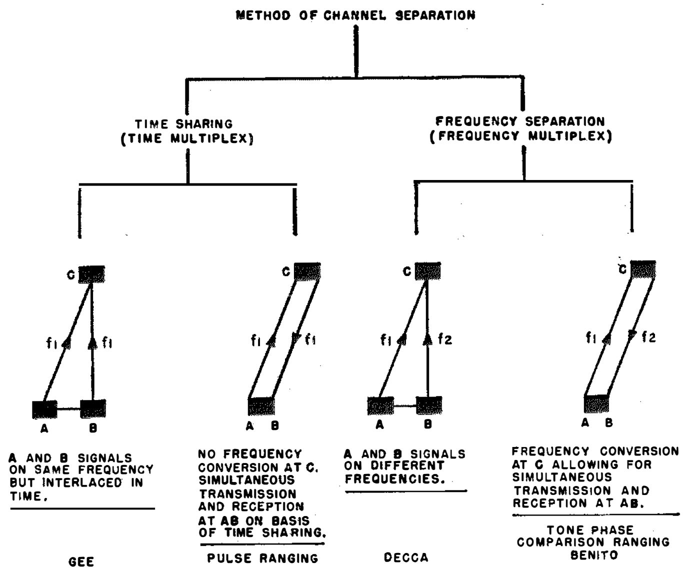

Fig. 6—Division of radiolocation according to method of channel separation. In general, radiolocation involves multiplex operation.

The three factors of method I have briefly discussed, namely marking, modulation, and channel separation, are evidently closely related. Thus, where pulse-marking is used, time multiplex is obviously indicated, and indeed the main object of pulse-marking is to obtain time-multiplex effects, including the resolution of signals resulting from reflections from many objects, but when phase-comparison methods are used there is an incentive to use frequency multiplex to avoid the necessity of successive as distinct from continuous phase comparison. Yet the factors need some separate consideration, as there are cases in which the methods are associated in less usual ways, as for example in P.O.P.I., which, though a phase-comparison system, relies on time multiplex for channel separation.

The possible use of these or similar factors in the preparation of a complete chart of classification is something which must be left. I have aimed only at indicating some of the factors which would enter into the consideration. However, there is one point I would emphasize as having a bearing on our understanding of the term radar. That is the distinction, as applied to radar, between discontinuous and continuous marking, or, in more common terms, between pulse and continuous-wave techniques. Either method is applicable when we are concerned with the location of a single object, but when we are concerned with "seeing" very many objects simultaneously, as for example in marine or ground-surveillance radar, we are almost bound to resort to pulse technique, which enables us to work very many echoes simultaneously on what is, in effect, a basis of time-sharing multiplex operation. As both methods have their place, it seems that we should reserve the term radar for the art of radiolocation without co-operation, irrespective of the technical methods used, and avoid any tendency to associate the term particularly with pulse technique and time-sharing multiplex methods.

I have tended throughout in this brief review, I think, to emphasize the close relationship between radiolocation and radiocommunication as branches of a single art. Now in the time which remains, I propose to describe very briefly a system which, although somewhat hypothetical at present, will serve to illustrate that point. This is a time-sharing multiplex system combining radiolocation and radiocommunication services to aircraft on a common frequency.

The idea is that a multi-channel pulse communication transmitter, such as might be used for a point-to-point radio-link service, could possibly be used as an omni-range beacon while at the same time serving to transmit a number of communication channels. The transmitter delivers a number of interlaced pulse trains or comb carriers—one for synchronization and one for

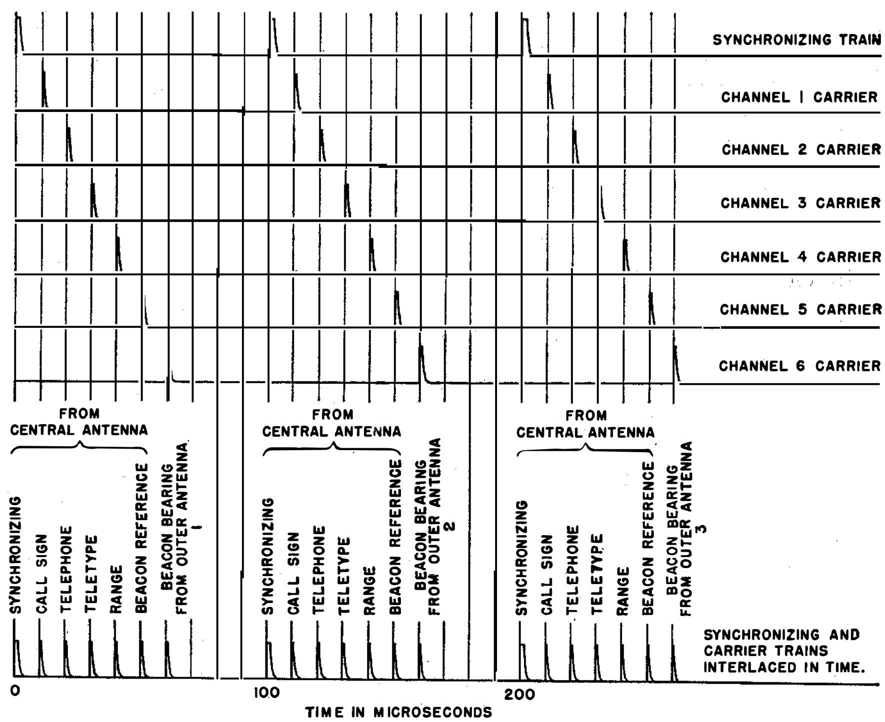

Fig. 7—Time-multiplex beacon and communication system. Distribution of carriers in time.

each channel (Fig. 7). The communication channels are modulated by advancing and retarding the pulses in accordance with the input speech or tone signals. The omni-range bearing channel is similarly pulse-time modulated, only in this case the modulation is space modulation, being effected by transmitting the pulses of the channel carrier successively from a number of antennae spaced evenly round the station on a circle of about 300-metre radius. The pulse train then becomes sinusoidally modulated owing to the different distances of the radiators from the receiver. The modulation is detected in the receiver, giving a low-frequency tone, the phase of which varies with the bearing of the receiver. By phase comparison between that signal and a reference tone transmitted on one of the communication channels the bearing can be determined.

In addition, the aircraft could measure its distance from the beacon. The aircraft transmits a suitable tone on its very-high-frequency equipment. The tone is received at the ground station and sent back on one of the communication channels, so that by phase comparison in the aircraft between the outgoing and incoming tones the range can be derived as in the Benito system. We should thus have a combined system giving azimuth, range, and communication, all on a single frequency on a basis of time-sharing multiplex operation.

And now to summarize very briefly: We are concerned with one art, which is radio, dividing, as I see it, into radiocommunication and radiolocation, applying the latter term now in a new and broader sense to embrace all methods of position determination by radio.

Then it appears that radiolocation itself might be divided initially into two sections concerned, respectively, with time-sum and time-difference measurement, giving in the one case elliptical and circular position lines and in the other, hyperbolic and linear position lines. For the time being, I used the terms "range determination" and "direction determination" to denote these two fundamental divisions.

Within these two categories there can be further division as between broad-based systems and narrow-based systems, and in "direction determination" we must distinguish between transmitting and receiving systems, or, as I have said, between "direction-giving" systems and "direction-finding" systems.

Further, in range and direction-finding systems we must distinguish between radar and non-radar applications, reserving the term "radar" for position determination without co-operation.

Then, having first classified systems on broad lines related to function, we could differentiate further by the technical methods used. Some of the factors which would be relevant in that connection are, first, the method of marking, whether discontinuous as in pulse systems or continuous as in tone or radio-frequency phase-comparison methods; secondly, the method of modulation, whether amplitude modulation as in overlapping-pattern systems or constant-amplitude time modulation as in systems depending on pulse-interval measurement or phase comparison; and thirdly, the method of channel separation, whether by time multiplex or frequency multiplex.

Finally, it will be understood that my approach to this subject has been purely exploratory. I have aimed only at framing a question and whetting the appetite for a wider discussion of the problems involved.

Simplified Procedure for Computing Behavior of Multiconductor Lossless Transmission Lines

By SIDNEY FRANKEL

Federal Telecommunication Laboratories, Incorporated, Nutley, New Jersey

PROBLEMS involving radio-frequency transmission lines of more than two conductors, or problems involving combinations of two-conductor lines lying geometrically parallel, occur frequently. It is often useful to treat such lines as though they were lossless and operating in the *TEM* mode. Under such conditions, the description of the line behavior is particularly simple. It can be shown that, apart from terminal conditions, the electromagnetic conditions on the line can be expressed in terms of the velocity of propagation, which depends only on the electromagnetic constants of the medium, and on an additional set of constants, which may be either the coefficients of electrostatic capacitance of the line or the coefficients of external magnetostatic inductance.

• • •

1. *Line Equation*

Consider the case of a uniform lossless line consisting of $n+1$ cylindrical conductors of arbitrary cross section excited in the *TEM* mode. As a result of this excitation, two waves of fields travel along the line in opposite directions, accompanied by currents in the various conductors and potential differences between them. In the present discussion, the potential of the $(n+1)$th conductor is taken as zero and the potentials of all other conductors are referred to it. If we take rectangular coordinates x,y,z with the direction of increasing z as the direction of travel of the forward wave, then the forward-wave electric and magnetic fields are given in meter-kilogram-second units by

$$\left.\begin{aligned} \mathbf{E}_f &= \mathbf{E}_1(x,y)f(z-ct), \\ \mathbf{H}_f &= \left(\frac{\mathcal{E}}{\mu}\right)^{\frac{1}{2}}(\mathbf{K}\times\mathbf{E}_f), \end{aligned}\right\} \qquad (1)$$

where

$\mathbf{E}_f$ = forward-wave electric vector,
$\mathbf{E}_1$ = a vector function of position,
f = a scalar function,
$\mathbf{H}_f$ = forward-wave magnetic vector,
$\mathcal{E}$ = dielectric constant,
μ = permeability constant,
$\mathbf{K}$ = unit vector in z direction,
$c=(\mu\mathcal{E})^{-\frac{1}{2}}$ = velocity of wave propagation,
t = time.

$\mathbf{E}_1$ depends on the conductor charge distributions in any transverse plane, while f depends on the way the line is excited, or may be considered as being excited, at any transverse plane as a function of time.

Similarly the back-wave fields are given by

$$\left.\begin{aligned} \mathbf{E}_b &= \mathbf{E}_2(x,y)g(z+ct), \\ \mathbf{H}_b &= -\left(\frac{\mathcal{E}}{\mu}\right)^{\frac{1}{2}}(\mathbf{K}\times\mathbf{E}_b), \end{aligned}\right\} \qquad (2)$$

where

$\mathbf{E}_b$ = back-wave electric vector,
$\mathbf{E}_2$ = a vector function of position,
g = a scalar function,
$\mathbf{H}_b$ = back-wave magnetic vector.

Similar comments apply to $\mathbf{E}_2$ and g as to $\mathbf{E}_1$ and f, respectively.

By virtue of (1) and (2), simple relations exist between currents and charges on the various conductors. As the conductors are assumed to be perfect, $\mathbf{E}_f$ and $\mathbf{E}_b$ are normal to the conductor surfaces, while $\mathbf{H}_f$ and $\mathbf{H}_b$ are tangential thereto. Let $\mathbf{E}$ and $\mathbf{H}$ represent either forward- or back-wave intensities, and let q_k be the total charge per meter on the kth conductor. On a section of surface bounded by transverse planes one meter apart, Gauss' theorem yields

$$q_k = \mathcal{E}\oint \mathbf{E}\cdot d\mathbf{s}, \qquad (3)$$

the loop integral being taken on the path $\mathbf{s}$ represented by the intersection of the kth conductor by a transverse plane.

Let I_k be the total current in the kth conductor. Then by Ampere's theorem

$$I_k = \oint \mathbf{H}\cdot d\mathbf{s}, \qquad (4)$$

where the path of integration is the same as for (3). Equations (1) through (4) then lead immediately to

$$I_k = \pm c q_k, \tag{5}$$

the positive or negative sign depending on whether the wave under consideration is a forward wave or a back wave.

In a transverse plane, the electric field is described by a potential that satisfies Laplace's equation. Hence the charges on the various conductors are characterized by Maxwell's coefficients of capacitance and the conductor potentials by

$$q_k = \sum_{j=1}^{n} C_{kj} V_j, \quad k = 1, \ldots, n, \tag{6}$$

provided that

$$\sum_{j=1}^{n+1} q_k = 0,$$

where

$C_{kj} = C_{jk}, \quad j,k = 1, \ldots, n,$
= coefficient of capacitance between jth and kth conductor,
V_j = potential of jth conductor, $j = 1, \ldots, n$.

Thus, we have immediately

$$I_k = \pm \sum_{j=1}^{n} Y_{kj} V_j, \quad k = 1, \ldots, n, \tag{7}$$

where

$Y_{kj} = Y_{jk} = cC_{kj} = cC_{jk}, \quad j,k = 1, \ldots, n,$
= coefficient of characteristic admittance between jth and kth conductor.

For waves of a single angular frequency ω, the root-mean-square potential of the kth conductor may be written

$$V_k = A_k e^{-i\theta} + B_k e^{i\theta}, \; k = 1, \ldots, n, \tag{8}$$

where

A_k, B_k = arbitrary constants,
θ = electrical distance along the line,
$= \omega z / c$.

The terms in the right-hand member of (8) correspond to the forward wave and back wave, respectively; A_k and B_k are usually expressed in terms of conditions at the ends of the line. Then (8) and (7) imply

$$I_k = \sum_{j=1}^{n} Y_{kj}(A_j e^{-i\theta} - B_j e^{i\theta}), \; k = 1, \ldots, n. \tag{9}$$

Equations (8) and (9) are the general steady-state solutions of the lossless multiconductor line. They reduce to the usual two-wire lossless-line equations when $n = 1$.

Equation (7) may be solved for the V_j's to yield

$$\begin{aligned} V_j &= \pm \sum_{k=1}^{n} Z_{jk} I_k, \\ &= \pm \sum_{k=1}^{n} c Z_{jk} q_k, \\ &= \pm \sum_{k=1}^{n} P_{jk} q_k, \end{aligned} \tag{10}$$

where the P_{jk}'s are recognized as Maxwell's coefficients of potential, and Z_{jk} may be termed a characteristic-impedance coefficient. Thus,

$$Z_{jk} = \frac{P_{jk}}{c}. \tag{10A}$$

The general line equations may also be written

$$\left. \begin{aligned} I_k &= C_k e^{-i\theta} + D_k e^{i\theta}, \\ V_k &= \sum_{j=1}^{n} Z_{jk}(C_k e^{-i\theta} - D_k e^{i\theta}). \end{aligned} \right\} \tag{11}$$

It is seen from these considerations that, apart from terminal conditions, the line behavior may be characterized completely by Maxwell's coefficients of capacitance and by the velocity of propagation. The well-known expression for the characteristic admittance of a two-wire line:

$$Y_0 = cC \tag{12}$$

is a special case of this result.

2. *Inductance Coefficients*

It may be shown that the line may equally well be characterized by its coefficients of inductance rather than by the capacitance coefficients; as a result, it is possible to compute the former from the latter.

The coefficient of external inductance L_{jk} is defined as the magnetic flux per unit length of line passing between the jth conductor and the reference $(n+1)$th conductor when the current in the kth conductor is one ampere. This leads to

$$\phi_k = \sum_{j=1}^{n} L_{kj} I_j \tag{13}$$

for the flux per unit length of line between the kth conductor and the $(n+1)$th conductor. Applying Faraday's law to a differential length of line then yields

$$\frac{\partial V_k}{\partial Z} = -\sum_{j=1}^{n} L_{jk} \frac{\partial I_k}{\partial t}. \tag{14}$$

For waves traveling with velocity c,

$$\frac{\partial}{\partial t} = \pm c \frac{\partial}{\partial Z},$$

the lower or upper signs depending on whether the wave is a forward wave or a back wave. Using this result in (14) and integrating with respect to Z yields for traveling waves

$$V_k = \pm \sum_{k=1}^{n} c L_{jk} I_k. \tag{15}$$

Comparing (15) with (10), we have

$$c L_{jk} = Z_{jk} = \frac{P_{jk}}{c} \tag{16}$$

or

$$L_{jk} = \frac{P_{jk}}{c^2}. \tag{16A}$$

On the other hand, as is well known,

$$P_{jk} = \frac{\Delta_{jk}}{\Delta},$$

where Δ is the determinant $|C_{jk}|$ and Δ_{jk} is the minor of the jth row, kth column of Δ. Thus, the L_{jk} may be computed when the C_{jk} are known.

It should be noted that since C_{jk} is proportional to $\mathcal{E}$, P_{jk} is proportional to $\mathcal{E}^{-1}$; therefore L_{jk} is proportional to $\mathcal{E}^{-1}c^{-2} = \mu$, so that the dielectric constant and velocity of propagation disappear in a calculation of L_{jk}.

An additional set of relations exists between the L's and C's,

Form the product $L_{jk}C_{kl}$ and sum over k, thus

$$\sum_{k=1}^{n} L_{jk} C_{kl} = \frac{1}{c^2} \sum_{k=1}^{n} P_{jk} C_{kl} = \frac{1}{c^2 \Delta} \sum_{k=1}^{n} \Delta_{jk} C_{kl}.$$

By elementary theory of determinants, the last sum is zero for $j \neq l$ and is equal to Δ for $j = l$; thus

$$\sum_{k=1}^{n} L_{jk} C_{kl} = \frac{1}{c^2} \delta_j^l = \mu \mathcal{E} \delta_j^l, \tag{17}$$

where

$$\delta_j^l = \text{Kronecker delta}$$
$$= 0,\ k \neq l$$
$$= 1,\ k = l.$$

2.1 Examples

The usefulness of the results above will now be illustrated by some examples. These will be restricted to the case of two small round wires at equal heights above plane ground *in vacuo*, as shown in Fig. 1. For this three-conductor

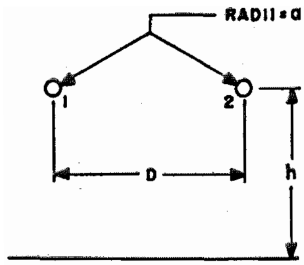

Fig. 1.

system, $n = 2$. Approximate values for the admittance coefficients are well known. For D, $h \gg a$,

$$\left.\begin{aligned} Y_{11} = Y_{22} = cC_{11} &= -\frac{1}{60} \frac{\xi}{\xi^2 - \eta^2}, \\ Y_{12} = Y_{21} = cC_{12} &= \frac{1}{60} \frac{\eta}{\xi^2 - \eta^2}, \end{aligned}\right\} \tag{18}$$

where

$$\left.\begin{aligned} \xi &= \ln \frac{a}{2h}, \\ \eta &= \ln \frac{D}{G}, \\ G &= (D^2 + 4h^2)^{\frac{1}{2}}. \end{aligned}\right| \tag{18A}$$

The usual characteristic admittances of the line may be computed from the admittance coefficients. To compute the characteristic admittance, we assume forward waves only so that (8) and (9) become

$$V_1=A_1e^{-i\theta},$$
$$V_2=A_2e^{-i\theta},$$
$$I_1=(Y_{11}A_1+Y_{12}A_2)e^{-i\theta},$$
$$I_2=(Y_{21}A_1+Y_{22}A_2)e^{-i\theta}.$$

For a balanced line, $V_2=-V_1$, $A_2=-A_1$, $I_2=-I_1$, and

$$Y_0=\frac{I_1}{V_1-V_2}=\frac{I_1}{2V_1}=\frac{Y_{11}-Y_{12}}{2}. \qquad (19)$$

For an unbalanced-fed line, $V_2=V_1$, so that $A_2=A_1$, $I_2=I_1$, and

$$Y_0=\frac{I_1+I_2}{V_1}=2(Y_{11}+Y_{12}). \qquad (20)$$

Using (18) and (18A) in (19) and (20) yields the well-known results

Balanced Line $$Y_{ob}=\left(120 \ln \frac{2hD}{aG}\right)^{-1}, \qquad (21A)$$

Unbalanced Line $$Y_{ou}=\left(30 \ln \frac{2hG}{aD}\right)^{-1}. \qquad (21B)$$

2.2 Input Admittance of a Short-Circuited Line Above a Ground Plane

The case to be analyzed is shown in Fig. 2.

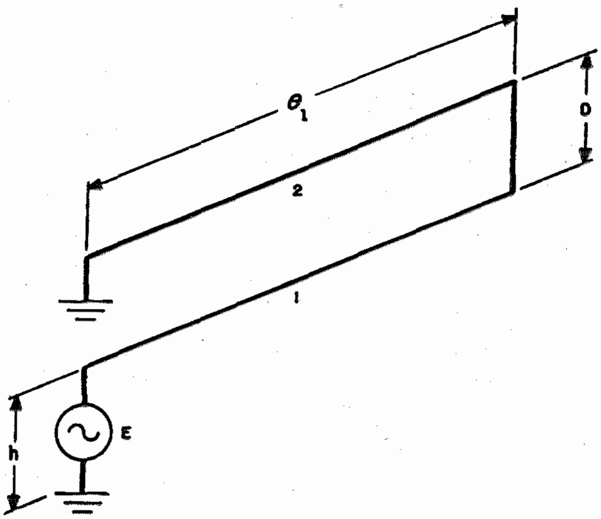

Fig. 2.

This has been previously analyzed by an artificial arrangement of exciting generators shown in Fig. 3. This arrangement clearly excites line *1* at potential E and line *2* at potential zero. The current in line *1* may be determined by adding the effects of (1) the balanced generator pair and (2) the generator exciting the line against ground.

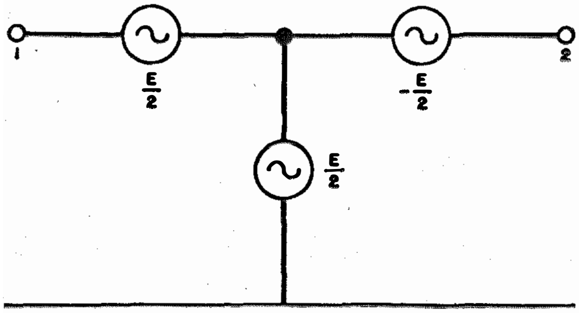

Fig. 3.

For part (1), the line is a shorted line of length θ_l; its input admittance is

$$Y_b=-iY_{ob}\cot\theta_l,$$

and the balance current into conductor *1* is

$$I_b=-iY_{ob}E\cot\theta_l. \qquad (22A)$$

For part (2), the line is an open line of length θ_l; the input admittance to conductor *1* is

$$Y_u=i\left(\frac{Y_{ou}}{2}\right)\tan\theta_l,$$

and the unbalance current into conductor *1* is

$$I_u=i\left(\frac{Y_{ou}}{2}\right)\left(\frac{E}{2}\right)\tan\theta_l. \qquad (22B)$$

The input admittance at conductor *1* is, therefore,

$$Y_1=\frac{I_b+I_u}{E}=i(\tfrac{1}{4}Y_{ou}\tan\theta_l-Y_{ob}\cot\theta_l). \qquad (23)$$

Equation (23) is obtainable from the foregoing theory in a straightforward manner. In (9), with $n=2$, we introduce the following boundary conditions (Fig. 2):

$$V_1=E, \quad \text{when} \quad \theta=0,$$
$$V_1=V_2, \quad \text{when} \quad \theta=\theta_l,$$
$$V_2=0, \quad \text{when} \quad \theta=0,$$
$$I_1=-I_2, \quad \text{when} \quad \theta=\theta_l.$$

Setting $s=e\exp[i\theta_l]$ yields a set of equations:

$$A_1+B_1=E,$$
$$s^{-1}A_1+sB_1=s^{-1}A_2+sB_2,$$
$$A_2+B_2=0,$$
$$s^{-1}A_1-sB_1=-s^{-1}A_2+sB_2,$$

which can be solved for the A's and B's. The input current to line *1* in terms of E is then completely known; in fact this current is

$$(I_i)_0 = Y_{11}(A_1 - B_1) + Y_{12}(A_2 - B_2),$$

whence the admittance is found to agree with (23).

3. "Loop" or "Short-to-Short" Coupling Between Lines

The configuration to be analyzed is shown in Fig. 4. Line *1* is driven and power is induced in line *2* and absorbed in the load $2Y_0$. The problem is to find the input admittance at $M-M$ on line *1*. The solution in the present instance is restricted to the case where the geometry of the lines is identical and where the transverse traces of the centers of the wires constitute the corners of a rectangle.

This problem has been studied previously;[1] in the earlier discussion, the characteristic impedances of the driving and driven lines were considered to be unaffected by their proximity to each other. The effect of proximity is accounted for automatically in the present procedure.

To fit the problem into the present discussion, consider both lines balanced with respect to ground so that the configuration of Fig. 1 can be substituted. Then the boundary conditions are

$$\begin{aligned} V_1 &= E, \quad \text{when} \quad \theta = 0, \\ V_1 &= 0, \quad \text{when} \quad \theta = \theta_l, \\ V_2 &= 0, \quad \text{when} \quad \theta = 0, \\ I_2 &= 2Y_0(V_2)_{\theta=\theta_l}, \quad \text{when} \quad \theta = \theta_l. \end{aligned}$$

The current in line *1* at $\theta = 0$ is

$$(I_i)_0 = Y_{11}(A_1 - B_1) + Y_{12}(A_2 - B_2), \qquad (24)$$

and the input admittance is

$$Y_{in} = \frac{(I_i)_0}{2E}. \qquad (25)$$

Substitution of the boundary conditions in (8) and (9) yields the following set of equations.

$$\begin{aligned} A_1 + B_1 &= E, \\ s^{-1}A_1 + sB_1 &= 0, \\ A_2 + B_2 &= 0, \end{aligned}$$

$$s^{-1}Y_{21}A_1 - sY_{21}B_1 + s^{-1}(Y_{22} - 2Y_0)A_2 - s(Y_{22} + 2Y_0)B_2 = 0.$$

These equations are readily solved to yield

$$\left.\begin{aligned} A_1 &= \frac{-Es}{s - s^{-1}}, \\ B_1 &= -\frac{Es^{-1}}{s - s^{-1}}, \\ A_2 &= -\frac{2Y_{12}E}{(s - s^{-1})[(s + s^{-1})Y_{22} + 2(s - s^{-1})Y_0]}, \\ B_2 &= -A_2. \end{aligned}\right\} \qquad (26)$$

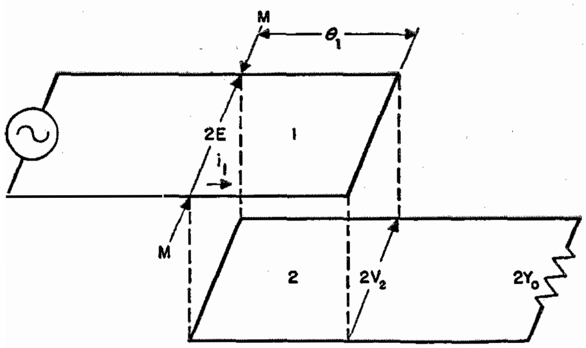

Fig. 4.

Substitution of (26) in (24) and (25) gives, after simple reductions,

$$Y_{in} = \frac{Y_{11}}{2i}\cot\theta_1 - \frac{Y_{12}^2}{2i\sin\theta_1(Y_{22}\cos\theta_1 + i2Y_0\sin\theta_1)}$$

or, finally,

$$Y_{in} = \frac{Y_{11}}{2i}\cot\theta_1\left[1 - \frac{Y_{12}^2}{Y_{11}} \times \frac{1}{\cos\theta_1(Y_{11}\cos\theta_1 + i2Y_0\sin\theta_1)}\right] \qquad (27)$$

as $Y_{22} = Y_{11}$ for the configuration discussed.

This result is found to check the earlier result[1] when the separation between the two lines is made sufficiently great.

Of course, it must be pointed out that the simple procedures given here make no allowances for end effects on the lines; such effects are minimized when the spacing between conductors is small compared with line length.

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[1] A. Alford, "Coupled Networks in Radio-Frequency Circuits," *Proceedings of the I.R.E.*, v. 29, pp. 55–69; February, 1941: see p. 68.

Reduction by Limiters of Amplitude Modulation in an Amplitude- and Frequency-Modulated Wave

By A. G. CLAVIER, P. F. PANTER, and W. DITE

Federal Telecommunication Laboratories, Incorporated, Nutley, New Jersey

A MATHEMATICAL method is described for computing the effect of idealized limiters on an amplitude- and frequency-modulated wave of the form $A \sin \phi(t)$, where A may be a function of time. The output components of the limiter are shown to be of the form $V_{2\nu+1}(A) \sin (2\nu+1)\phi(t)$ and the dynamic characteristics $V_{2\nu+1}(A)$ are used to compute the residual amplitude modulation in the output. The dynamic characteristics are plotted for several limiters assumed to behave according to known mathematical functions. The effectiveness of such limiters is displayed in curves showing the ratio of residual amplitude-modulation index to the amplitude-modulation index in the original wave as a function of the applied voltage.

• • •

1. Introduction

In many problems, the action of a four-terminal network is characterized by a curve showing the output V in terms of the input v. This curve may not be linear and such a case may be treated in a number of ways. One approach is to represent the output-versus-input characteristic by a power series in the form

$$V = f(v) = \sum_{n=0}^{\infty} a_n v^n. \quad (1)$$

Another approach is to represent the characteristic function by means of a trigonometric series[1] in the form

$$V = A_0 + \sum_{1}^{\infty} \left(A_n \cos \frac{2\pi n v}{v_0} + B_n \sin \frac{2\pi n v}{v_0} \right), \quad (2)$$

where v_0 equals the range over which this expansion is valid.

The representations given in (1) and (2) are useful in numerical analysis where only a few terms are required to give an approximate result. For general analysis, (1) is applicable only to continuous functions and is very difficult to handle as the result is in the form of an infinite series. Equation (2), while giving rise to an infinite series, may sometimes be treated by the method given in the appendix.

A third approach, which is applied in this paper, makes use of the Fourier transform. It is similar to the contour-integral method used by Bennett[2] and others but has the advantage that the integrals involved are real.

2. Outline of Method

The specific problem that will be treated here is the action of amplitude limiters on a signal that may be modulated both in amplitude and frequency. Our discussion will be limited to the case where the static characteristic is an odd function of the input voltage v, so that

$$f(v) = -f(-v),$$

where $v = A(t) \sin \phi(t)$, $A(t)$ and $\phi(t)$ being given functions of time.

To compute the output of the limiter, use will be made of the Fourier transform in the following manner. Any limiter characteristic may be represented approximately by Fig. 1*A*.

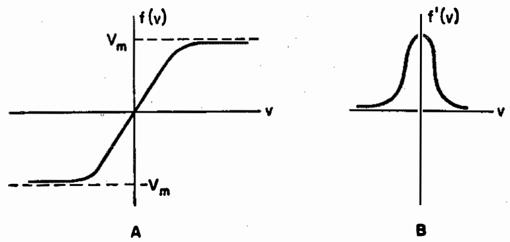

Fig. 1—*A* is the static characteristic of the limiter, and *B* is the derivative of that static characteristic.

While there are a number of known functions that may be used to realize such a characteristic, there is obviously one common property to all of

[1] L. W. Barrow, "Contribution to the Theory of Nonlinear Circuits with Large Applied Voltages," *Proceedings of the I.R.E.*, v. 22, pp. 964–980; August, 1934.

[2] W. R. Bennett, "Response of a Linear Rectifier to Signal Noise," *Bell System Technical Journal*, v. 23, pp. 97–113; January, 1944.

them, namely: that the derivative $f'(v)$ of the limiter curve is finite at $v=0$ and tends to zero as $v\rightarrow\pm\infty$, also $f'(v)=f'(-v)$ as shown in Fig. 1*B*. This property of the derivative $f'(v)$ enables its Fourier transform to be found without difficulty. Following the notation used in a previous paper,[3] let

$$\mathcal{T}_v^u f'(v)=g(u)=\frac{2}{(2\pi)^{\frac{1}{2}}}\int_0^\infty f'(v)\cos(uv)dv. \quad (3)$$

In the particular case considered for which $f(v)$ is bounded everywhere, it can be shown that the Fourier transform of $f(v)$ is related to the Fourier transforms of $f'(v)$ by

$$\mathcal{T}_v^u f(v)=\frac{1}{ju}\mathcal{T}_v^u f'(v).$$

$$\therefore \quad G(u)=\mathcal{T}_v^u f(v)=\frac{1}{ju}\mathcal{T}_v^u f'(v)$$

$$=\frac{2}{ju(2\pi)^{\frac{1}{2}}}\int_0^\infty f'(v)\cos(uv)dv.$$

The output signal of the limiter is given by

$$V=f(v)=\mathcal{T}_u^v G(u)=\frac{2j}{(2\pi)^{\frac{1}{2}}}\int_0^\infty G(u)\sin(uv)du$$

$$=\frac{2}{\pi}\int_0^\infty\frac{\sin(uv)du}{u}\int_0^\infty f'(v)\cos(uv)dv. \quad (4)$$

Here V is a function of the input voltage v expressed in the form of a definite integral. Since $v=A(t)\sin\phi(t)$ and $\sin(uv)=2\sum_{\nu=0}^{\infty}J_{2\nu+1}(uA)\times\sin(2\nu+1)\phi(t)$, the coefficient of $\sin(2\nu+1)\phi(t)$ in the output may be defined by analogy with the case of a simple sine wave as the amplitude of the $(2\nu+1)$th harmonic of the fundamental and is given by

$$V_{2\nu+1}(A)=\frac{4}{\pi}\int_0^\infty\frac{J_{2\nu+1}(uA)du}{u}\int_0^\infty f'(v)\cos(uv)dv. \quad (5)$$

In particular, the amplitude of the fundamental voltage is of interest.

$$V_1(A)=\frac{4}{\pi}\int_0^\infty\frac{J_1(uA)du}{u}\int_0^\infty f'(v)\cos(uv)dv. \quad (6)$$

[3] A. G. Clavier, P. F. Panter, and D. D. Grieg, "PCM Distortion Analysis," *Electrical Engineering*, v. 66, pp. 1110–1122; November, 1947.

In practical cases where the limiter is followed by a frequency discriminator for demodulation, it is obvious that the frequency of the frequency-modulated carrier should be chosen so that the significant sidebands of the harmonics should not fall within the sidebands of the fundamental.

3. *Application to Several Functions that Approximate an Amplitude Limiter*

Following the general idea outlined above, limiter action may be analyzed by curves, the closest to the experimental result being finally chosen. Several known mathematical functions, which represent such curves and their derivatives, are given in Figs. 2–6.

The effectiveness of the various limiters listed above is clearly shown when their derivatives are compared. While the derivative of the semi-ideal limiter drops suddenly to zero, the derivative of the inverse-tangent limiter varies as $1/(1+x^2)$. However, the derivative of the error-integral limiter varies as e^{-x^2}, which indicates a high degree of limiting.

In the following, the expression given for $f'(v)$ for the various limiter curves outlined above will be substituted in (4) from which the dynamic characteristics and the reduction of amplitude modulation will be evaluated.

3.1 Ideal and Semi-Ideal Limiters

Consider the semi-ideal limiter $f(v)$ shown in Fig. 2*B* and its derivative $f'(v)$ in Fig. 2*A*. Starting with $f'(v)$ and applying (4), we have

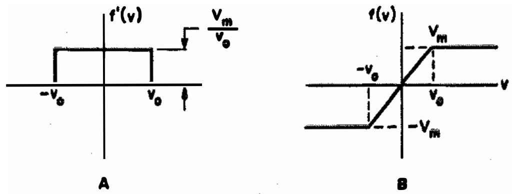

Fig. 2—*A* is the derivative of a semi-ideal limiter, and *B* is its static characteristic.

$$\int_0^\infty f'(v)\cos(uv)dv=\frac{V_m}{v_0}\int_0^{v_0}\cos(uv)dv$$

$$=\frac{V_m}{v_0}\frac{\sin(uv_0)}{u}.$$

$$\therefore \quad f(v)=\frac{2}{\pi}\frac{V_m}{v_0}\int_0^\infty\frac{\sin(uv_0)\sin(uv)du}{u^2}, \quad (7)$$

when $v_0 \rightarrow 0$, (7) reduces to

$$f(v) = \frac{2}{\pi} V_m \int_0^\infty \frac{\sin (uv) du}{u}, \tag{8}$$

which is the equation of the ideal limiter as shown in Fig. 3B. The dynamic characteristic of the $(2\nu+1)$th harmonic is given by[4]

[4] G. N. Watson, "A Treatise on the Theory of Bessel Functions," 2nd Edition, Cambridge University Press, Cambridge, England, 1944. Page 391, equation 1.

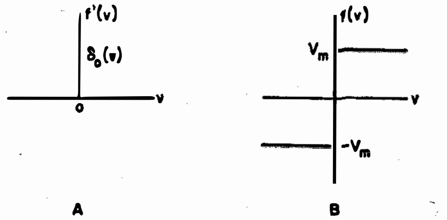

Fig. 3—*A* is the derivative of an ideal limiter, and *B* is its static characteristic.

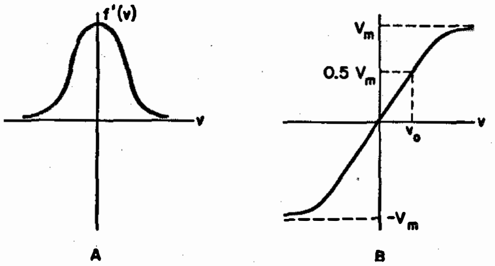

Fig. 4—*A* is the derivative of an inverse-tangent limiter, $f'(v) = \frac{2}{\pi} \frac{V_m}{v_0} \frac{v_0^2}{v^2+v_0^2}$. *B* is the static characteristic, $f(v) = \frac{2}{\pi} \times V_m \tan^{-1} \frac{v}{v_0}$.

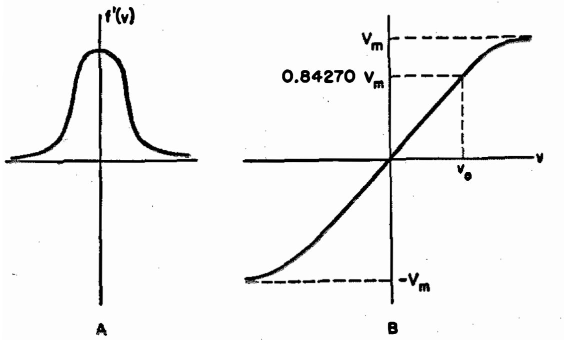

Fig. 5—*A* is the derivative of an error-integral limiter, $f'(v) = \frac{V_m}{v_0} \frac{2}{\pi^{\frac{1}{2}}} e^{-(v/v_0)^2}$. *B* is the static characteristic, $f(v) = \frac{2 V_m}{\pi^{\frac{1}{2}}} \times v_0 \int_0^v e^{-(v/v_0)^2} dv$.

$$V_{2\nu+1}(A) = \frac{4 V_m}{\pi} \int_0^\infty \frac{J_{2\nu+1}(uA) du}{u} = \frac{4 V_m}{\pi} \frac{1}{2\nu+1}. \tag{9}$$

It is obvious from (9) that the output signal of an ideal limiter is independent of the amplitude of the input. It is also apparent that the ideal limiter may be used as a frequency multiplier.

To continue with the semi-ideal limiter, from (5) may be obtained an expression for its dynamic characteristic of the $(2\nu+1)$th harmonic.

$$V_{2\nu+1}(A) = \frac{4 V_m}{\pi v_0} \int^\infty \frac{J_{2\nu+1}(uA) \sin (uv_0) du}{u^2}.$$

This integral may be evaluated by the relation

$$J_{n+1}(x) + J_{n-1}(x) = \frac{2n}{x} J_n(x)$$

and (2) of reference 4, page 405.

$$\therefore \quad V_{2\nu+1}(A) = \frac{2 V_m A}{\pi v_0 (2\nu+1)} \times \int_0^\infty \frac{J_{2\nu}(uA) + J_{2\nu+2}(uA)}{u} \sin (uv_0) du.$$

The fundamental is given by

$$V_1(A) = A \left(\frac{V_m}{v_0} \right), \quad A \leqslant v_0,$$
$$= \frac{2}{\pi} A \left(\frac{V_m}{v_0} \right) \left\{ \sin^{-1} \frac{v_0}{A} + \frac{v_0}{A} \left[1 - \left(\frac{v_0}{A} \right)^2 \right]^{\frac{1}{2}} \right\}, \tag{10}$$

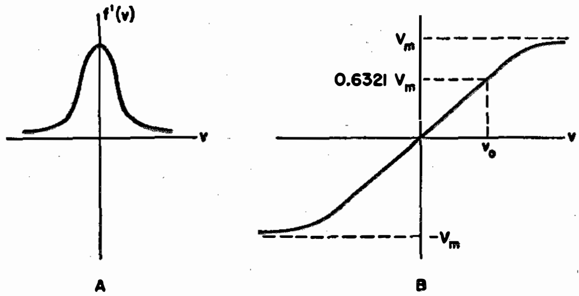

Fig. 6—*A* is the derivative of an exponential limiter, $f'(v) = \frac{V_m}{v_0} e^{-(v_0/v)}$, $v \geqslant 0$; $f'(v) = \frac{V_m}{v_0} e^{(v/v_0)}$, $v \leqslant 0$. *B* is the static characteristic, $f(v) = V_m(1 - e^{-(v/v_0)})$, $v \geqslant 0$; $f(v) = -V_m(1 - e^{(v/v_0)})$, $v \leqslant 0$.

$A \geqslant v_0$, and the harmonics are given by

$$V_{2\nu+1}(A)=0, \quad A \leqslant v_0,$$
$$=\frac{A}{\pi(2\nu+1)}\left(\frac{V_m}{v_0}\right)\left\{\frac{\sin\left[2\nu \sin^{-1}\frac{v_0}{A}\right]}{\nu}+\frac{\sin\left[(2\nu+2)\sin^{-1}\frac{v_0}{A}\right]}{\nu+1}\right\}, \quad A \geqslant v_0. \quad (11)$$

Thus we see from (10) and (11) that on the linear portion of the static curve where $A \leqslant v_0$, the output is proportional to the input, as expected, and the harmonics are equal to zero. However, in the range $A > v_0$, harmonics are generated as a result of the nonlinearity of the system, the degree of limiting of the fundamental and its harmonics depending on the amplitude A of the input signal. When $A \gg v_0$, (10) of the semi-ideal limiter reduces to (9) of the ideal one, where the limiting is perfect. The dynamic characteristics of the semi-ideal limiter are shown in Fig. 7.

3.2 Inverse-Tangent Limiter

Referring to Figs. 4*A* and 4*B*, the derivative of the inverse-tangent limiter is given by

$$\therefore \quad f'(v)=\frac{2}{\pi}\left(\frac{V_m}{v_0}\right)\frac{v_0^2}{u^2+v_0^2},$$

and its static curve is given by

$$F(v)=\frac{2}{\pi}V_m \tan^{-1}\frac{v}{v_0}. \quad (12)$$

Following the procedure outlined above, we have

$$\int_0^\infty f'(v)\cos(uv)dv=\frac{2V_m v_0}{\pi}\int_0^\infty \frac{\cos(uv)}{u^2+v_0^2}dv$$
$$=V_m e^{-uv_0}.$$
$$\therefore \quad f(v)=\frac{2V_m}{\pi}\int_0^\infty \frac{e^{-uv_0}\sin(uv)du}{u} \quad (13)$$

and the dynamic characteristics are given by[5]

$$V_{2\nu+1}(A)=\frac{4V_m}{\pi}\int_0^\infty \frac{e^{-uv_0}J_{2\nu+1}(uA)du}{u}$$
$$=\frac{4V_m}{\pi(2\nu+1)}\left\{\left[1+\left(\frac{v_0}{A}\right)^2\right]^{\frac{1}{2}}-\frac{v_0}{A}\right\}^{2\nu+1}. \quad (14)$$

The static curve and its dynamic characteristics are plotted in Fig. 8. As expected, such a limiter is less desirable than the semi-ideal one.

3.3 Limiter Equation Given by Error Integral

The static curve and its derivative are shown in Fig. 5, then

$$\left.\begin{aligned} f(v)&=\frac{2V_m}{v_0\pi^{\frac{1}{2}}}\int_0^\infty e^{-(v/v_0)^2}dv,\\ f'(v)&=\frac{V_m}{v_0}\frac{2}{\pi^{\frac{1}{2}}}e^{-(v/v_0)^2}.\end{aligned}\right\} \quad (15)$$

$$\therefore \quad \int_0^\infty f'(v)\cos(uv)dv$$
$$=\frac{2V_m}{v_0\pi^{\frac{1}{2}}}\int_0^\infty e^{-(v/v_0)^2}\cos(uv)dv$$
$$=V_m e^{-(uv_0/2)^2}.$$
$$\therefore \quad f(v)=\frac{2V_m}{\pi}\times\int_0^\infty \frac{e^{-(uv_0/2)^2}\sin(uv)du}{u}. \quad (16)$$

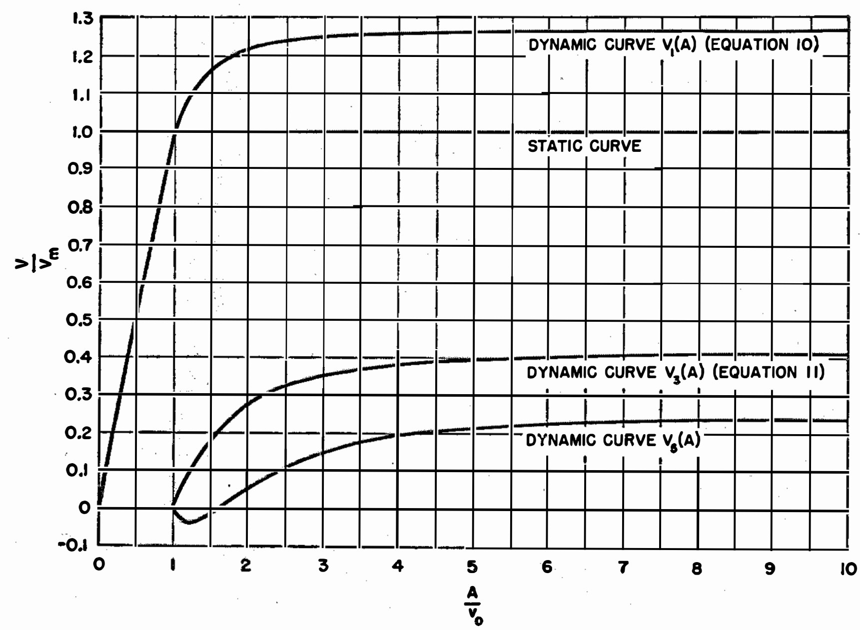

Fig. 7—Semi-ideal limiter.

[5] Reference 4, page 386, equation 7.

The dynamic characteristics are given by[6]

$$V_{2\nu+1}(A)=\frac{4V_m}{\pi}\int_0^\infty \frac{e^{-(uv_0/2)^2}J_{2\nu+1}(uA)du}{u}$$

$$=\frac{2V_mA}{\pi(2\nu+1)}\int_0^\infty e^{-(uv_0/2)^2}\times[J_{2\nu}(uA)+J_{2\nu+2}(uA)]du$$

$$=\frac{2V_m}{\pi^{\frac{1}{2}}}\frac{A}{v_0}\frac{e^{-(A^2/2v_0^2)}}{(2\nu+1)}\times\left[I_\nu\left(\frac{A^2}{2v_0^2}\right)+I_{\nu+1}\left(\frac{A^2}{2v_0^2}\right)\right], \quad (17)$$

[6] Reference 4, page 394, equation 5.

where $I_\nu(x)$ is the modified Bessel function of order ν. The dynamic characteristic of the fundamental and its harmonics is shown in Fig. 9, making use of available tables of $e^{-x}I_\nu(x)$ and $e^{-x}I_{\nu+1}(x)$ as given in reference 4.

3.4 Limiter Equation Given by an Exponential

This is shown in Fig. 6.

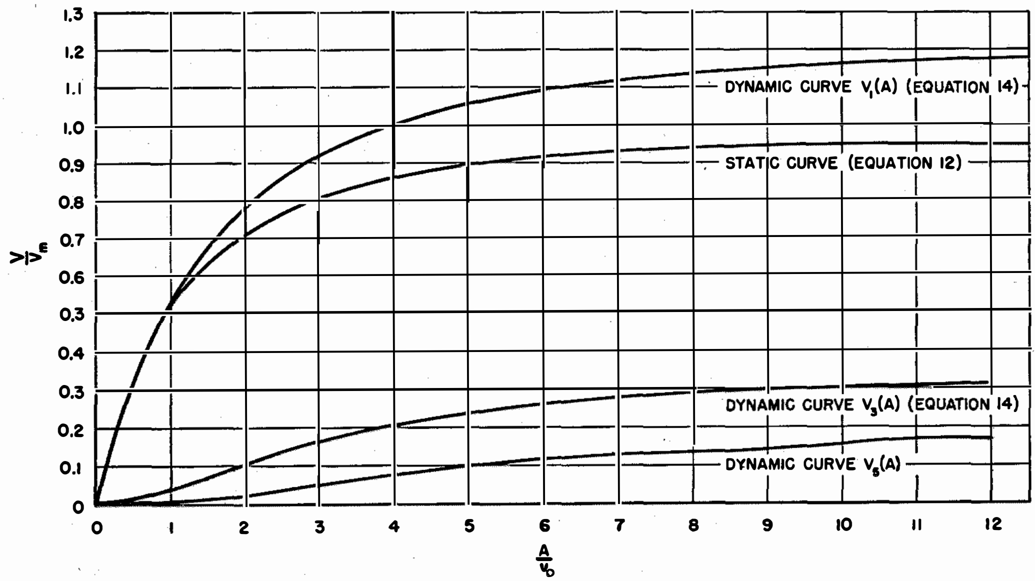

Fig. 8—Inverse-tangent limiter.

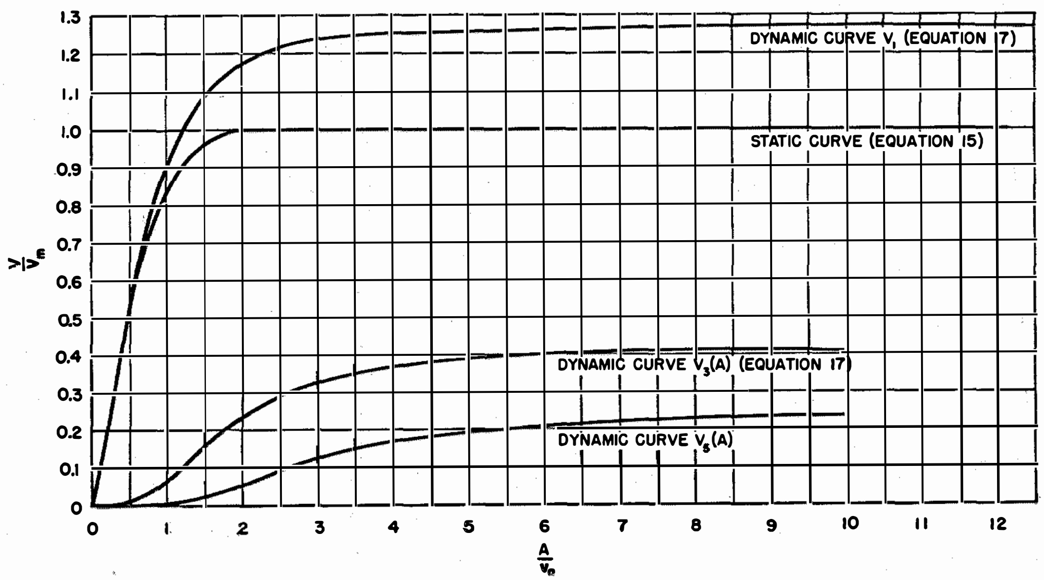

Fig. 9—Error-integral limiter.

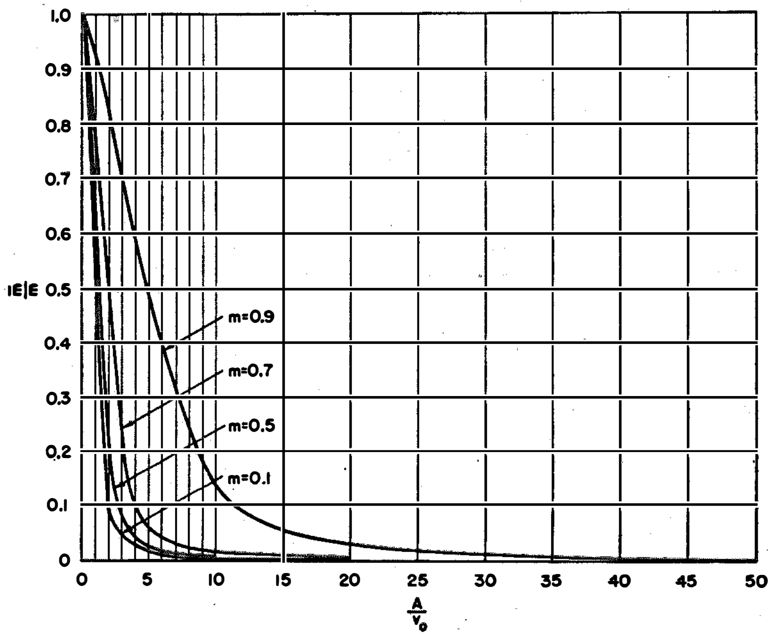

Fig. 10—Reduction in amplitude modulation versus input voltage for a semi-ideal limiter.

$$f(v) = V_m(1-e^{-(v/v_0)}), \quad v \geqslant 0,$$
$$= -V_m(1-e^{v/v_0}), \quad v \leqslant 0,$$

and

$$\left.\begin{aligned} f'(v) &= \frac{V_m}{v_0} e^{-(v/v_0)}, & v \geqslant 0,\\ &= \frac{V_m}{v_0} e^{v/v_0}, & v \leqslant 0. \end{aligned}\right\} \quad (18)$$

$$\therefore \int_0^\infty f'(v) \cos(uv) dv$$
$$= \frac{V_m}{v_0} \int_0^\infty e^{-(v/v_0)} \cos(uv) dv$$
$$= V_m \frac{1}{1+(uv_0)^2},$$
$$f(v) = \frac{2V_m}{\pi} \int_0^\infty \frac{\sin(uv) du}{u(1+\overline{uv}_0^2)}. \quad (19)$$

The dynamic characteristics are given by

$$V_{2\nu+1}(A) = \frac{4V_m}{\pi} \int_0^\infty \frac{J_{2\nu+1}(uA) du}{u(1+\overline{uv}_0^2)}. \quad (20)$$

The fundamental reduces to[7]

$$V_1(A) = \frac{4V_m}{\pi} \int_0^\infty \frac{J_1(uA) du}{u(1+\overline{uv}_0^2)}$$
$$= 2V_m\left[I_1\left(\frac{A}{v_0}\right) - L_1\left(\frac{A}{v_0}\right)\right]. \quad (21)$$

Where the function $L_\nu(x)$ is defined by the equation[8]

$$L_\nu(x) = \sum_{m=0}^{\infty} \frac{(x/2)^{\nu+2m+1}}{\Gamma(m+\frac{3}{2})\Gamma(\nu+m+\frac{3}{2})},$$

the function $L_\nu(x)$ bears the same relation to Struve's function as $I_\nu(x)$ bears to $J_\nu(x)$.

No curves were plotted for this limiter due to the fact that the authors are not aware of tables listing $L_1(x)$.

4. Reduction of Amplitude Modulation

Let $A(t)$ be an amplitude-modulated wave, namely, $A(t) = A_0(1+m \sin pt)$. The amplitude of the input varies, therefore, between the limits $A_0(1 \pm m)$. The effect of the limiter on such a wave is to reduce the index of modulation m. The output index of amplitude modulation will be defined by the relation

$$\bar{m} = \frac{V_1[A_0(1+m)] - V_1[A_0(1-m)]}{V_1[A_0(1+m)] + V_1[A_0(1-m)]}, \quad (22)$$

which may be obtained from the dynamic curve of the fundamental. The ratio $\bar{m}/m$, when plotted versus the input voltage v, gives a measure of the reduction in amplitude modulation effected by the action of the limiter.

Curves showing the variation of $\bar{m}/m$ versus A/v_0 are plotted in Figs. 10–12, for the limiters discussed above. The degree of limiting as a function of the input voltage may also be investigated by expanding $V_1(A)$ in powers of v_0/A. For the semi-ideal limiter,

$$V_1(A) = \frac{2V_m}{\pi}\left\{\frac{A}{v_0} \sin^{-1} \frac{v_0}{A} + \left[1-\left(\frac{v_0}{A}\right)^2\right]^{\frac{1}{2}}\right\}$$
$$= \frac{4V_m}{\pi}\left[1 - \frac{1}{6}\left(\frac{v_0}{A}\right)^2 - \frac{1}{40}\left(\frac{v_0}{A}\right)^4\right]. \quad (23)$$

For the error-integral limiter, using the asymptotic expansion of $I_0(x)$ and $I_1(x)$,

$$V_1(A) = \frac{4V_m}{\pi}\left[1 - \frac{1}{4}\left(\frac{v_0}{A}\right)^2 - \frac{3}{32}\left(\frac{v_0}{A}\right)^4 \cdots \right].$$

[7] Reference 4, page 426, equation 11.

[8] Reference 4, page 329, equation 11.

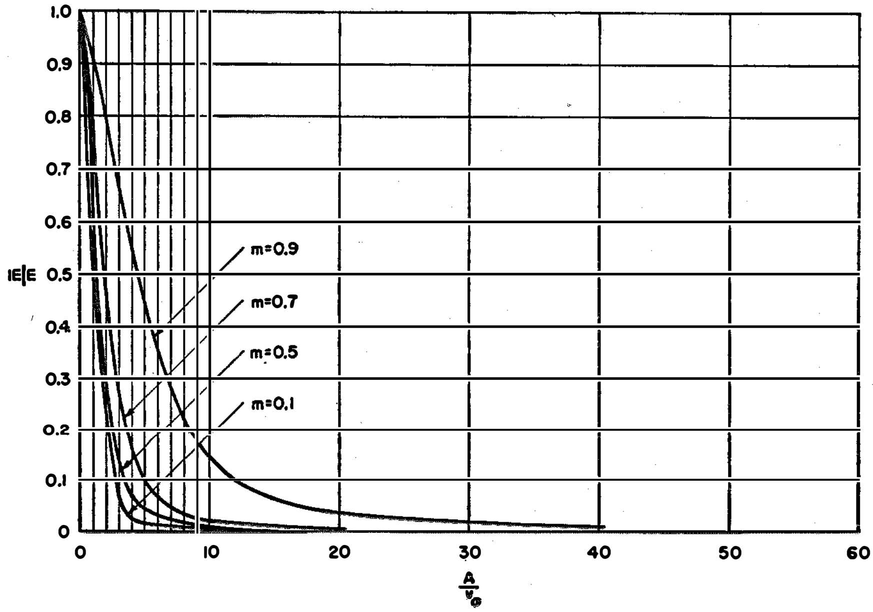

Fig. 11—Reduction in amplitude modulation versus input voltage for an error-integral limiter.

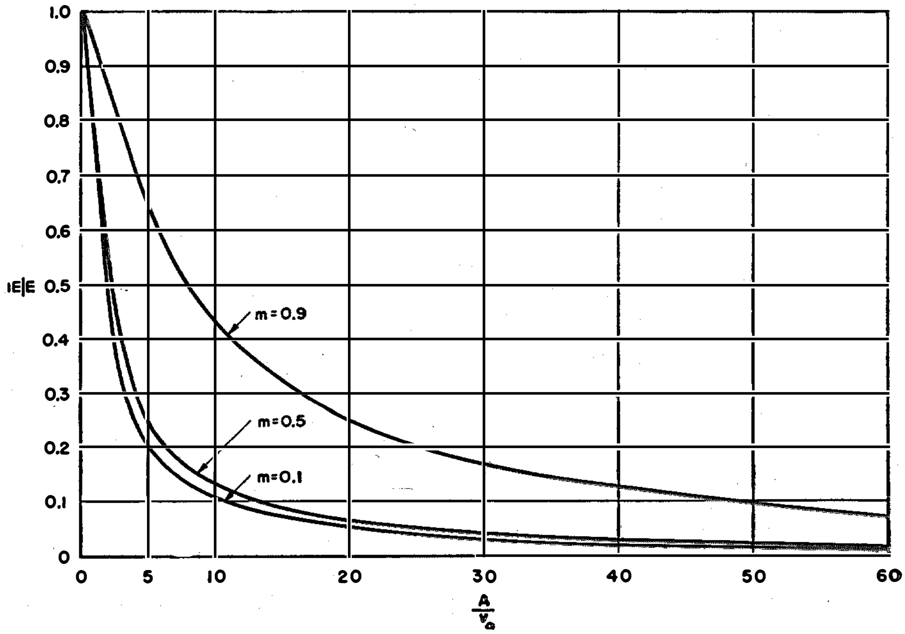

Fig. 12—Reduction in amplitude modulation versus input voltage for an inverse-tangent limiter.

Using these relations and (22) for $\tilde{m}/m$, for the semi-ideal limiter

$$\frac{\tilde{m}}{m}=\frac{1}{3}\left(\frac{v_0}{A_0}\right)\frac{1}{(1-m^2)^2}, \qquad (24)$$

and for the error-integral limiter

$$\frac{\tilde{m}}{m}=\frac{1}{2}\left(\frac{v_0}{A_0}\right)^2\frac{1}{(1-m^2)^2}. \qquad (25)$$

The last two equations illustrate the effectiveness of these limiters, which is also borne out in Figs. 10 and 11. However, for the inverse-tangent limiter,

$$V_1(A)=\frac{4V_m}{\pi}\left\{\left[1+\left(\frac{v_0}{A}\right)^2\right]^{\frac{1}{2}}-\frac{v_0}{A}\right\}$$
$$=\frac{4V_m}{\pi}\left[1-\frac{v_0}{A}+\frac{1}{2}\left(\frac{v_0}{A}\right)^2\cdots\right].$$

In this case

$$\frac{\tilde{m}}{m}\doteq\frac{v_0}{A_0}\frac{1}{1-m^2}. \tag{26}$$

The performance of such a limiter in the reduction of the index of modulation would then be much poorer than the preceding ones, which is clearly illustrated in Fig. 12.

5. Conclusions

It has been shown that the effectiveness of a limiter is conveniently described by means of the derivative of the static characteristic curve. A number of different equations have been chosen for this derivative and the effect of the corresponding limiters on a wave having both frequency and amplitude modulation has been evaluated by means of Fourier transforms. The output has been found to consist of a series of terms of the same type as the input wave, but the phase functions of which are multiplied by odd integers. These terms have been called fundamental and harmonics. In general, the carrier frequency of the input wave is chosen so that the so-called harmonics can in practice be filtered out from the fundamental. The fundamental presents a residual amplitude modulation and the ratio of this residual amplitude-modulation index to the output amplitude-modulation index has been plotted versus the input voltage for the different cases of limiter characteristics that have been examined.

The method used can obviously be extended to other nonlinear four-terminal networks including, for instance, rectifiers or vacuum tubes, when the effect of saturation is considered.

6. Appendix

The expressions given for the semi-ideal limiter shown in Fig. 13 may be obtained by expanding the static curve as a Fourier series valid over the range $-V_1$ to $+V_1$.

The characteristic is defined by the equations:

$$\left.\begin{aligned} V&=-V_m, & -v_1\leqslant v\leqslant -v_0.\\ V&=\frac{V_m}{v_0}v, & v_0\leqslant v\leqslant v_0.\\ V&=+V_m, & v_0\leqslant v\leqslant v_1.\end{aligned}\right\} \tag{27}$$

To simplify the results, we may subtract the linear function defined by

$$V'=\frac{V_m}{v_1}v,\quad -v_1\leqslant v\leqslant v_1. \tag{28}$$

This gives the function shown in Fig. 14 defined by

$$\left.\begin{aligned} V''&=-V_m-\frac{V_m}{v_1}v, & -v_1\leqslant v\leqslant -v_0.\\ V''&=v\left(\frac{V_m}{v_0}-\frac{V_m}{v_1}\right), & -v_0\leqslant v\leqslant v_0.\\ V''&=V_m-\frac{V_m}{v_1}v, & v_1\leqslant v\leqslant v_0.\end{aligned}\right\} \tag{29}$$

The function V'' is an odd function so that it may be expanded into a sine series as follows.

$$f(v)=\sum_{n=1}^{\infty}a_n\sin\frac{2\pi nv}{v_1}, \tag{30}$$

where

$$a_n=\frac{2}{v_1}\int_0^{v_1}f(v)\sin\frac{2\pi nv}{v_1}dv.$$

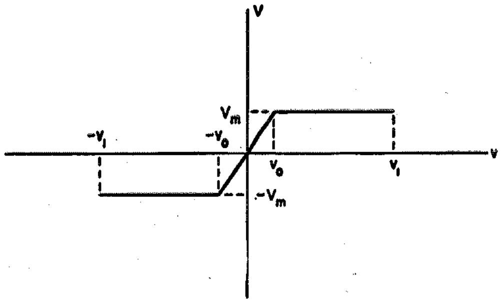

Fig. 13—Semi-ideal limiter.

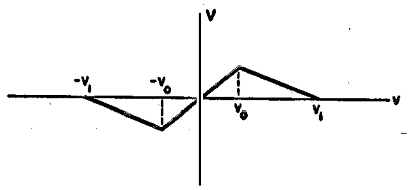

Fig. 14—The function V''.

Performing the integrations, we have as the equation of the static limiter curve

$$V=\frac{2V_m v}{v_1}+\frac{4V_m v_0}{v_1}\sum_{n=1}^{\infty}\frac{\sin\dfrac{2\pi n v_0}{v_1}}{\left(\dfrac{2\pi n v_0}{v_1}\right)^2}\sin\frac{2\pi n v}{v_1}$$

$$=-\frac{2V_m v}{v_1}+\frac{4V_m v_0}{v_1}\sum_{0}^{\infty}\frac{\sin\dfrac{2\pi n v_0}{v_1}}{\left(\dfrac{2\pi n v_0}{v_1}\right)^2}\sin\frac{2\pi n v}{v_1}. \quad (31)$$

If we let $v=A\sin\phi$, the coefficient of $\sin\phi$ is

$$V_1(A)=-\frac{2V_m}{v_1}A+\frac{8V_m v_0}{v_1}\sum_{0}^{\infty}\frac{\sin\dfrac{2\pi n v_0}{v_1}}{\left(\dfrac{2\pi n v_0}{v_1}\right)^2}J_1\left(\frac{2\pi n A}{v_1}\right). \quad (32)$$

To sum the infinite series, we may use the Euler-Maclaurin summation formula

$$f(a)+f(a+w)+\ldots.+f[a+(n-1)w]+f(a+nw)$$
$$=\frac{1}{w}\int_a^{a+nw}f(x)dx+\tfrac{1}{2}[f(a)+f(a+nw)]$$
$$-\frac{B_1 w}{2!}[f'(a+nw)-f'(a)]$$
$$+\frac{B_2 w^3}{4!}[f'''(a+nw)-f'''(a)]\ldots., \quad (33)$$

where $B_1, B_2, \ldots.$ are Bernoulli's numbers. Here $a=0$, $w=2\pi/v_1$, so that

$$f(x)=\frac{\sin v_0 x}{v_0^2 x^2}J_1(Ax). \quad (34)$$

As $f(x)$ is an even function, all the odd derivatives vanish when $x=0$. As x is allowed to become infinite, the function and its derivatives vanish. Thus:

$$\sum_{0}^{\infty}\frac{\sin\dfrac{2\pi n v_0}{v_1}J_1\left(\dfrac{2\pi n A}{v_1}\right)}{\left(\dfrac{2\pi n v v_0}{v}\right)^2}$$
$$=\frac{v_1}{2\pi v_0^2}\int_0^{\infty}\frac{\sin v_0 x J_1(Ax)dx}{x^2}+\frac{1}{4}\frac{A}{v_0}.$$

This gives

$$V_1(A)=\frac{4V_m}{v_0}\int_0^{\infty}\frac{\sin v_0 x J_1(Ax)dx}{x^2}, \quad (35)$$

which is the same formula as derived previously. The result is independent of the assumed range $-v_1$ to v_1 and hence is a general result. The expressions for the higher-order characteristics may be obtained in the same manner.

Thermomagnetic Generator

By L. BRILLOUIN and H. P. ISKENDERIAN

Federal Telecommunication Laboratories, Incorporated, Nutley, New Jersey

PROPOSALS have been made[1] to use the properties of ferromagnetic substances near the Curie point for constructing thermomagnetic current generators. Large flux variations could be induced in a coil and alternating currents generated by heating and cooling above and below its Curie point a ferromagnetic substance that is part of a magnetic circuit.

The mechanism, therefore, lies in the temperature dependence of the permeability of the substance and the associated thermomagnetic effects. In this paper, calculations are given of the magnitude of the effect and of the efficiencies obtainable.

• • •

1. *Thermodynamics of Magnetic Substances*

The thermodynamic properties of magnetic substances have been investigated for many years in connection with anomalies of the specific heat near the Curie point[2] and, more recently, a very important use of these theories has been made in the magnetic method of obtaining extremely low temperatures,[3] down to 1/100 of a degree, absolute. A short account of the theory may be found in textbooks.[4] Similar results have also been obtained on dielectrics.[5] A complete statistical theory of magnetism appears also in texts.[6]

The thermodynamic properties of magnetic substances will be summarized and some useful formulas for determining the conditions for maximum efficiency in a thermomagnetic generator will be derived. To avoid unnecessary complications, we will assume that hysteresis effects do not exist, thus indicating complete thermodynamic reversibility.

When heat dQ is applied to a magnetic substance, varying its temperature T by dT and its induction B by dB, we have

$$dQ = c(T,B)dT + fdB, \tag{1}$$

where c = heat capacity per unit volume at constant induction B, f = coefficient of "heat of magnetization."

The magnetic work dW done by the magnetic system per unit volume is given[7] by

$$-dW = HdB, \tag{2}$$

where H is the total field.

According to the law of conservation of energy, the increase dU in the internal energy of the magnetic body is given by

$$dU = dQ + (-dW) = c(T,B)dT + (f+H)dB. \tag{3}$$

Equation (3) is an exact total differential; hence

$$\left.\begin{aligned} &\frac{\partial}{\partial B}\left(\frac{\partial U}{\partial T}\right) = \frac{\partial}{\partial T}\left(\frac{\partial U}{\partial B}\right) \\ \text{or}\quad &\left.\frac{\partial c}{\partial B}\right]_T = \left.\frac{\partial f}{\partial T}\right]_B + \left.\frac{\partial H}{\partial T}\right]_B . \end{aligned}\right\} \tag{4}$$

Equation (4) shows the dependence of c on B.

Since a reversible process has been assumed, the entropy change

$$dS = \frac{dQ}{T} = \frac{c}{T}dT + \frac{f}{T}dB \tag{5}$$

must also be an exact total differential. Hence,

$$\left.\begin{aligned} &\frac{\partial}{\partial B}\left(\frac{\partial S}{\partial T}\right) = \frac{\partial}{\partial T}\left(\frac{\partial S}{\partial B}\right) \\ \text{or}\quad &\frac{\partial}{\partial B}\left(\frac{c}{T}\right) = \frac{\partial}{\partial T}\left(\frac{f}{T}\right) . \end{aligned}\right\} \tag{6}$$

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[1] Thomas Edison, British Patent 16,709; 1887: N. Tesla, U.S. Patent 428,057; 1890: Chilowsky, U.S. Patent Applications 627,832 and 635,988.

[2] Weiss and Forrer, "Magneto-Caloric Effect," *Annales de Physique*, v. 15, pp. 153–213; January–February, 1926.

[3] Giauque and MacDougall, "The Production of Temperatures Below One Degree Absolute by Adiabatic Demagnetization of Gadolinium Sulphate," *Journal of the American Chemical Society*, v. 57, pp. 1175–1185; July, 1935.

[4] Zemansky, "Heat and Thermo Dynamics," 2nd Edition, McGraw-Hill Book Company, New York, New York, pp. 271–279.

[5] Brillouin, "Propagation des Ondes Electromagnetiques dans les Milieux Matériels," *Congress International d'Electricité*, Paris, 1932; v. II, pp. 739–786.

[6] Van Vleck, "Theory of Electric and Magnetic Susceptibility," 1st Edition, Oxford-Clarendon Press, 1932.

[7] J. A. Stratton, "Electromagnetic Theory," 1st Edition, McGraw-Hill Book Company, New York, New York, 1941; p. 124: Also, R. W. P. King, "Electromagnetic Engineering," v. 1, 1st Edition, McGraw-Hill Book Company, New York, New York, 1945; p. 187.

Hence,

$$\frac{1}{T}\left(\frac{\partial c}{\partial B}\right)_T = -\frac{f}{T^2}+\frac{1}{T}\left(\frac{\partial f}{\partial T}\right)_B$$

and

$$\left[\frac{\partial c(T,B)}{\partial B}\right]_T = -\frac{f}{T}+\left[\frac{\partial f}{\partial T}\right]_B. \qquad (7)$$

From (4) and (7),

$$f = -T\left[\frac{\partial H}{\partial T}\right]_B \qquad (8)$$

and

$$\left.\frac{\partial c(T,B)}{\partial B}\right]_T = -T\left[\frac{\partial^2 H}{\partial T^2}\right]_B; \qquad (9)$$

hence, by integration of (9),

$$c(T,B) = c(T,O) - T\int\left[\frac{\partial^2 H}{\partial T^2}\right]dB. \qquad (10)$$

According to (3) this.... $= \left[\frac{\partial U}{\partial T}\right]_B$.

From (1) and (8), the heat given to the system becomes

$$dQ = TdS = c(T,B)dT - T\left[\frac{\partial H}{\partial T}\right]dB. \qquad (11)$$

We also have, from (3) and (8),

$$\frac{\partial U}{\partial B} = H - T\left[\frac{\partial H}{\partial T}\right]_B. \qquad (12)$$

The factors T and B were taken as the independent variables in the foregoing discussion. We may change to variables T and H, instead, by taking $B(T,H)$ or

$$dB = \left[\frac{\partial B}{\partial T}\right]_H dT + \left[\frac{\partial B}{\partial H}\right]_T dH. \qquad (13)$$

Then, corresponding to (1), we have the expression

$$dQ = c(T,H)dT + gdH, \qquad (14)$$

where $c(T,H)$ denotes heat capacity at a constant field H.

Starting from (2) and (13), we have, for work done by the system,

$$-dW = HdB = H\left(\frac{\partial B}{\partial T}\right)_H dT + H\left(\frac{\partial B}{\partial H}\right)_T dH. \qquad (15)$$

By an analogous reasoning, writing conditions that make dU and dS exact total differentials, we obtain

$$g = T\left[\frac{\partial B}{\partial T}\right]_H. \qquad (16)$$

$$\left.\begin{aligned} TdS = dQ &= c(T,H)dT + T\left(\frac{\partial B}{\partial T}\right)_H dH, \\ \left[\frac{\partial c(T,H)}{\partial H}\right]_T &= T\left.\frac{\partial^2 B}{\partial T^2}\right]_H, \\ dU &= cdT + (g+B)dH, \end{aligned}\right\} \qquad (17)$$

$$c(T,H) = c(T,O) + T\int_O^H \left(\frac{\partial^2 B}{\partial T^2}\right)_H dH, \qquad (18)$$

and

$$\left.\frac{\partial U}{\partial H}\right]_T = T\left[\frac{\partial B}{\partial T}\right]_H + H\left[\frac{\partial B}{\partial H}\right]_T. \qquad (19)$$

It should be noted that these relations do not imply any special assumption about the relations between B, H, and T.

2. *Simplifications for Substances Having Constant Permeability*

2.1 $B = \mu(T)H$

If we consider an average value of permeability μ dependent on temperature only,

$$H(T,B) = \frac{1}{\mu(T)}B, \qquad (20)$$

(3) and (5), with the help of (8), yield

$$U(T,B) = U(T,O) + \tfrac{1}{2}B^2\left(\frac{1}{\mu} - T\frac{\partial \frac{1}{\mu}}{\partial T}\right) \qquad (21)$$

and

$$S(T,B) = S(T,O) - \tfrac{1}{2}B^2\frac{\partial \frac{1}{\mu}}{\partial T}. \qquad (22)$$

Equation (10) then gives

$$c(T,B) = c(T,O) - \tfrac{1}{2}B^2 T\frac{\partial^2 \frac{1}{\mu}}{\partial T^2}, \qquad (23)$$

where

$$c(T,O) = \frac{\partial U(T,O)}{\partial T} = T\frac{\partial S(T,O)}{\partial T} \qquad (24)$$

is the heat capacity for zero induction. Equation (11) now becomes

$$dQ = c(T,B)dT - T\left[\frac{\partial \frac{1}{\mu}}{\partial T}\right]_B BdB. \qquad (25)$$

This equation gives, for $dT=0$, the amount of heat to be given to the system during a change of magnetization dB.

Turning now to variables T,H as in (13) to (18), by integration of dU,

$$U(T,H)=U(T,O)+\tfrac{1}{2}H^2\left(\mu+T\frac{\partial\mu}{\partial T}\right) \quad (26)$$

and

$$c(T,H)=c(T,O)+\tfrac{1}{2}H^2T\frac{\partial^2\mu}{\partial T^2}, \quad (27)$$

with

$$dQ=c(T,H)dT+T\frac{\partial\mu}{\partial T}HdH. \quad (28)$$

For paramagnetic substances that follow the Curie-Weiss law,

$$\mu=\mu_0+\frac{C}{T-\Theta}, \quad (29)$$

where $T>\Theta$ (Curie temperature), and μ_0, the permeability of a vacuum, may be neglected. From (29),

$$\frac{\partial}{\partial T}\frac{1}{\mu}=\frac{1}{C}$$

and

$$\frac{\partial^2}{\partial T^2}\frac{1}{\mu}=0.$$

Equations (25) and (28) become

$$dQ=c(T,B)dT-\frac{T}{C}BdB$$

$$=c(T,H)dT-\frac{CT}{(T-\Theta)^2}HdH. \quad (30)$$

The heat-capacity equations given by (23) and (27) become

$$c(T,B)=c(T,O)$$

and

$$c(T,H)=c(T,O)+H^2T\frac{C}{(T-\Theta)^3}. \quad (31)$$

As is known, the usual heat capacity $c(T,O)$ of solids drops to negligible values at very low temperatures of the order of T^3. During an adiabatic demagnetization, it follows from (30) and (31),

$$c(T,H)dT=H^2T\frac{C}{(T-\Theta)^3}dT$$

$$=\frac{CT}{(T-\Theta)^2}HdH.$$

Hence,

$$\frac{dT}{T-\Theta}=\frac{dH}{H} \quad (32)$$

or

$$T-\Theta=AH, \quad (33)$$

where A = a constant. By reducing H to zero, the temperature drops to the Curie point Θ. Then, from (29) and (33),

$$B=H=\frac{C}{T-\Theta}\times\frac{T-\Theta}{A}=\frac{C}{A},$$

meaning that B remains constant during this adiabatic process. Some salts, like gadolinium sulfate, have a Curie temperature very near absolute zero. Very low temperatures may be reached by this adiabatic demagnetization process.[3]

2.2 $B(T,H)=B(T,O)+\mu_\Delta H$

If we assume the soft ferromagnetic component of the generator to be nearly saturated throughout a heat cycle (only a few oersteds are required), we may write

$$B(T,H)=B(T,O)+\mu_\Delta H. \quad (34)$$

For this case, expressions for internal energy $U(T,H)$, heat capacity $c(T,H)$, and entropy $S(T,H)$ become as follows from (17), (18), (19), and (34):

$$U(T,H)=U(T,O)+HT\frac{\partial B(T,O)}{\partial T}+\tfrac{1}{2}H^2\left(\mu_\Delta+T\frac{\partial\mu_\Delta}{\partial T}\right), \quad (35)$$

$$c(T,H)=c(T,O)+HT\frac{\partial^2 B}{\partial T^2}(T,O)+\tfrac{1}{2}H^2T\frac{\partial^2\mu_\Delta}{\partial T^2}, \quad (36)$$

and

$$S(T,H)=S(T,O)+H\frac{\partial B(T,O)}{\partial T}+\tfrac{1}{2}H^2\frac{\partial\mu_\Delta}{\partial T}, \quad (37)$$

where

$$c(T,O)=\frac{\partial U(T,O)}{\partial T}=T\frac{\partial S(T,O)}{\partial T}$$

is the heat capacity for zero induction. Equation (17) gives

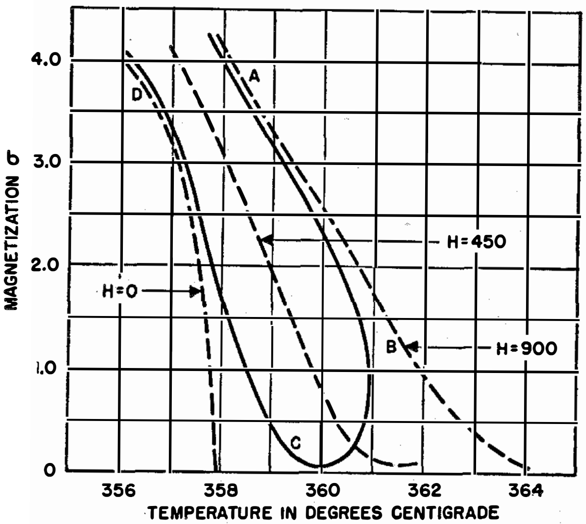


Fig. 1—Magnetization-versus-temperature curve for heat cycle A–B–C–D shown by solid line. Values of H are in oersteds. $(\overline{\partial\sigma}/\partial T)\simeq 1.2$ per heat cycle. Based on experimental data for nickel by Weiss and Forrer.

$$dQ = TdS$$

$$= c(T,H)dT + T\left[\frac{\partial B(T,O)}{\partial T} + H\frac{\partial \mu_\Delta}{\partial T}\right]dH \quad (38)$$

as the amount of heat required by the system to maintain its temperature constant during magnetization.

3. *Ideal Thermomagnetic Generator; Carnot and T,H Cycles*

In a thermomagnetic generator, the sample is acted on by a permanent magnet and a coil through which a current i flows, contributing to a magnetic field H, while the temperature is varied. Hence, it seems convenient to use T and H as independent variables; we shall assume here $B(T,H) = \mu(T)H$. Maximum efficiency should be attained with a Carnot cycle consisting of two adiabatic branches connecting two branches at T_1 and T_2.

First, consider an adiabatic transformation with $dQ = 0$. According to (27) and (28),

$$\left[c(T,O) + \tfrac{1}{2}H^2T\frac{\partial^2\mu}{\partial T^2}\right]dT + T\frac{\partial\mu}{\partial T}HdH = 0. \quad (39)$$

A rise dT in temperature is accompanied by an increase dH in magnetic field.

We intend to work with a ferromagnetic substance in which permeability decreases when T is increased and becomes μ_0 at the Curie temperature Θ. This suggests a law of the form

$$\mu = \mu_0 + A(\Theta - T)^n, \quad (40)$$

where $A > 0$, $T \leqslant \Theta$, and the exponent n seems to be of the order of 1 or 2.

Experimental data obtained by Weiss and Forrer on nickel show, in Fig. 1, a dependence of σ on H in addition to T. Since this leads to great complications, we shall take average values of A and Θ that correspond to an average field intensity and, using an exponent $n = 1$ (Fig. 2),

$$\left.\begin{aligned} \mu &= \mu_0 + A(\Theta - T), \\ \frac{\partial\mu}{\partial T} &= -A, \\ \frac{\partial^2\mu}{\partial T^2} &= 0, \end{aligned}\right| \quad (41)$$

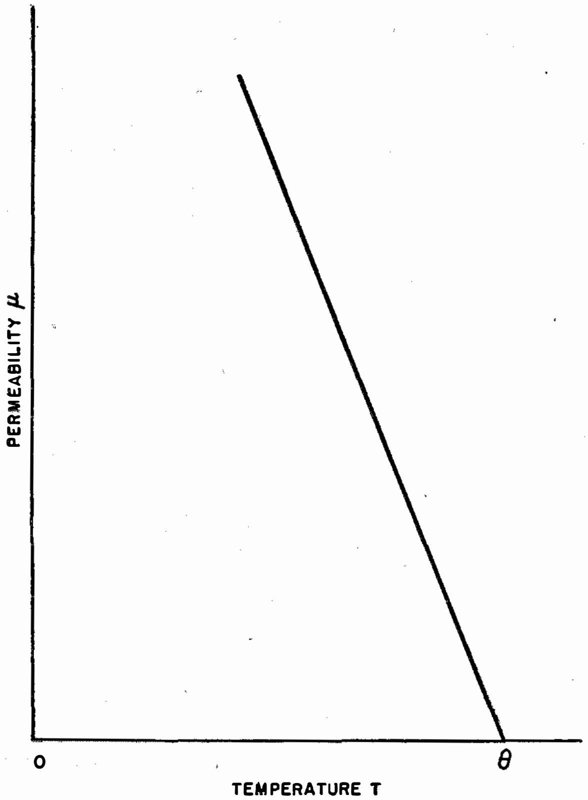


Fig. 2—Permeability μ plotted against temperature for a thermomagnetic generator. Θ is the Curie temperature. The slope of the curve $= -A$.

where $T \leqslant \Theta$. Then, from (27) and (39),

$$\left.\begin{array}{l} c(T,H)=c(T,O), \\ c(T,O)dT=ATH\,dH, \end{array}\right\} \quad (42)$$

for an adiabatic transformation. The heat capacity $c(T,O)$ can be treated as a constant c_0 and (42) is integrated:

$$c_0 \log\frac{T}{T_0} = \tfrac{1}{2}AH^2, \quad (43)$$

where T_0 is the temperature for which $H=0$.

$$T=T_0\, e \exp\left[\frac{A}{2c_0}H^2\right], \quad (44)$$

where $T \leqslant \Theta$. The Carnot cycle is approximately plotted in Fig. 3. Thermodynamic efficiency $\mathcal{E}$ is defined as the ratio

$$\mathcal{E}=\frac{W}{Q_1}, \quad (45)$$

which is work output W per cycle for a heat input Q_1, not counting the amount of heat $-Q_2$ returned to the source at a lower temperature T. On the other hand,

$$W=Q_1-|Q_2|=Q_1+Q_2 \quad (46)$$

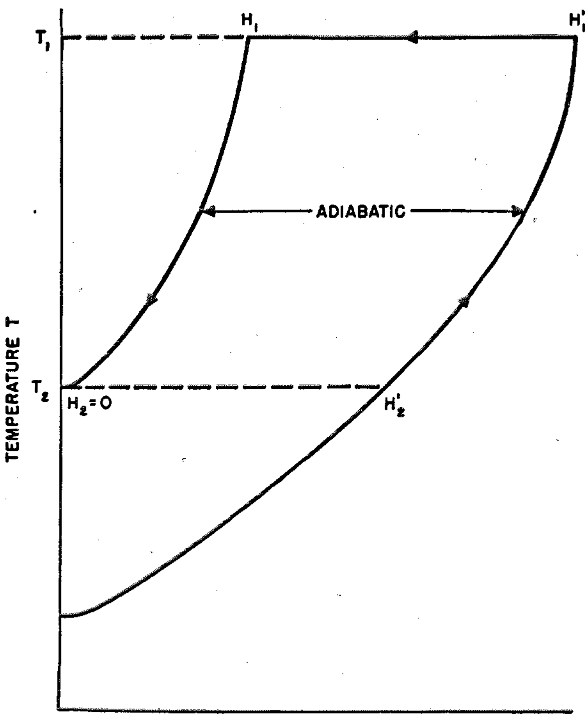


Fig. 3—Carnot cycle for a thermomagnetic generator.

in consideration of energy conservation; hence,

$$\mathcal{E}=1-\frac{Q_2}{Q_1}. \quad (47)$$

In this example, we can easily compute Q_1 and Q_2 from (28). During an isothermal transformation (at either T_1 or T_2), the amount of heat input is

$$Q=\int_H^{H'} dQ=T\frac{\partial\mu}{\partial T}\int_H^{H'} HdH$$
$$=\tfrac{1}{2}T\frac{\partial\mu}{\partial T}(H'^2-H^2), \quad (48)$$

or, according to (41),

$$Q=-\tfrac{1}{2}AT(H'^2-H^2), \quad (49)$$

where $T \leqslant \Theta$. From the cycle of Fig. 3 and using (43) for the adiabatic branches, we have

$$c_0 \log\frac{T_1}{T_2}=\tfrac{1}{2}AH_1^2=\tfrac{1}{2}A(H_1'^2-H_2'^2),$$

and thus $H_1^2-H_1'^2=-H_2'^2$. For the highest temperature T_1, (49) yields

$$Q_1=\tfrac{1}{2}AT_1(H_1^2-H_1'^2) \quad (50)$$

for heat input,

$$Q_2=-\tfrac{1}{2}AT_2H_2'^2$$

for heat output at the lowest temperature T_2, and the efficiency by (50) is

$$\mathcal{E}=1-\frac{|Q_2|}{Q_1}=1-\frac{T_2}{T_1}=\frac{T_1-T_2}{T_1}. \quad (51)$$

This is the expected maximum efficiency for a Carnot cycle.

Another cycle to be considered is the T,H cycle shown in Fig. 4. The heat given to the system along the isothermal branches at T_1 or T_2 can be computed from (49). In addition, we have to consider the heating process AB at a constant field H' and the cooling CO under zero field. The heat input is

$$Q_1=Q_{AB}+Q_{BC}=c(T,H)(T_1-T_2)+\frac{AT_1}{2}H'^2. \quad (52)$$

The heat output is

$$|Q_2|=|Q_{CO}|+|Q_{OA}|$$
$$=c(T,O)(T_1-T_2)+\frac{AT_2}{2}H'^2, \quad (53)$$

and according to (42), $c(T,H)=c(T,O)=c_0$. The efficiency becomes

$$\left.\begin{aligned}\mathcal{E}_{TH}&=1-\frac{|Q_2|}{Q_1}\\&=1-\frac{\frac{1}{2}AT_2H'^2+c_0(T_1-T_2)}{\frac{1}{2}AT_1H'^2+c_0(T_1-T_2)}\end{aligned}\right\} \quad (54)$$

and is obviously smaller than the efficiency for the Carnot cycle. If the heat capacity c_0 be large

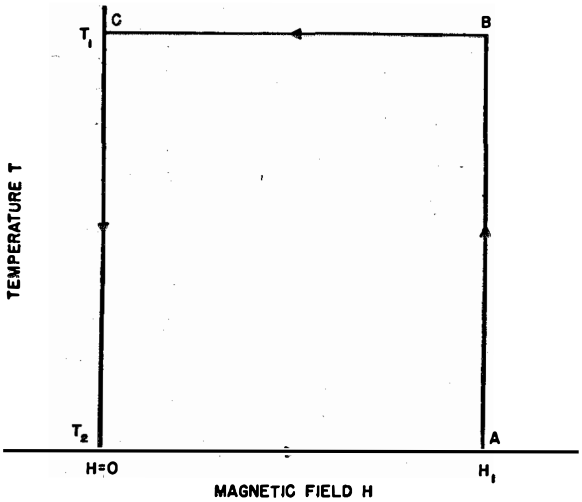


Fig. 4—*T,H* cycle for a thermomagnetic generator.

enough, the efficiency may become very small, as seen from simplification of (54).

$$\mathcal{E}_{TH}=\frac{T_1-T_2}{T_1+\frac{2c_0}{AH'^2}(T_1-T_2)}. \quad (55)$$

4. *Actual Thermomagnetic Generator and Its Cycle for Case of B(T,H) = μ(T)H*

4.1 Optimum Current and Power

Assume a structure like that represented in Fig. 5, with a magnetically soft[8] component of variable temperature T in a field H with a large average component H_0 due to a permanent magnet, plus the field induced by the current i in the coils:

$$H=H_0+n_0i \quad (56)$$

in meter-kilogram-second rational units, where n_0 = number of turns of the coil per unit length, $n=n_0l$ = total number of turns for a coil of length l. The temperature is supposed to vary sinusoidally,

$$T=T_a+b\sin\omega t. \quad (57)$$

Highest temperature $=T_1=T_a+b\leqslant\Theta$.
Lowest temperature $=T_2=T_a-b$.

The permeability consequently follows a similar law:

$$\mu=\mu_a-Ab\sin\omega t, \quad (58)$$
$$\mu_a=\mu(T_a),$$

are average values assuming for $\mu(T)$ the same temperature dependence as in (41) and taking for A the average value of $-(\partial\mu/\partial T)$ over a whole cycle. The magnetic induction is

$$B=\mu H=(\mu_a-Ab\sin\omega t)(H_0+n_0i). \quad (59)$$

Let us assume the coil to be connected to a resistance R and write the electrical equation of the circuit. Calling $\phi=SB$ = the flux through a turn of surface S, we have

$$n\frac{d\phi}{dt}=nS\frac{dB}{dt}=-Ri, \quad (60)$$

or, according to (59),

$$\mu_a nn_0S\frac{di}{dt}-nn_0SAb\frac{d}{dt}(i\sin\omega t)+Ri$$
$$=nSAbH_0\cos\omega t. \quad (61)$$

In the first term of this equation, we recognize the self-induction of the circuit,

$$L=\mu_a nn_0S. \quad (62)$$

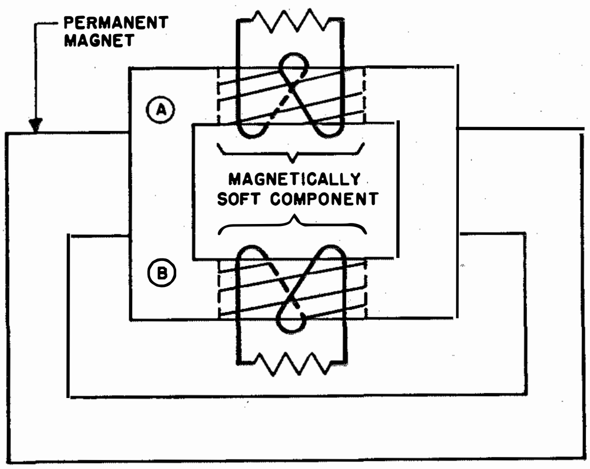


Fig. 5—Magnetic circuit of a thermomagnetic generator.

[8] *Magnetically soft* refers to materials with high μ's, in contrast to *magnetically hard* materials used for permanent magnets.

Assuming that the magnetic field due to the current i remains small[9] compared with H_0,

$$n_0 i \ll H_0, \tag{63}$$

we may ignore the second term as being small compared with the right-hand term, and obtain

$$L\frac{di}{dt}+Ri=\beta\omega\cos\omega t, \tag{64}$$

where $\beta = nSAbH_0$. We are not interested in the transients at the start of the operation, and look only for the final steady-state oscillations.

$$i = Ie^{j\omega t}, \tag{65}$$

where $I=\frac{\beta\omega}{j\omega L+R}$, which becomes maximum for $R=\omega L \ldots . |I_{\max}| = \beta/2^{\frac{1}{2}}L$. The power output is

$$P=\tfrac{1}{2}R|I|^2=\tfrac{1}{2}\left(\frac{\beta^2\omega^2 R}{L^2\omega^2+R^2}\right), \tag{66}$$

and becomes maximum when

$$\left.\begin{aligned} R &= L\omega,\\ P_{\max} &= \frac{\beta^2\omega}{4L}\\ &= \frac{\omega}{4}\frac{nS}{\mu_a n_0}(AbH_0)^2\\ &= \frac{\omega V}{4\mu_a}(AbH_0)^2, \end{aligned}\right| \tag{67}$$

according to (62) and (64), where $n = n_0 l$ and $V = Sl$ is the volume of the sample.

If the highest temperature is the Curie temperature Θ, for which μ is practically zero, we must state

$$\mu(T_1)=\mu(\Theta)=\mu_a-Ab=0 \tag{68}$$

in (58), and (67) then reduces to

$$\left.\begin{aligned} P_{\max} &= \frac{(\omega)}{4}V\mu_a H_0^2,\\ \text{and}\qquad T_1 &= T_a+b=\Theta, \end{aligned}\right\} \tag{69}$$

where $\mu_a=\mu(T_a)=Ab=\frac{1}{2}\mu(T_2)=\frac{1}{2}\mu_{\max}$. The work done per cycle and per unit volume is

$$\frac{W}{Vf}=\frac{\pi}{2}\mu_a H_0^2. \tag{70}$$

[9] Retaining $d/dt(i\sin\omega t)$ in the equation does not materially change the practical results of the discussion but introduces higher harmonics in the current.

4.2 Efficiency of Generator

We must now investigate the heat input of the system at different phases of a complete cycle to compute the efficiency. Let us assume the optimum resistance (67) in the electric circuit that will result in a current (65);

$$i=\frac{1}{L(1+j)}e^{j\omega t}=\frac{\beta}{2^{\frac{1}{2}}L}e\exp\left[j\left(\omega t-\frac{\pi}{4}\right)\right],$$

or

$$\left.\begin{aligned} i &= \frac{\beta}{2^{\frac{1}{2}}L}\cos\left(\omega t-\frac{\pi}{4}\right)\\ &= \frac{\beta}{2^{\frac{1}{2}}L}\sin\left(\omega t+\frac{\pi}{4}\right). \end{aligned}\right\} \tag{71}$$

Hence,

$$H=H_0+\frac{\beta n_0}{2^{\frac{1}{2}}L}\sin\left(\omega t+\frac{\pi}{4}\right)$$

according to (56). Referring to (62) and (64), we have

$$\begin{aligned} \frac{\beta n_0}{2^{\frac{1}{2}}L} &= \frac{nn_0SAbH_0}{2^{\frac{1}{2}}\mu_a nn_0 S}\\ &= \frac{Ab}{2^{\frac{1}{2}}\mu_a}H_0\\ &= \frac{1}{2^{\frac{1}{2}}}H_0, \end{aligned}$$

when the highest temperature is the Curie point

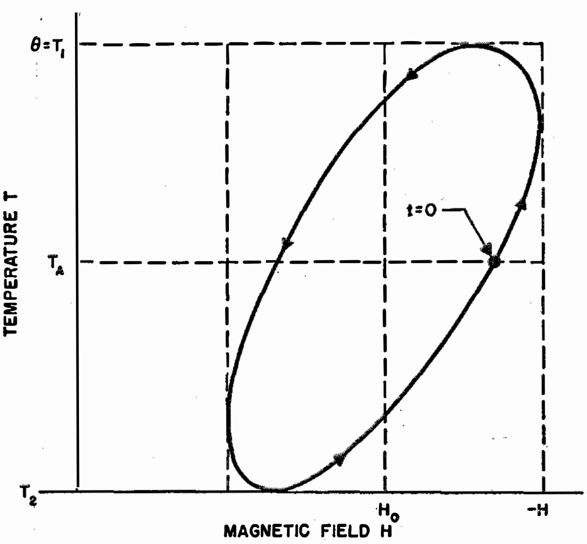


Fig. 6—Magnetizing field plotted against temperature.

Θ and (68) is satisfied. Then,

$$H=H_0\left[1+\frac{1}{2^{\frac{1}{2}}}\sin\left(\omega t+\frac{\pi}{4}\right)\right]. \qquad (72)$$

Comparing (72) and (57), we obtain the H,T cycle plotted in Fig. 6. If we compare (72) with (59) and (63), we see that the variable term, representing the field due to current i, is not very small ($H_0/2^{\frac{1}{2}}$ compared with H_0). A more detailed calculation shows, however, that this only introduces harmonics in the current without much change in the main contribution. For a small transformation dT, dH (equation (28)),

$$dQ=c(T,H)dT+T\frac{\partial\mu}{\partial T}HdH,$$

gives the heat input per unit volume. Or

$$dQ=c(T,O)dT-ATHdH, \qquad (73)$$

when we use the magnetization law of (41). We can treat the heat capacity $c(T,O)$ as a constant c_0, and use (57) and (72);

$$\left.\begin{aligned}\frac{dQ}{dt}&=c_0\frac{dT}{dt}-\tfrac{1}{2}AT\frac{d(H^2)}{dt}\\&=c_0b\omega\cos\omega t\\&\quad-\tfrac{1}{2}AT_aH_0^2\frac{d}{dt}\left(1+\frac{1}{2^{\frac{1}{2}}}\sin\phi\right)^2\\&\quad-\tfrac{1}{2}Ab\sin\omega tH_0^2\frac{d}{dt}\left(1+\frac{1}{2^{\frac{1}{2}}}\sin\phi\right)^2,\end{aligned}\right\} \qquad (74)$$

where we have $\phi=\omega t+(\pi/4)$; now,

$$\frac{d}{dt}\left(1+\frac{1}{2^{\frac{1}{2}}}\sin\phi\right)^2=\omega 2^{\frac{1}{2}}\cos\phi\left(1+\frac{1}{2^{\frac{1}{2}}}\sin\phi\right)$$
$$=\omega 2^{\frac{1}{2}}\cos\phi+\frac{\omega}{2}\sin 2\phi.$$

Then,

$$\frac{1}{\omega}\frac{dQ}{dt}=c_0b\cos\omega t-\frac{A}{2^{\frac{1}{2}}}T_aH_0^2\cos\phi$$
$$-\frac{A}{4}T_aH_0^2\sin 2\phi-\frac{A}{2^{\frac{1}{2}}}bH_0^2\sin\omega t\cos\phi$$
$$-\frac{A}{4}bH_0^2\sin\omega t\sin 2\phi. \qquad (75)$$

This equation may be put in the form

$$\frac{1}{\omega}\frac{dQ}{dt}=\frac{A}{4}bH_0^2$$
$$+c_0b\cos\omega t-\frac{A}{2^{\frac{1}{2}}}T_aH_0^2\cos\phi+\frac{A}{8}bH_0^2\sin\omega t$$
$$-\frac{A}{4}T_aH_0^2\sin 2\phi-\frac{AbH_0^2}{2\times 2^{\frac{1}{2}}}\sin\left(2\omega t+\frac{\pi}{4}\right)$$
$$-\frac{A}{8}bH_0^2\sin 3\omega t. \qquad (76)$$

The net input for a complete cycle is

$$q=\int_{t=0}^{t=2\pi/\omega}\frac{dQ}{dt}dt=A\frac{\pi}{2}bH_0^2, \qquad (77)$$

since only the first constant term contributes to the integral taken over a whole period. This corresponds exactly to (70), relating to the work done by the system per cycle for energy conservation.

As in the examples discussed in the preceding section, we must distinguish between the heat input Q_1 during one half of the cycle, and the heat output $Q_2=-|Q_2|$ during the other half. The net input q is

$$q=Q_1+Q_2=Q_1-|Q_2|. \qquad (78)$$

To compute the heat input, we integrate from $\omega t=\theta$ to $\omega t=\theta+\pi$, and we choose θ such as to make Q_1 maximum and positive.[10] The integration of terms in 2ϕ or $2\omega t$ obviously gives zero. Replacing ϕ by $\omega t+\pi/4$, and expanding and regrouping terms, we obtain

$$Q_1=\tfrac{1}{2}q+b\int_\theta^{\theta+\pi}\left[\left(c_0-\frac{T_a}{2b}AH_0^2\right)\cos\omega t\right.$$
$$\left.+\left(\frac{1}{8}+\frac{T_a}{2b}\right)AH_0^2\sin\omega t-\tfrac{1}{8}AH_0^2\sin 3\omega t\right]dt \qquad (79)$$

or

$$Q_1=\tfrac{1}{2}q+b\left[\left(2c_0-\frac{T_a}{b}AH_0^2\right)\sin\theta\right.$$
$$\left.-\left(\frac{1}{4}+\frac{T_a}{b}\right)AH_0^2\cos\theta+\tfrac{1}{12}AH_0^2\cos 3\theta\right].$$

[10] This means that we choose a half cycle during which heat is given to the system, while the other half cycle, from $\theta+\pi$ to $\theta+2\pi$, corresponds to heat released by the system.

The last term is small and may be dropped. Then,

$$Q_1 \simeq \tfrac{1}{2}q + b\left[\left(2c_0 - \frac{T_a}{b}AH_0^2\right)^2 + \left(\frac{1}{4} + \frac{T_a}{b}\right)^2 A^2H_0^4\right]^{\frac{1}{2}}. \tag{80}$$

The thermodynamic efficiency is given by

$$\mathcal{E} = \frac{q}{Q_1}$$

$$= \frac{q}{\tfrac{1}{2}q + \left[(2c_0b - T_aAH_0^2)^2 + \left(\frac{b}{4} + T_a\right)^2 A^2H_0^4\right]^{\frac{1}{2}}}$$

$$= \frac{\pi/2}{\frac{\pi}{4} + [(D-X)^2 + (\frac{1}{4}+X)^2]^{\frac{1}{2}}}, \tag{81}$$

using (77) for q and putting $D = 2c_0/AH_0^2$ and $X = T_a/b$. We must discuss the variation in efficiency when the temperature variation $\Delta T = 2b$ is continuously changed from 0 to its maximum (and unattainable) value $2T_a$, when $b = T_a$. This corresponds to a variation of X from infinity to 1.

4.2.1 *Case I*

If $b \ll T_a/D$ and $X \gg D$,

$$\mathcal{E}_{\mathrm{I}} = \frac{\frac{1}{2}\pi}{\frac{1}{4}\pi + 2^{\frac{1}{2}}X} = \frac{2\pi b}{\pi b + 4\times 2^{\frac{1}{2}}T_a} \simeq \frac{\pi\Delta T}{4\times 2^{\frac{1}{2}}T_1}. \tag{82}$$

Then, efficiency amounts to $\pi/4\times 2^{\frac{1}{2}} = 0.555$ times the corresponding Carnot efficiency, $\mathcal{E}_c = \Delta T/T_1$.

4.2.2 *Case II*

If $b = T_a/D$ and $X = D$,

$$\mathcal{E}_{\mathrm{II}} = \frac{\frac{\pi}{2}}{\frac{\pi}{4} + X + \frac{1}{4}} = \frac{2\pi}{\pi + 1 + 4D} \tag{83}$$

maximum. When b is increased further, the radical goes through a minimum that corresponds to maximum efficiency:

$$D - X = \tfrac{1}{4} + X,$$

$$X = \tfrac{1}{2}D - \tfrac{1}{8}, \quad \text{or} \quad \Delta T \simeq \frac{4T_a}{D}, \tag{84}$$

$$(D-X)^2 + (\tfrac{1}{4}+X)^2 = \tfrac{1}{2}(D+\tfrac{1}{4})^2,$$

and

$$\mathcal{E}_{\max} = \frac{\frac{\pi}{2}}{\frac{\pi}{4} + \frac{1}{2^{\frac{1}{2}}}(D+\frac{1}{4})} = \frac{2\pi}{\pi + \frac{1}{2^{\frac{1}{2}}} + 2\times 2^{\frac{1}{2}}D} \simeq \frac{\pi}{2^{\frac{1}{2}}D} \tag{85}$$

when D is large.

4.2.3 *Case III*

Larger values of b, if they can be obtained, yield a finite efficiency; if $b \gg T_a/D$, $X \ll D$,

$$\mathcal{E}_{\mathrm{III}} = \frac{\pi/2}{\pi/4 + D} = \frac{2\pi}{\pi + 4D} \simeq \frac{\pi}{2D}$$

for large D values, and the variation of efficiency with respect to b is represented by the curve of Fig. 7. The question of whether the maximum

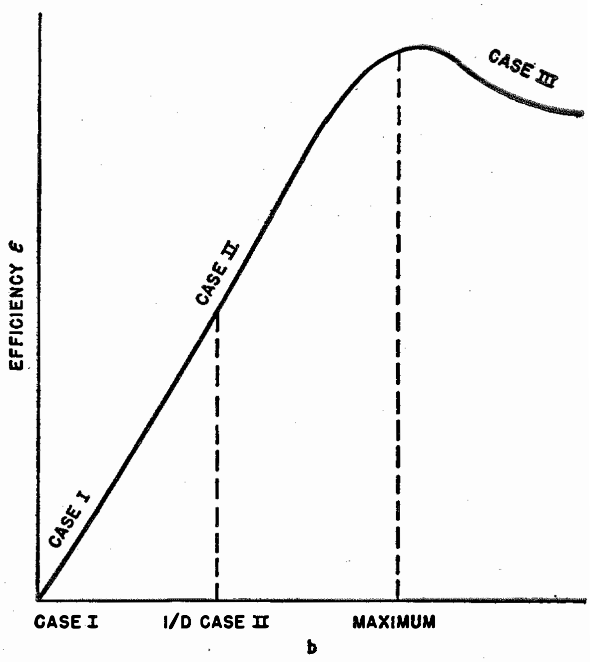


Fig. 7—Efficiency $\mathcal{E}$ plotted against b; $1/X = b/T_a$.

can be reached depends on its position, for we always have the *limitation*

$$\frac{1}{X} = \frac{b}{T_a} \leqslant 1. \tag{86}$$

Much will depend on the actual value of the coefficient

$$D = \frac{2c_0}{AH_0^2},$$

where c_0 = heat capacity per unit volume under zero magnetic field,
$-A = \partial\mu/\partial T$ = average rate of change of $\mu(T)$, and
H_0 = average magnetic field from permanent magnet.

This coefficient D is a dimensionless quantity that can be written

$$\left.\begin{aligned} D &= \frac{2c_0\Delta T}{\Delta\mu H_0^2} = \frac{\Delta Q}{\Delta W_m}, \\ \Delta Q &= c_0\Delta T, \\ \Delta W_m &= \tfrac{1}{2}\Delta\mu H_0^2, \end{aligned}\right\} \quad (88)$$

in meter-kilogram-second units, where

ΔQ = caloric energy needed to increase the temperature of a certain volume of matter by ΔT,

ΔW_m = corresponding increase of magnetic energy.

5. *Actual Thermomagnetic Generator and Its Cycle for* $B(T,H) = B(T,O) + \mu_\Delta H$

5.1 Optimum Current and Power

We may derive expressions for optimum power and input energy in a manner similar to the preceding case. In (34), μ_Δ is taken to be nearly independent of temperature; hence,

$$\frac{\partial B(T,H)}{\partial T} \simeq \frac{\partial B(T,O)}{\partial T}.$$

In centimeter-gram-second electromagnetic units,

$$B(T,O) = 4\pi\rho\sigma(T). \quad (89)$$

We may write

$$\sigma_T \simeq k(\Theta - T), \quad (90)$$

where k = a constant. Then, $B(T,O) = 4\pi\rho k(\Theta - T)$ in centimeter-gram-second electromagnetic units, or

$$B(T,O) = K(\Theta - T) \quad (91)$$

in meter-kilogram-second units if $K = 4\pi\rho \times k10^{-4}$. In the meter-kilogram-second system,

$$\mu_\Delta = h\mu_0, \quad (92)$$

where h has a magnitude of a few units and $\mu_0 = 1.26 \times 10^{-6}$. Hence,

$$B(T,H) = B(T,O) + \mu_\Delta H = K(\Theta - T) + h\mu_0 H \quad (93)$$

as shown in Fig. 8. Using these values in (36) and (38), we obtain $c(T,H) = c(T,O)$, and

$$dQ = c(T,O)dT - KTdH. \quad (94)$$

The equation of the generator will be

$$E = nS\frac{dB}{dt}(T,H), \quad (95)$$

where

$$B(T,H) = B(T,O) + \mu_\Delta(H_0 + n_0 i) \quad (96)$$

and

$$E = nS\frac{dB(T,O)}{dT}\frac{dT}{dt} + Sn\mu_\Delta n_0\frac{di}{dt}. \quad (97)$$

Assuming $T = T_a + b\sin\omega t$, we have

$$E = -nSKb\omega\cos\omega t + L\frac{di}{dt} = -Ri, \quad (98)$$

and, finally,

$$L\frac{di}{dt} + Ri = \beta'\omega\cos\omega t, \quad (99)$$

$\beta' = nSKb$.

This equation is identical in form to (64); however, there is no restriction such as (63), i.e., the only requirement is that

$$n_0 i \leqslant H_0. \quad (100)$$

The solution of (99) is given by

$$i = Ie\exp[j\omega t],$$

where $I = \dfrac{\beta'\omega}{j\omega L + R}$.

Again, for optimum conditions, $\omega L = R$, and we obtain (see (65) and (67))

$$\left.\begin{aligned} I_{\text{opt}} &= \frac{\beta'}{2^{\frac{1}{2}}L}, \\ i &= I_{\text{opt}}\sin\left(\omega t + \frac{\pi}{4}\right), \end{aligned}\right\} \quad (101)$$

and

$$P_{\text{opt}} = \frac{\omega V}{4\mu_\Delta}(Kb)^2. \quad (102)$$

Also, in view of (99) and (100),

$$n_0 I_{\text{opt}} = \frac{Kb}{2^{\frac{1}{2}}\mu_\Delta} \leqslant H_0.$$

Now, since it is desirable to increase n_0I as much as possible, we take $n_0I_{\text{opt}}=H_0$, and the total H becomes

$$H=H_0\left[1+\sin\left(\omega t+\frac{\pi}{4}\right)\right]. \qquad (103)$$

It is to be noted that the maximum current here will be $2^{\frac{1}{2}}$ times greater than for the preceding case of (72).

Setting $\phi=\omega t+\frac{\pi}{4}$ in (103),

$$H=H_0(1+\sin\phi),$$

and

$$dH=\omega H_0\cos\phi dt.$$

5.2 Efficiency

The heat input for unit volume is given by (94) and, with the aid of (57),

$$\left.\begin{aligned}\frac{dQ}{dt}&=c(T,O)\frac{dT}{dt}-KT\frac{dH}{dt}\\&=c_0b\omega\cos\omega t\\&\qquad -K(T_a+b\sin\omega t)\omega H_0\cos\phi,\end{aligned}\right\} \qquad (104)$$

or

$$\frac{1}{\omega}\frac{dQ}{dt}=c_0b\cos\omega t-KT_aH_0\cos\phi -KbH_0\sin\omega t\cos\phi,$$

or

$$\frac{1}{\omega}\frac{dQ}{dt}=c_0b\cos\omega t-KT_aH_0\cos\phi +KbH_0\left[\frac{1}{2\times 2^{\frac{1}{2}}}-\tfrac{1}{2}\sin\left(2\omega t+\frac{\pi}{4}\right)\right]. \qquad (105)$$

The net input for a cycle is

$$q=\int_{t=0}^{2\pi/\omega}\left(\frac{dQ}{dt}\right)dt=\frac{\pi}{2^{\frac{1}{2}}}KbH_0. \qquad (106)$$

To compute the heat input, we again integrate over a half-period θ, $\theta+\pi$, where θ is chosen so as to make Q_1 maximum and positive; this means that we choose the half-cycle when heat flows in and exclude the other half-cycle in which heat is released.

By carrying out this integration,

$$\begin{aligned}Q_1&=\tfrac{1}{2}q+c_0b[\sin(\theta+\pi)-\sin\theta]\\&\quad -KT_aH_0\left[\sin\left(\theta+\pi-\frac{\pi}{4}\right)-\sin\left(\theta+\frac{\pi}{4}\right)\right]\\&=\tfrac{1}{2}q-2c_0b\sin\theta+2KT_aH_0\sin\left(\theta+\frac{\pi}{4}\right),\\&=\tfrac{1}{2}q+2[(c_0b)^2+(KT_aH_0)^2\\&\qquad -2^{\frac{1}{2}}c_0bKT_aH]^{\frac{1}{2}}.\end{aligned} \qquad (107)$$

Now the thermodynamic efficiency of the generator becomes

$$\begin{aligned}\mathcal{E}&=\frac{q}{Q_1}\\&=\frac{q}{\tfrac{1}{2}q+2[(c_0b)^2+(KT_aH_0)^2-2^{\frac{1}{2}}c_0bKT_aH_0]^{\frac{1}{2}}}.\end{aligned} \qquad (108)$$

Substituting for q from (106) in the preceding,

$$\mathcal{E}=\frac{\pi}{\frac{\pi}{2}+2\left[2\left(\frac{c_0}{KH_0}\right)^2+2\left(\frac{T_a}{b}\right)^2-2\frac{2^{\frac{1}{2}}c_0T_a}{KbH_0}\right]^{\frac{1}{2}}}. \qquad (109)$$

Setting $X=T_a/b$ and $P=c_0/KH_0$, and noting that $P=c_0/-4\pi\rho H_0(\partial\sigma/\partial T)$ and $D=2c_0/AH_0^2$ $=2c_0/-4\pi\rho H_0(\partial\sigma/\partial T)$, hence $P=D/2$, where D is given by (87) and (88), we obtain

$$\mathcal{E}=\frac{\pi}{\frac{\pi}{2}+2\times 2^{\frac{1}{2}}(P^2+X^2-2^{\frac{1}{2}}PX)^{\frac{1}{2}}}. \qquad (110)$$

As in our previous discussion, when P is given, $\mathcal{E}$ depends on X.

5.2.1 Case I

For $X\gg P$ (or small $b/T_a=\Delta T/2T_a$),

$$\mathcal{E}_{\text{I}}=\frac{\pi}{\frac{\pi}{2}+2\times 2^{\frac{1}{2}}X}\simeq\frac{\pi}{2\times 2^{\frac{1}{2}}X}=\frac{\pi}{4\times 2^{\frac{1}{2}}}\left(\frac{\Delta T}{T_a}\right), \qquad (111)$$

or, as in the preceding case (82), $\mathcal{E}_{\text{I}}\simeq 0.55\times$ Carnot efficiency.

5.2.2 Case II

For $P\gg 1$, $X=P$, and $b=2T_a/D$,

$$\mathcal{E}_{\text{II}}=\frac{2\pi}{\pi+4.30P}\simeq\frac{\pi}{2.15P}. \qquad (112)$$

If b increases further, the radical in (110) goes through a minimum and this gives maximum efficiency; this is obtained by the usual differentiations which yield

$$P-\frac{1}{2^{\frac{1}{2}}}X=\frac{X}{2^{\frac{1}{2}}}$$

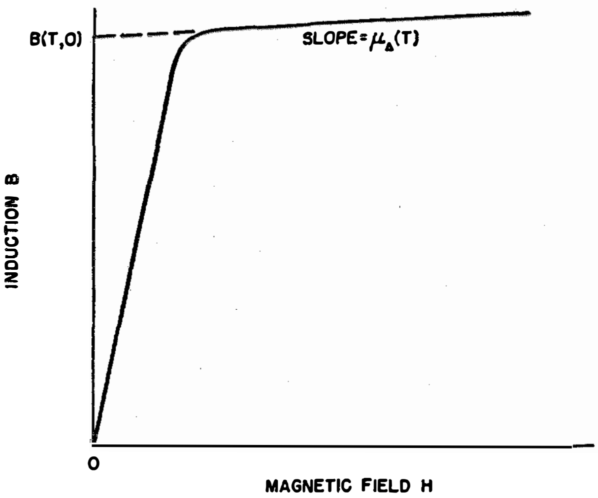


Fig. 8—Magnetization characteristic of the magnetically soft component in a thermomagnetic generator.

and

$$X=\frac{T_a}{b}=\frac{2T_a}{\Delta T}=\frac{P}{2^{\frac{1}{2}}}.$$

Hence,

$$\Delta T=\frac{2\times 2^{\frac{1}{2}}T_a}{P}=\frac{4\times 2^{\frac{1}{2}}T_a}{D}, \tag{113}$$

and

$$\mathcal{E}_{\max}=\frac{\pi}{\frac{\pi}{2}+2\times 2^{\frac{1}{2}}[P^2(1+\frac{1}{2}-1)]^{\frac{1}{2}}}\simeq\frac{\pi}{2P}=\frac{\pi}{D}, \tag{114}$$

when $P\gg 1$.

5.2.3 Case III

For larger values of b, if they can be obtained, we reach a finite efficiency; i.e., for

$$X=T_a/b=2T_a/\Delta T\ll X_{\text{opt}}$$

or

$$\Delta T\gg\frac{2\times 2^{\frac{1}{2}}T_a}{P},$$

$$\mathcal{E}_{\text{III}}=\frac{\pi}{\frac{\pi}{2}+2\times 2^{\frac{1}{2}}P}=\frac{\pi}{\frac{\pi}{2}+2^{\frac{1}{2}}D}\simeq\frac{\pi}{2^{\frac{1}{2}}D}.$$

For the case of Fig. 8, we obtain an efficiency curve that is quite similar to that of Fig. 7, except that the values are increased by a factor of $2^{\frac{1}{2}}$. This is also true of the optimum T (compare (113) and (84)).

Summarizing our results for the two types of magnetization characteristics, i.e., $B=\mu(T)H$ and $B(T,H)=B(T,O)+\mu_\Delta(H)$, we find that the latter yields optimum current and over-all efficiency larger by a factor of $2^{\frac{1}{2}}$ than the former. As already pointed out, the latter magnetization characteristic is also a closer approximation to the actual curve.

6. Increase in Carnot-Cycle Efficiency

The Carnot-cycle efficiency of the proposed system, hence the over-all efficiency, may be increased by connecting a number of these generators in series, using magnetically soft components with descending Curie temperatures.

In such a series arrangement, the heating fluid leaving the first machine would enter the second, then the third, and so on. A similar arrangement could be used for the cooling fluid.

In concluding this discussion, it should be emphasized that the foregoing represents only a first approximation, because the following effects have been ignored:

A. Hysteresis.
B. Nonlinearity in B versus H relations.
C. Nonlinearity in μ versus T relations.
D. Weiss' magnetocaloric effect that corresponds to anomalous specific heat near the Curie point.

These effects would decrease the efficiency and result in harmonics in the output of the generator. It should be added, however, that by a proper choice of the magnetically soft component having a high value of $\partial\sigma/\partial T$, and by using a series arrangement of such generators, as described, it should be possible to improve the over-all efficiency.

Recent Telecommunication Development

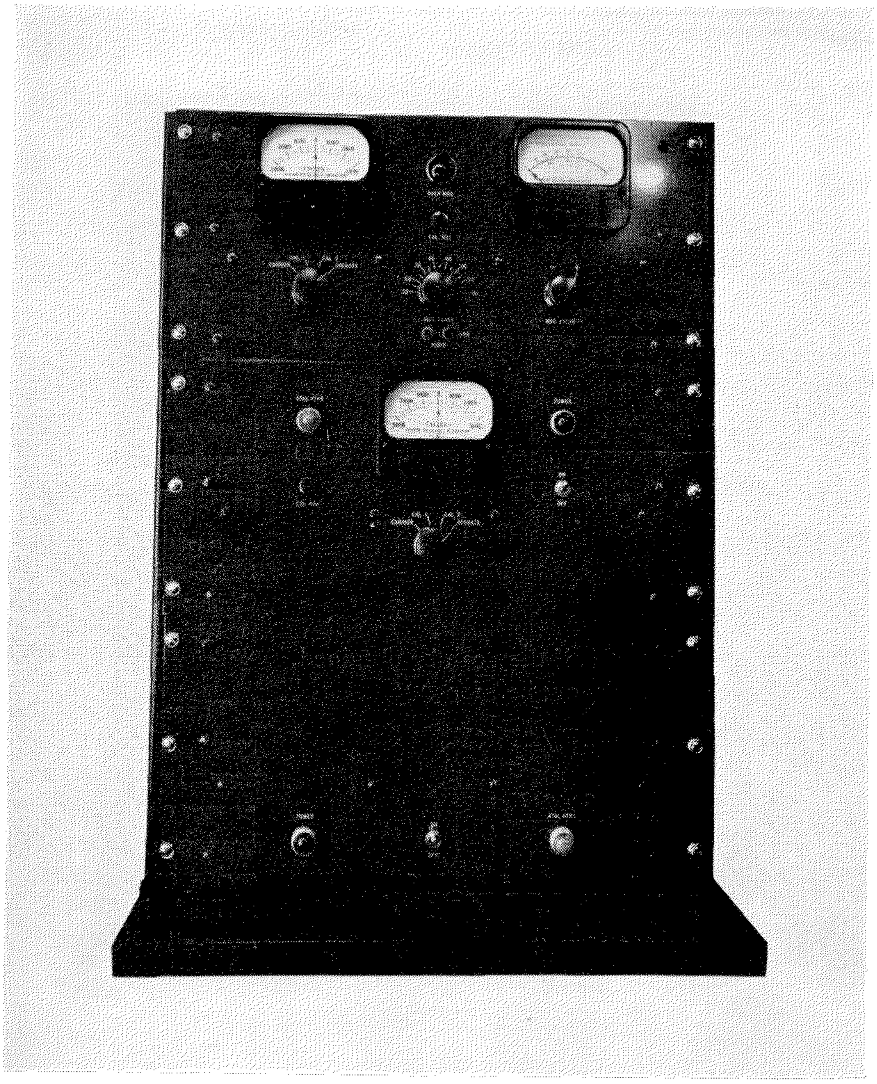
TELEVISION MONITOR—Federal Telecommunication Laboratories has developed a television station monitor, which measures the carrier frequency of the picture transmission and the center frequency and percentage of modulation of the sound transmission. An overmodulation indicator is provided and will operate an alarm when a preset percentage of modulation is exceeded.

The monitor for the amplitude-modulated picture transmitter has an accuracy of frequency measurement within two parts in a million with proper calibration of the reference oscillator, with a long-time stability of frequency within one part in a hundred thousand. The accuracy of center-frequency indication for the frequency-modulated sound transmitter under conditions of 100-percent modulation is within two parts in a million with proper calibration of the reference oscillator. The long-time stability of frequency measurement is one part in a hundred thousand. The "off-frequency" indicator has a full-scale calibration of ±3000 cycles.

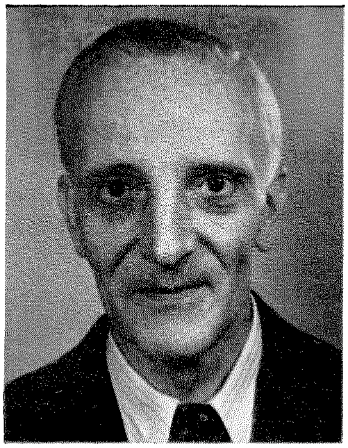
Modulation measurements are based on a frequency deviation of ±25 kilocycles for 100-percent modulation. Modulation percentage and overmodulation indications are performed within ±5 percent.

The sound-transmitter monitor is linear within 0.5 decibel from 50 to 15,000 cycles. The inherent noise level is 75 decibels below a reference level corresponding to 100-percent modulation, and over-all inherent distortion does not exceed 0.25 percent.

Remote indicators may be used for the major monitoring services including the overmodulation indicator and all meters. Monitors are available for any specified channel assigned to television in the U.S.A. (44 to 88 and 174 to 216 megacycles).



Contributors to This Issue



Leon N. Brillouin

Leon N. Brillouin was born on August 7, 1889, in Sevres, France. He was educated at the University of Paris, receiving a doctorate in 1920.

During World War I, he served in the French Army as a radio engineer. In 1928, he was appointed professor of theoretical physics at the Institut H. Poincaré of the University of Paris, and in 1932 joined the faculty of the College de France in the same capacity.

He served as general director of the French National Broadcasting System from July, 1939, to January, 1941, when he came to the U.S.A. From 1941 to 1942, he was a professor at the University of Wisconsin, and spent the next academic year on the staff of Brown University. He was engaged in defense research work at Columbia University from 1942 to 1945, and is now teaching at Harvard University.

Dr. Brillouin has been a consultant to Le Matériel Téléphonique in Paris since 1936, and to Federal Telecommunication Laboratories since 1941.

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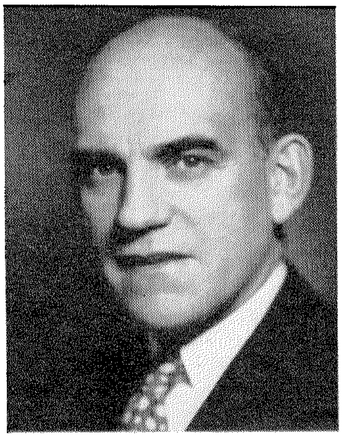

H. H. Buttner

H. H. Buttner was graduated from the University of California in 1915 with the degree of B.S. in electrical engineering. He was employed by the U. S. Navy Department as a civilian employee planning and constructing radio stations on the Pacific coast and in American Samoa. He enlisted in the U. S. Navy and was later transferred to work in connection with the construction of the Lafayette naval transatlantic station at Bordeaux, France. He remained in Bordeaux as a civilian after termination of the war to direct the completion of this station and arrange for its transfer to the French authorities. He returned to the United States as an expert radio aide, U. S. Navy, at the New York Navy Yard.

After serving in the engineering department of the Western Electric Company (later Bell Telephone Laboratories) as a radio development engineer, he joined the International Telephone and Telegraph Corporation in 1926.

From 1930 to 1936, he was Managing Director of International Marine Radio Corporation, an I. T. & T. System associate company.

In 1936, he returned to the United States, joining the group that later became Federal Telecommunication Laboratories. In addition to being President of Federal Telecommunication Laboratories, he is Vice President of International Telephone and Telegraph Corporation, and Vice President and Director of Federal Telephone and Radio Corporation and of Federal Electric Manufacturing Company.

Mr. Buttner is a Fellow of the Institute of Radio Engineers and a member of the Institute of Aeronautical Sciences.

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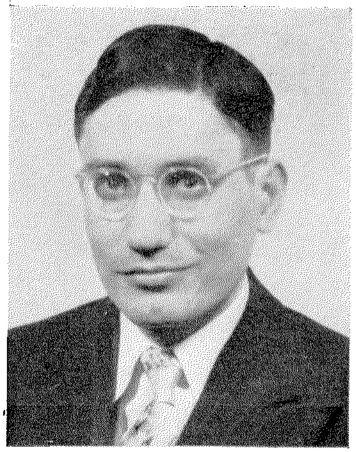

William Dite

William Dite was born in New York City on March 2, 1919. He received the B.E.E. degree from the College of the City of New York in 1940.

From 1940 to 1943, he was with the Signal Corps Laboratories, Fort Monmouth, New Jersey, working on sound-ranging and radar equipment. Since 1943, he has been associated with Federal Telecommunication Laboratories, Nutley, New Jersey, where his work has been largely concerned with communication systems employing pulses.

Mr. Dite is a member of the American Institute of Electrical Engineers.

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C. W. Earp

C. W. Earp was born at Cheltenham, Gloucestershire, England, on July 14, 1905. He received the B.A. degree with First Class Honours in 1927 from Cambridge University.

In September, 1927, he joined the International Standard Electric Corporation at New Southgate, and until 1929 assisted in the study of high-frequency transatlantic transmission.

PER E. ERIKSON

In 1929, he joined the Paris laboratory as a radio development engineer where he was chiefly concerned with receiver design, including ship-shore telephone equipments and single-sideband technique.

In 1933, he joined the broadcast receiver development group, which was then transferred from Paris to the Kolster Brandes factory at Sidcup, England, where he became chief of the advance development section.

In 1935, he joined Standard Telephones and Cables at New Southgate as section head for development of radio receivers and direction finders. In 1940, he became head of the newly formed advance development section of the radio division.

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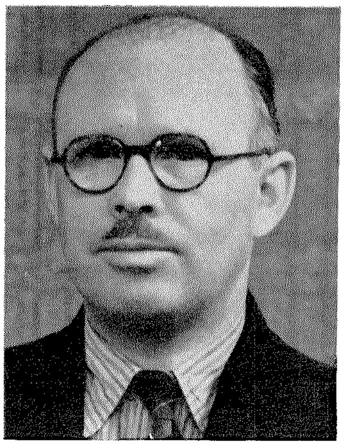

E. C. FIELDING

PER E. ERIKSON received his degree in electrical engineering from the Royal Institute of Technology in Stockholm in 1903, and joined the Western Electric Company in New York as a shop student the same year.

Assigned to the engineering department, he was engaged on the early development of loading coils and balanced toll cables. Appointed transmission engineer for Europe in 1909 with headquarters in London, he was in charge of the construction of the London-Birmingham cable, the first loaded long-distance cable installed in Europe.

During 1918, he carried out the reconstruction of the Rio de Janeiro–San Paulo toll line, the first of its kind in Brazil to be equipped with repeaters and loaded toll entrance cables. As assistant European chief engineer of the International Western Electric Company, he had charge of the design of toll transmission systems, which were being introduced into various European countries after the first World War. In 1928, he was made assistant vice president of the International Standard Electric Corporation and European chief engineer in 1930.

Mr. Erikson has been associated with the Comité Consultatif International Téléphonique since 1925. From 1929 to date, he has been a delegate for the International Telephone and Telegraph System operating companies at meetings of that body and since 1934, he has been secretary of the System's committee.

He is a Member of the Institution of Electrical Engineers, London, and a Fellow of the American Institute of Electrical Engineers.

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E. C. FIELDING was born in Halifax, Yorkshire, England, on March 14, 1903. He received his technical education at Halifax Municipal Technical College and earned a London University honours degree in mechanical engineering. He was also awarded a royal scholarship tenable at the Imperial College of Science and Technology, London.

He has been with Standard Telephones and Cables in London since 1924, and is now senior mechanical engineer on aircraft radio development and design. He was associated for some years with the technical problems of

HAIG P. ISKENDERIAN

automatic telephone systems, but transferred his activities early in the war in response to the more important call for aircraft radio equipment for the armed services.

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HAIG P. ISKENDERIAN was born in Constantinople, Turkey, on January 23, 1905. After completing his secondary education there, he came to the United States in January, 1923, to enter the University of Michigan, from which he received the B.S. degree in electrical engineering in June, 1927.

On graduation, he was associated with the Bell Telephone Laboratories until 1932. He then entered Columbia University and received the Ph.D. degree in physics in 1937. He was an assistant in physics at Columbia University from 1935 to 1937, and an

WILLIAM C. LANE

E. M. S. McWhirter

instructor of physics at Stevens Institute of Technology during 1937. He then became an instructor of physics and mathematics at Pratt Institute until 1940; also an evening instructor of physics and engineering mechanics at Brooklyn Polytechnic Institute and at Cooper Union, during this period.

Dr. Iskenderian was engaged as a research physicist by the U. S. Navy Department Bureau of Ordnance from 1940 to 1943. He joined Federal Telecommunication Laboratories in 1943, in charge of work on magnetic components.

Dr. Iskenderian is a member of the American Physical Society, Institute of Radio Engineers, and Society of Sigma Xi.

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William C. Lane was born on July 11, 1904, in Goldsboro, North Carolina. He received the B.S. degree in electrical engineering from North Carolina State College in 1928.

From 1928 to 1930, he was with the General Electric Company and during the following three years was employed by Radio Corporation of America, Kolster Radio Corporation, and Federal Telegraph Company. From 1933 to 1936, he was with Hygrade Sylvania Corporation.

In 1936, Mr. Lane joined the engineering staff of Federal Telegraph Company, which later became Federal Telephone and Radio Corporation. In 1947, he was transferred to Federal Telecommunication Laboratories, Incorporated, as a project engineer on military receiver developments.

Mr. Lane is coauthor of the article "Very-High-Frequency Single-Channel Receiver" that appeared in Volume 25, Number 2.

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E. M. S. McWhirter was born on May 24, 1901 in Kent, England. He attended City and Guilds Engineering College of the Imperial College.

In 1924, he joined the Western Electric Company (later Standard Telephones and Cables) in London as a student engineer. Initially engaged in the design of special apparatus and systems allied to automatic telephone switching practices, he has been closely associated with the development of remote-control systems and became head of the remote-control department in 1935.

He is an Associate of the City and Guilds Institute, and a Member of the Institution of Electrical Engineers. Mr. McWhirter was awarded a Lord Kitchener Memorial Scholarship in 1921 at the Imperial College; and for a paper "Operational Control of Electricity Supply Systems," written in collaboration with Mr. W. Kidd, was awarded the John Snell premium of the Institution of Electrical Engineers in 1946.

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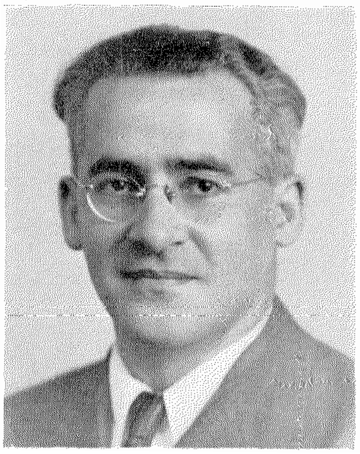
Joseph D. Mountain was born in Kansas in 1904. A graduate of the U. S. Army Air Service Flying School, he also attended the University of Southern California.

From 1927 to 1937, he was engaged in aerial photography and mapping and spent two years in exploratory expeditions to Saudi Arabia.

Joseph D. Mountain



P. F. Panter

In 1937, he joined Trans World Airlines as a pilot. He served also in several administrative posts including director of training and chairman of the all-weather flying committee.

During World War II, Colonel Mountain was on active duty in Washington and India. He organized and directed the training program of the Army Air Transport Command and in the last year of the war served as executive officer of the air navigation and traffic-control committee of the Secretary of War.

Returning to Trans World Airlines, Colonel Mountain was loaned to Federal Telecommunication Laboratories as a consultant. In 1947, he joined the I.T.&T. System to devote most of his time to the development of Intelex. He is also manager of Federal Telecommunication Laboratories' aviation operation department.

Colonel Mountain holds an army rating of command pilot and a Civil Aeronautics Administration rating of airline transport pilot.

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Philip F. Panter was born in 1908 in Poland. After early schooling in Tel-Aviv, Palestine, he later received from McGill University, Montreal, Canada, the following degrees: B.Sc. in 1933, B. Eng. in electrical engineering in 1935, and Ph.D. in physics in 1936. He continued research in spectroscopy at McGill for an additional year.

After teaching mathematics and physics in Palestine for a year, he returned to Canada as assistant professor of mathematics and physics in the evening division of Sir George Williams College in Montreal. He served also on the staff of the physics department of McGill University as instructor in physics and later as part-time lecturer, until the end of 1945.

Early in 1941, Dr. Panter joined the transmitter department of the Canadian Marconi Company in Montreal. In October, 1945, he was appointed senior engineer, responsible for the development of frequency-modulation broadcast equipment, at Federal Telephone and Radio Corporation. He later transferred to Federal Telecommunication Laboratories and is now in charge of the theoretical group of the communications division.

Dr. Panter is a member of the Institute of Radio Engineers and the Radio Club of America.

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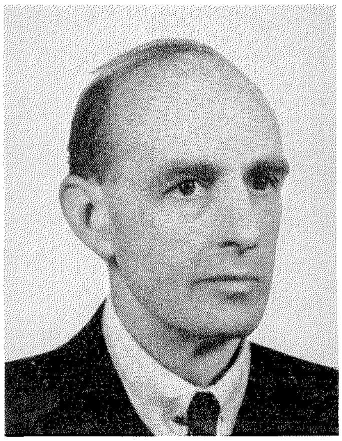

L. C. Pocock

L. C. Pocock received the B.Sc. (Eng.) degree with First Class Honours from City and Guilds of London Institute. He took his M.Sc. (Eng.) degree in 1925, in which year he was awarded a premium by the Institution of Electrical Engineers for his paper on "Faithful Reproduction".

He entered the National Telephone Company a few months before its transfer to the General Post Office at the end of 1911. He then joined the Western Electric Company in London in 1912, and in 1915 took over the general apparatus laboratory work at Woolwich.

During the 1914–1918 war he worked as a radiologist in the Anglo-Russian Hospital in Russia. On his return to the company, he continued in laboratory work, specialising in subscribers' apparatus problems.

He has served for many years on the Comité Consultatif International Téléphonique committee dealing with subscribers' apparatus and transmission measurements, and is chairman of International Telephone and Telegraph System Technical Committee on Electroacoustic Systems.

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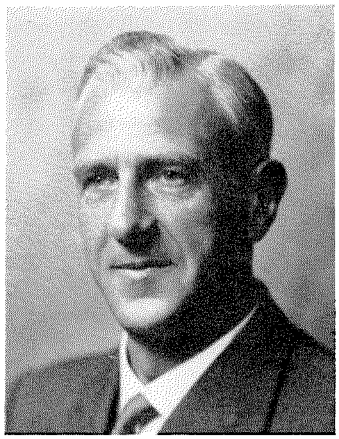

C. E. Strong

C. E. Strong was born in Omagh, County Tyrone, Ireland, on November 15, 1898. He received the degrees of B.A. from Trinity College, Dublin, and B.A.I. from the University of Dublin in 1922.

In 1917, he entered the Royal Military Academy, Woolwich, receiving later a commission in the Royal Artillery. He served in France in 1918.

Mr. Strong joined the International Western Electric Company in 1922 and participated in the technical work carried out in England on the establishment of the first transatlantic telephone circuit. Later he was responsible for the development of high-frequency transmitters of the type used for the British empire broadcasting system and for numerous overseas telephone services.

In 1929, he transferred to the Paris laboratories, where he played a leading part in the development of high-power broadcasting equipment. In 1939, he was appointed chief radio engineer of Standard Telephones and Cables, London.

Mr. Strong was appointed an Officer of the Order of the British Empire in 1947. He has for many years been an active member of the Institution of Electrical Engineers and was elected chairman of the Radio Section for the current session. He is also a Senior Member of the Institute of Radio Engineers.

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For the biographies and photographs of Henri Busignies, A. G. Clavier, and Sidney Frankel, see Volume 25, Number 2, pages 205 to 207.

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION

Associate Manufacturing and Sales Companies

United States of America

International Standard Electric Corporation, New York, New York

Federal Telephone and Radio Corporation, Newark and Clifton, New Jersey

International Standard Trading Corporation, New York, New York

Great Britain and Dominions

Standard Telephones and Cables, Limited, London, England

Branch Offices: Birmingham, Leeds, Manchester, England; Glasgow, Scotland; Dublin, Ireland; Cairo, Egypt; Calcutta, India; Johannesburg, South Africa

Creed and Company, Limited, Croydon, England

International Marine Radio Company Limited, Liverpool, England

Kolster-Brandes Limited, Sidcup, England

Standard Telephones and Cables Pty. Limited, Sydney, Australia

Branch Offices: Melbourne, Australia; Wellington, New Zealand

Silovac Electrical Products Pty. Limited, Sydney, Australia

Austral Standard Cables Pty. Limited, Sydney, Australia

New Zealand Electric Totalisators Limited, Wellington, New Zealand

Federal Electric Manufacturing Company, Ltd., Montreal, Canada

South America

Compañía Standard Electric Argentina, Sociedad Anónima, Industrial y Comercial, Buenos Aires, Argentina

Standard Electrica, S.A., Rio de Janeiro, Brazil

Compañía Standard Electric, S.A.C., Santiago, Chile

Europe and Far East

Vereinigte Telephon- und Telegraphenfabriks Aktien-Gesellschaft Czeija, Nissl and Company, Vienna, Austria

Bell Telephone Manufacturing Company, Antwerp, Belgium

China Electric Company, Limited, Shanghai, China

Standard Electric Aktieselskab, Copenhagen, Denmark

Compagnie Générale de Constructions Téléphoniques, Paris, France

Le Matériel Téléphonique, Par s, France

Les Téléimpr eurs, Paris, Fran e

Lignes Télégraphiques et Téléphoniques, Paris, France

Ferdinand Schuchhardt Berliner Fernsprech- und Telegraphenwerk Aktiengesellschaft, Berlin, Germany

Lorenz, C., A.G. and Subsidiaries, Berlin, Germany

Mix & Genest Aktiengesellschaft and Subsidiaries, Ber in, Germany

Süddeutsche Apparatefabrik Gesellschaft M.B.H., Nuremberg, Germany

Telephonfabrik Berliner A.G. and Subsidiaries, Berlin, Germany

Nederlandsche Standard Electric Maatschappij N.V., Hague, Netherlands

Dial Telefonkereskedelmi Részvény Társaság, Bu apest, Hungary

Standard Villamossági Részvény Társaság, Budapest, Hungary

Telefongyár R.T., Budapest, Hungary

Fabbrica Apparecchiature per Comunicazioni Elettriche, Milan, Italy

Standard Elettrica Italiana, Milan, Italy

Societa Italiana Reti Telefoniche Interurbane, Milan, Italy

Nippon Electric Company, Limited, Tokyo, Japan

Sumitomo Electric Industries, Limited, Osaka, Japan

Standard Telefon- og Kabelfabrik A/S, Oslo, Norway

Standard Electrica, Lisbon, Portugal

Compañía Radio Aerea Maritima Españo a, Madrid, Spain

Standard Eléctrica, S.A., Madrid, Spain

Aktiebolaget Standard Radiofabrik, Stockholm, S den

Standard Telephone et Radio S.A., Zurich, Switzerland

Telephone Operating Systems

Compañía Telefónica Argentina, Buenos Aires, Argentina

Compañía Telegráfico-Telefónica Comercial, Buenos Aires, Argentina

Compañía Telegráfico-Telefónica del Plata, Buenos Aires, Argentina

Companhia Telefonica Paranaense S.A., Curitiba, Brazil

Companhia Telefonica Rio Grandense, Porto Alegre, Brazil

Compañía de Teléfonos de Chile, Santiago, Chile

Compañía Telefónica de Magallanes S.A., Punta Arenas, Chile

Cuban Telephone Company, Havana, Cuba

Cuban American Telephone and Telegraph Company, Havana, Cuba

Mexican Telephone and Telegraph Company, Mexico City, Me ico

Compañía Peruana de Teléfonos Limitada, Lima, Peru

Porto Rico Telephone Company, San Juan, Puerto Rico

Shanghai Telephone Company, Federal, Inc., U.S.A., Shanghai, China

Radiotelephone and Radiotelegraph Operating Companies

Compañía Internacional de Radio, Bue os Aires, Argentina

Compañía Internacional de Radio Boliviana, La Paz, Bolivia

Companhia Radio Internacional do Brasil, Rio de Janeiro, Brazil

Compañía Internacional de Radio, S.A., Santiago, Chile

Radio Corporation of Cuba, Havana, Cuba

Radio Corporation of Porto Rico, Santurce, Puerto Rico[1]

[1] **Radiotelephone and Radio Broadcasting services.**

Cable and Radiotelegraph Operating Companies

(Controlled by American Cable & Radio Corporation)

The Commercial Cable Company, New York, New York[2]

Mackay Radio and Telegraph Company, New York, New York[3]

All America Cables and Radio, Inc., New York, New York[4]

Sociedad Anónima Radio Argentina, Buenos Aires, Argentina[5]

[2]Cable service. [3]International and Marine Radiotelegraph services.
[4]Cable and Radiotelegraph services. [5]Radiotelegraph service.

Laboratories

International Telecommunication Laboratories, Inc., New York, New York

Federal Telecommunication Laboratories, Inc., Nutley, New Jersey

Standard Telecommunication Laboratories Ltd., London, England

Laboratoire Central de Télécommunications, Paris, France