ELECTRICAL COMMUNICATION

Technical Journal of the
International Telephone and Telegraph Corporation
and Associate Companies

JUNE, 1946

VOL. 23 No. 2

ELECTRICAL COMMUNICATION

Technical Journal of the
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
and Associate Companies

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Published Quarterly by the

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
67 BROAD STREET, NEW YORK 4, N.Y., U.S.A.

Sosthenes Behn, President Charles D. Hilles, Jr., Vice President and Secretary

Subscription, $1.50 per year; single copies, 50 cents

Volume 23 June, 1946 Number 2

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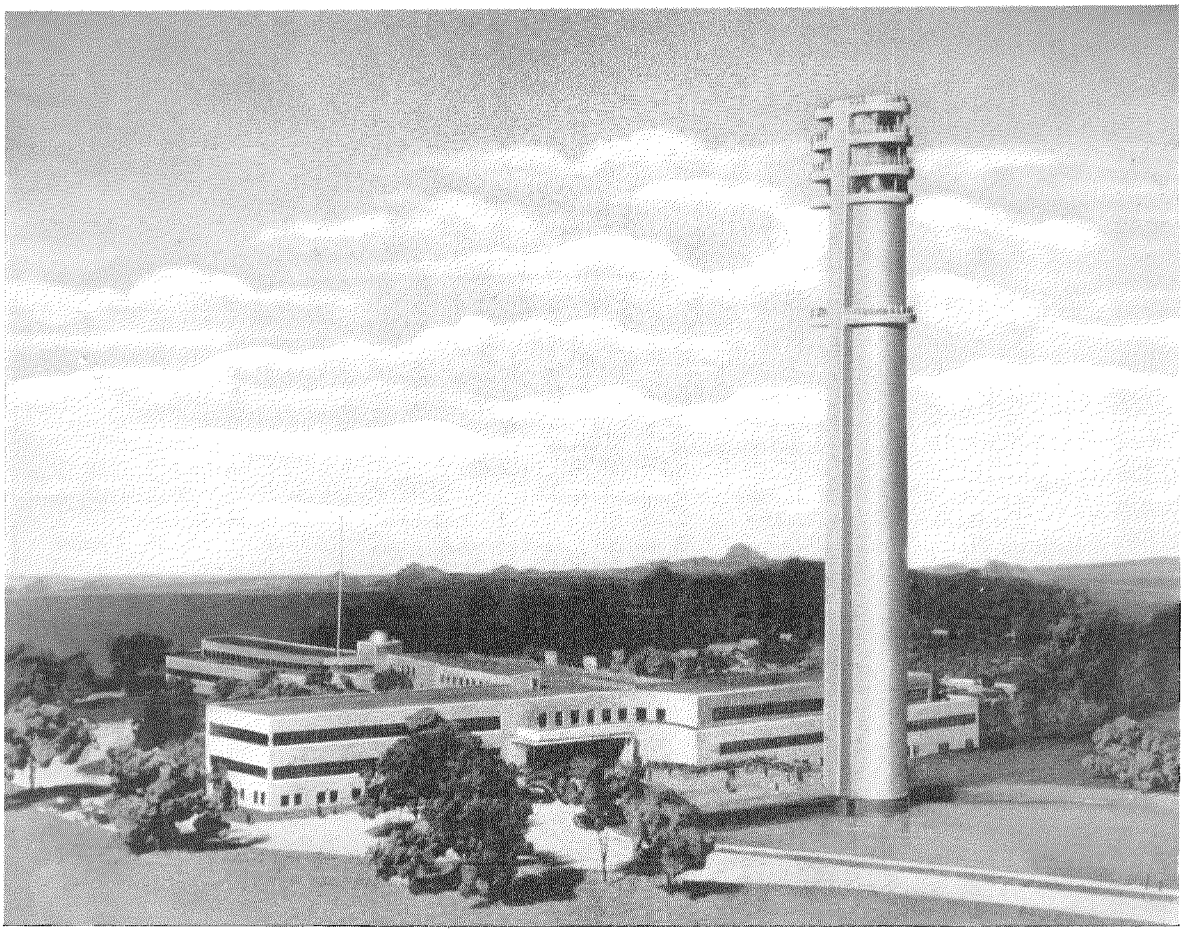


MICROWAVE TOWER AND LABORATORIES

ARCHITECT'S MODEL SHOWING THE NEW BUILDINGS AND MICROWAVE TOWER BEING CONSTRUCTED AT NUTLEY, NEW JERSEY, FOR FEDERAL TELECOMMUNICATION LABORATORIES. THE FIRST UNIT OF 50,000 SQUARE FEET FLOOR AREA WAS COMPLETED AND DEDICATED IN OCTOBER, 1945. GROUND WAS BROKEN RECENTLY FOR THE SECOND STRUCTURE OF 65,000 SQUARE FEET AND FOR THE MICROWAVE TOWER.

THE 300-FOOT TOWER WILL BE DEVOTED TO ULTRA-HIGH-FREQUENCY RESEARCH ON RADAR, AERIAL NAVIGATION, FREQUENCY MODULATION, PLUSE-TIME MODULATION, TELEVISION, MOBILE RADIO, AND POINT-TO-POINT LONG-DISTANCE TELEPHONY. SPECIAL MOUNTS HAVE BEEN DESIGNED TO SIMPLIFY INSTALLATION AND MODIFICATION OF ANTENNAS FOR EXPERIMENTAL PURPOSES.

Aerial Navigation and Traffic Control with Navaglobe, Navar, Navaglide, and Navascreen*

By H. BUSIGNIES, PAUL R. ADAMS, and ROBERT I. COLIN

Federal Telecommunication Laboratories, Inc., New York, New York

Editor's Note: This article embodies the results of a concentrated effort in the direction of systematic planning of radio aids to aerial navigation and traffic control. Parts I, II, and III are directed toward the problems of (I) long-range world-wide navigation; (II) navigation and traffic control near airports; and (III) instrument or automatic landing of airplanes on a selected runway. Part IV, the Navascreen, is directed toward a new problem: collecting, co-ordinating, and displaying, on the ground, all available information from all kinds of sources as to the movements of airplanes.

Introduction

A LITTLE more than 2 years ago, the laboratories of Federal Telephone and Radio Corporation became convinced that their work on radio aids to air navigation and the work of other companies and agencies engaged in this field were sadly in need of co-ordinated systems planning. The instrument landing omnidirectional range, and fixed-course range equipments, developed and manufactured by Federal and affiliate companies during the previous decade, were individually satisfactory, but the relationship of all these aids to each other and to the products made by other agencies appeared to lack basic co-ordination. Under the pressure of war needs and the impetus given to new developments by wartime discoveries, and because of anticipated increase in air-traffic densities, it was apparent that many overlapping plans were being made. As a result, a concentrated effort toward systematic planning was urgently required if the whole art of radio aids to navigation and traffic control was to be saved from chaos.

In view of this realization, Federal commenced an intensive campaign of system studies and, at the same time, a campaign of consultation with airlines and service groups. It soon became apparent that many other agencies were thinking along the same lines and that almost all agreed on the need for long-range systematic planning of future developments.

From the consultations with airlines and Army and Navy agencies, a certain basic classification of the problems to be solved began to take form. Starting with the over-all global navigation problem and working toward the end point of a final landing at a congested airport, the main divisions of the problem were formulated by E. M. Deloraine as follows:

* Based on Technical Memorandum No. 155.

a. The problem of guiding aircraft over oceans or uninhabited jungle or arctic regions.
b. The problem of navigating aircraft along pre-established airways which can be provided with chains of radio ranges or other similar facilities.
c. The problem of navigation and traffic control in the vicinity of airports where the traffic densities and the operational requirements necessitate an especially high order of service.
d. The problem of bringing the aircraft safely down to the contact point on the selected runway (and perhaps also of further guiding it along this runway for a short time until its speed had slackened sufficiently to change over to some other form of control).

A fifth subdivision of the problem, namely, the problem of guiding aircraft in their slower taxiing movements around the airport was briefly considered, but was not listed as a primary requirement as it appeared quite possible that this might be done without radio aids.

Many apparently desirable solutions to the 4 principal problems listed above presented themselves. Those solutions which appeared to be the most attractive were analyzed in greater detail and some of these were reduced to the form of definite written proposals which were presented to and discussed with various government agencies, particularly the erstwhile Aircraft Radio Laboratories at Wright Field, Watson Laboratories, and Dr. Stratton's committee attached to the Office of the Secretary of War. Consultations were also continued with civilian agencies such as the Civil Aeronautics Administration and Aeronautical Radio, Inc.

As a result of comments, criticisms, and suggestions made in regard to these earlier proposals, the subject matter was reviewed again and again, each time eliminating a number of objections or deficiencies, but each time discovering new difficulties. One of the basic requirements early pointed out by the Aircraft Radio Laboratories was that a tightly co-ordinated system, which could not readily be adopted in piecemeal fashion, must be ruled out because of the practical impossibility of making any sudden universal change on a world-wide or even a nationwide basis. Yet all agreed that some consolidation of separate functions, at least in the airplane, must be aimed at to reduce the amount of airborne equipment required.

Guided by the advice and suggestions mentioned above, the system planning of Federal has gradually assumed a form which appears reasonably well fitted to the existing plans and practices of the civil and armed-service agencies as well as to their anticipated needs.

In the following pages, 4 systems or sets of equipments are briefly presented as Federal's contribution toward solving the basic needs of aerial navigation and traffic control. These 4 systems do not correspond exactly to the 4 subdivisions originally outlined.

The problem of navigation along airways or over civilized continental areas, for one thing, appears already to be partially solved by the Civil Aeronautics Administration's proposed very-high-frequency omnidirectional ranges which will be installed in chains throughout the United States during the coming decade. Supplemental aids such as distance indicators will probably be added to these omnidirectional ranges. Some form of collision-warning equipment will probably also be considered a desirable addition, at least in the more densely travelled regions of the United States. It appears quite feasible, however, to use for such additional distance indication and anticollision features the same airborne equipment which is adopted for solving the third problem: navigation and air traffic control around airports. Accordingly, the following presentation of 4 Federal systems does not include any separate system directed solely at the problem of navigation along airways, although it is anticipated that the Navar system for navigation and control around airports will be used in part along the airways to supplement the very-high-frequency omnirange system.

The 3 systems—"Navaglobe," "Navar," and "Navaglide"—first discussed in the following articles may therefore be considered as being primarily directed toward the 3 problems: long-range world-wide navigation, navigation and traffic control near airports, and instrument or automatic landing on a selected runway. The fourth of the systems hereafter described, the "Navascreen," is directed toward a new problem, namely, the problem of collecting, co-ordinating, and displaying on the ground, all available information from all kinds of sources as to the movements of airplanes. This Navascreen system is not in itself a radio aid to navigation, but is rather a data-posting, recording, and displaying system particularly designed for the special problems of air navigation.

Part I—Navaglobe System of Long-Range Navigation Over Oceans and Continents

1.1 Basic Philosophy

More than a hundred different systems for long-range navigation have been proposed, and more than a dozen of these have been given very serious study by Federal. Probably the most difficult and yet the most important factor involved in deciding among such systems is the basic question, "Which attributes are most important for a long-range navigation system?" Accuracy, reliability, convenience of use, range of operation, weight, cost, convenience of siting, and many other advantages are advanced as the primary factors by proponents of various systems. All are obviously desirable, but the basic question is, which are fundamental?

After many discussions with operational personnel of several airlines and of the Armed Services, Federal has come to the conclusion that the 3 essential properties of a long-range navigation system are:

a. 100 percent reliability of propagation of the signals over the rated coverage area at every hour of day and night and every season of every year.
b. A rated minimum-coverage area sufficiently large so that every travelled portion of the earth's surface may be covered by at least 2 separate stations without requiring the construction of man-made islands for basing such stations.
c. Some provision for double-checking the correctness of the indications given.

In other words, Federal believes that, if necessary, an airline would accept a considerable sacrifice in convenience, accuracy, weight, cost, or any other factor, if it could be sure every one of its planes would always be able to determine its position at any place in the world; at any time of day or night; any day of any year; and would always be able to double check such determination.

Following far behind these 3 fundamental factors, Federal would list certain other secondary factors in more or less the following order:

d. Simplicity of operation together with convenience of reading.
e. Practicability of siting the ground stations according to the so-called "single site" principle instead of the so-called "double site" principle.
f. Reduction of drag of airborne antennas, reduction of airborne weight, reduction of cost of air and ground radio equipment.
g. Capability of being modified for giving fractional-degree accuracy in a few portions of the world during wartime or other special conditions.

It should be noted that in the above list, high accuracy is considered as the least important requirement. This is because, in long-range aerial navigation, it is immaterial to an airplane flying in the middle of an ocean whether it deviates 10, 25, or even 100 miles from its ideal position, provided that it approaches the correct position as it comes to its destination. Agencies so far consulted have agreed that accuracy is desirable if it involves no sacrifices of other features, but have admitted that the actual commercial need for accuracy at points remote from transmitting stations has never been substantiated. Most operational people dismiss the whole question with the statement that "over the ocean nobody cares where he is within 20 or 30 miles." The only suggestions that have been made for commercially utilizing accuracies better than 1 degree are that, if high accuracy could readily be provided, it could enable ground speed to be determined by successive fixes; and, further, that for some military purposes, where mobilization or guidance toward enemy objectives were desirable, higher accuracies might temporarily be desired.

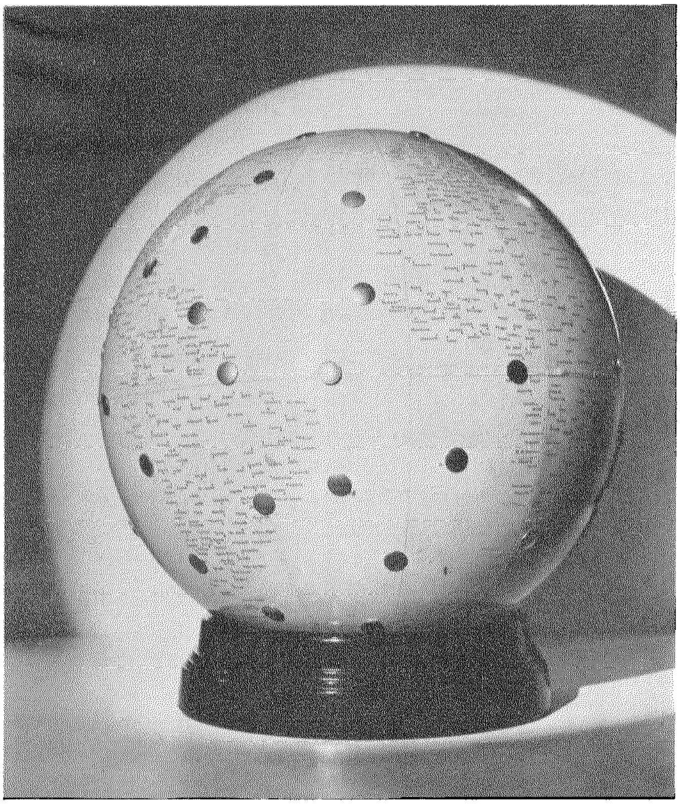


Fig. 1—Globe view 1.*

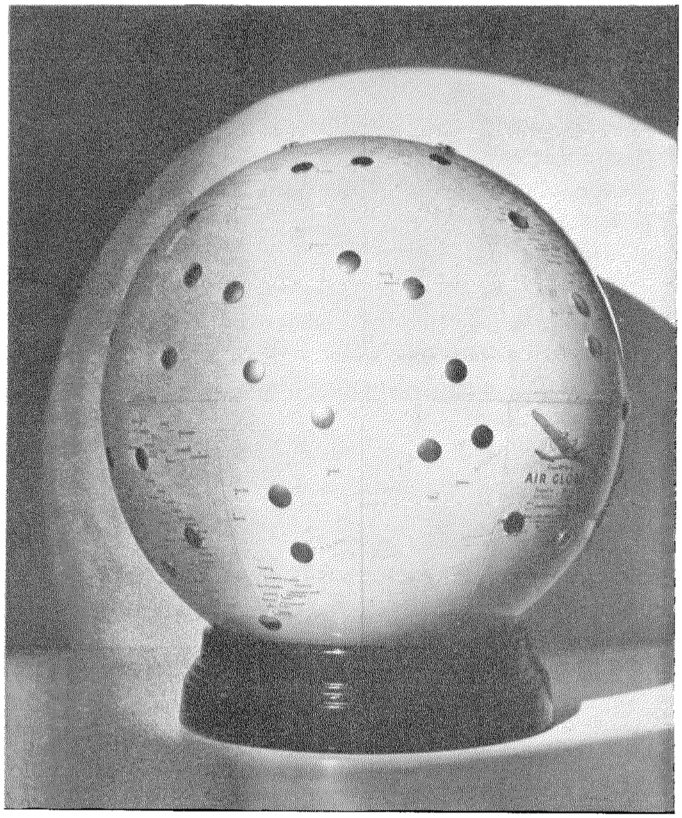
1.2 First Year's Study

In investigating the possibility of obtaining the 2 most fundamental factors—100 percent reliability and world-wide coverage—it was necessary to consider first the second of these problems, world-wide coverage, and to ascertain the necessary range of operation required from each ground station, since the question of reliability cannot be determined until after the distance of propagation has been specified. Accordingly, the disposition of the land masses on the earth was studied intensively by reference to existing maps and by consultation with the Hydrographic Office. It appeared that a reliable transmission radius of at least 1500 miles would be necessary to provide duplicate coverage of the important ocean regions of the globe from land based stations. Duplicate coverage means that all points are within service radius of at least *2* ground stations to enable navigators to establish cross fixes.

Figs. 1, 2, and 3 show a possible pattern of stations which would achieve the result of duplicate coverage of the ocean regions all over the globe, except for the south polar region. Considerable flexibility of pattern was found to be possible excepting in the south-east Pacific region. No consideration was given to the stations required to cover the continental areas since it was clear that this presented no difficulty. The only question considered was how small a working radius could be used while still insuring coverage of all travelled ocean regions.

As mentioned above, this study showed that a working radius of 1500 miles over sea water would be es-

Fig. 2—Globe view 2.



* Base map copyright by Rand McNally & Co., Chicago, Ill., R. L. 4632.

sential for a long-range navigation system intended to be extended to all travelled portions of the globe. The study further showed that a total of somewhat less than 60 stations would suffice for covering all ocean areas. It was clear that only a few additional stations would be required for coverage of each continent, so that not more than 75 stations in all would be needed for complete coverage of the globe exclusive of the south polar cap.

An intensive review of all available data on propagation characteristics of various radio frequencies was next undertaken. This study was directed to the question of which frequencies could be relied on to propagate to a distance of 1500 miles over sea water 100 percent of the time. Needless to say, it was soon found that no radio propagation can be said to be 100 percent reliable. Nevertheless, after careful review of more than 100 published articles covering some 20 years, it was finally found that it is possible to achieve reliability in excess of 99 percent; but this is practical only through the use of low frequencies in the vicinity of 70 kilocycles per second and with extremely narrow bandwidths of the order of 10 to 20 cycles per second.

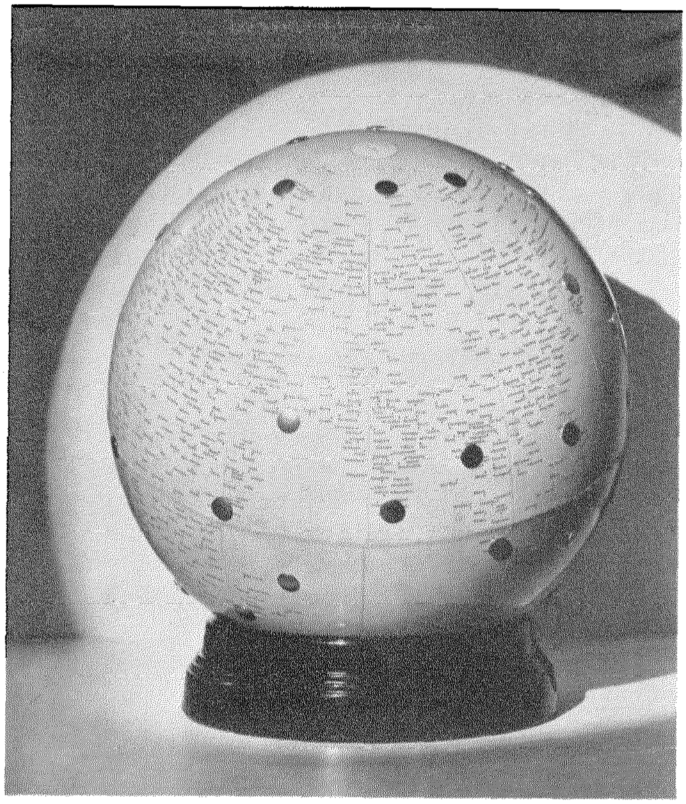


Fig. 3—Globe view 3.

A summary of propagation studies[1] shows that frequencies between 15 kilocycles and 70 kilocycles are the best from the standpoint of reliable reception from a distance of 1500 miles with a given radiated power, taking into account the weakest signal propagation and the highest atmospheric noise level, but disregarding practical considerations of antenna cost and antenna efficiency. If the antenna efficiencies are taken into account and the antennas are limited to simple 2-tower flat-tops or single-mast umbrella loaded types with effective heights of the order of 300 feet, then it appears that the optimum frequency (i.e. the frequency giving a reliable 1500-mile working radius with the least *power input to the antenna*) is between 50 and 100 kilocycles. If it is desired to cheapen the antennas slightly at some increased cost in required input power, this study shows that the frequency may be raised as high as 125 kilocycles with only about 50 percent increase in required power, and may even be raised as high as 175 kilocycles with only approximately a 3-fold power increase.

On the assumption that the receiver bandwidths can be narrowed down to 20 cycles, it appears from the above-mentioned study that the input powers required for almost 100 percent reliability would be of the order of 7 kilowatts in northern United States and Canada, 25 kilowatts in the vicinity of New York, and 100 kilowatts for most tropical stations. These full powers, however, would be required only during certain days of certain seasons, so that the stations would normally operate with less than a quarter of the powers mentioned. The antenna efficiencies are estimated to be about 60 percent so that the radiated powers would be of the order of 4200 watts in Maine, 15 kilowatts in New

[1] P. R. Adams and R. I. Colin, "Frequency, Power, and Modulation for a Long-Range Radio Navigation System," *Electrical Communication*, v 23; June, 1946.

York, and 60 kilowatts in the tropics during the worst seasons and a third or a quarter as much during other times.

It is estimated that, except for a regular brief interruption of propagation lasting about 15 minutes at an accurately predictable time in the evening, the signal-to-noise ratio at a radius of 1500 miles would be sufficient for reliable operation approximately 99.9 percent of the time.

1.3 General Description of Navaglobe System

The Navaglobe system is essentially a low-frequency continuous-wave omnidirectional range which is received on the airplane by a very narrow-band receiver equipped with a special azimuth indicator as illustrated at the left of Fig. 4. This narrow-band range receiver makes use of a loop antenna, shielded to minimize the effects of precipitation static and cross-field corona static. Advantage is taken of the loop's directive pattern to provide additionally an automatic-direction-finder indication in the airplane, as illustrated at the right of Fig. 4. Both the azimuth meter indication provided according to the omnidirectional range principle, and the bearing indication provided by the automatic-direction-finder principle, are fully automatic. Thus, when the equipment is switched to a desired ground station, the indicators shown in Fig. 4 automatically turn to indicate either the azimuth of the airplane from the station, or the true bearing of the station from the airplane, respectively, depending on the position of the system selector switch.

As will be seen from Fig. 4, the azimuth meter is arranged to make 2 revolutions for 360 degrees. In Fig. 4, the pointer of the azimuth meter is shown as indicating an azimuth of 255 degrees. This represents the azimuth angle of the airplane as seen from the ground station. The true bearing from the aircraft to the ground station would be the reciprocal[2] of this azimuth angle, namely 75 degrees. (This is true up to the point where convergence of the meridians matters.) Referring to the right-hand or automatic-direction-finder (ADF) meter, it will be seen that the pointer indicates a true bearing angle of 75 degrees. The double-scale feature of the left-hand or azimuth meter greatly facilitates the operation of checking one meter against the other since the 2 scales shown on the azimuth meter are reciprocals of each other, i.e., the reading of one scale is equal to 180 degrees plus the reading of the other scale. Since the true bearing from the aircraft to the ground station as shown by the automatic-direction-finder meter is the reciprocal of the azimuth angle, the reading of the automatic-direction-finder meter should agree with the reading of the nonused scale of the azimuth meter. Thus, in the case assumed for illustration, where the azimuth is assumed to be 255 degrees, the lower set of numerals on the azimuth meter represents the true azimuth scale and the upper set is disregarded. For the purpose of checking with the automatic-direction-finder meter, however, the upper or unused scale of the azimuth meter showing a figure of 75 degrees should correspond to the reading of the automatic-direction-finder meter.

At first sight, it might appear that 2 readings being derived from the same transmitter would be subject to the same errors so that one would not constitute a reliable check on the accuracy of the other. Practically, however, the errors of the 2 readings are quite independent, so that checking one of these readings against the other is a reliable way of detecting any errors.

It is true that a complete failure, i.e., a breakdown of the transmitter or receiver, will disable both meters. This, however, will be apparent at once. The most serious danger which must be guarded against in any navigation system is not so much the danger of an obvious failure, caused by breakdown, but the danger of incorrect operation which is not apparent. It is axiomatic that no system relied on for safety of human life should be capable of giving an incorrect reading without providing some method of revealing such incorrectness.

The possible errors in the airborne direction finder of the Navaglobe system are quite independent of the possible errors in the omnidirectional range portion of this system. The principle sources of direction-finder error are polarization errors, errors in alignment or balancing of the loop, and errors in the mechanism used for converting the loop signals into meter indications.

[2] In Navigation, A and B are reciprocal angles where $A \pm 180° = B$.

The principle sources of azimuth-meter error are waves reflected from large objects such as mountains in the vicinity of the transmitter, errors in relative phasing of the transmitting antennas (resulting from detuning of the antennas by sleet or sag, or from misadjustment of phase-determining circuits in the transmitter or transmission-line equipment), and finally errors in the indication equipment used for producing the pointer deflection of the azimuth meter. It can be shown that none of these errors is likely to affect similarly both the azimuth and the automatic-direction-finder meters. Therefore, by checking these meters, one against the other, the pilot or navigator can assure himself that none of these errors is present.

Although it provides 2 quite separate indications of each directional reading, as above described, the Navaglobe system requires only a single low-frequency receiver on the aircraft with its single loop antenna. The only equipment which is separate for the 2 types of readings comprises the 2 indicators themselves, plus a small amount of control equipment in the receiver.

The Navaglobe airplane equipment is arranged so that fly-left and fly-right signals can be taken therefrom, for application to the right-left needle of the standard crosspointer (see Fig. 15 of Part III) or for application to an automatic pilot. For this purpose, the azimuth meter is provided with a colored path-selecting needle adjusted by a suitable knob; and a simple voltage divider is provided in the back of the meter for producing right-left signals in accordance with the deviations of the airplane's azimuth from the selected azimuth as set on this colored needle.

In order that the automatic-direction-finder meter may read true bearing rather than relative bearing, the inner finely calibrated dial of this meter is arranged to be rotated by a selsyn repeater controlled from some suitable aircraft compass such as an earth-inductor, flux-gate, or gyrosyn compass. Under normal conditions, when the true north can be determined reasonably accurately, the automatic-direction-finder meter, therefore, reads true bearing and can be double checked against the reading of the nonused scale on the azimuth meter as previously described.

An interesting feature of the Navaglobe system is that by reversing this process the direction of true north could be determined. This might conceivably be made use of in flights near polar regions or under conditions of magnetic storms when the magnetic compass fails. To do this it is merely necessary to adjust the variation control of the magnetic compass until the readings of the azimuth and automatic-direction-finder meters in the Navaglobe indicator group agree with each other. Then, the reading of the magnetic compass will be correct.

Another feature of the Navaglobe system may be mentioned although this is not of importance for most civil use. By the addition of a small special relay and 2 switches, the Navaglobe receiver

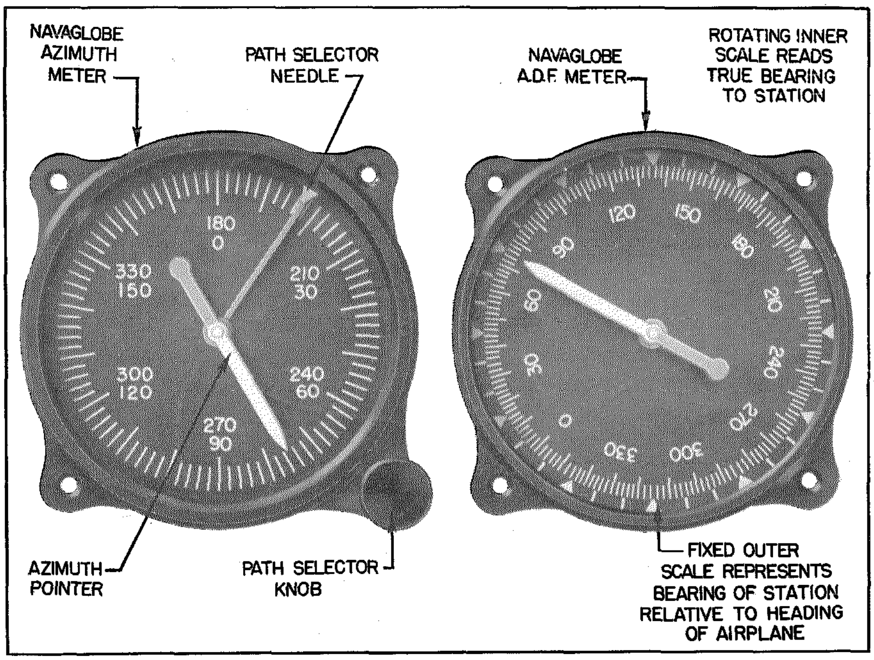


Fig. 4—Standard Navaglobe indicators.

can be adapted to operate not only with the standard Navaglobe transmitting stations herein described, but also with a modified or "vernier" type of Navaglobe station that gives high-accuracy readings at the cost of a less-convenient operating procedure. When the receiver is equipped with these additional components, a group of 11 ring-shaped dials will also be provided; they can be snapped into position on the face of the azimuth meter. These dials are arranged to show the airplane's azimuth in tenths of a degree on a very expanded scale so that each dial covers only about 10 or 12 degrees of azimuth. When using this high-accuracy system, the airplane's approximate azimuth must first be determined within 20 degrees or so by use of the automatic-direction-finder meter or other means to determine which dial should be employed. Then the correct dial is attached and the meter is used to read directly the correct azimuth in tenths of degrees. While this feature is probably not of interest to commercial aviation, it is mentioned as an advantage of the Navaglobe system because there is reason to believe that the armed services would lend their support more readily to a navigation system capable of being used for fine vernier readings as well as for coarse readings.

1.4 Technical Principles of Navaglobe

As previously mentioned, the Navaglobe principle consists basically of a narrow-band long-wave omnidirectional range on the ground, with the addition of an automatic-direction-finder feature in the airborne range receiver. The omnidirectional range operates by the amplitude-comparison principle similar to the conventional 2-course ranges existing throughout the U. S. A. Instead of giving aural indications, however, Navaglobe gives direct-reading pointer-type indications. Moreover, these are given at any azimuthal position of the airplane rather than along 2 or 4 fixed courses. For this purpose, the system makes use of 3 successively radiated signals plus an initial synchronizing signal, the whole cycle taking place once per second.

The ground transmitter makes use of 3 antennas disposed in an equilateral triangle as indicated by the 3 dots in the center of Fig. 5. Only 2 of these antennas are used at any time; the *A* pair of antennas is used to produce the *A* radiation pattern, the *B* pair is thereafter energized to produce the *B* radiation pattern, and lastly the *C* pair is used to produce the *C* radiation pattern. The 3 successive signals are separated in a receiver and applied to a mechanism that produces the required indication by a process of vector comparison. The function performed by this mechanism is the same as would be performed by a ratiometer consisting of 3 coils disposed at 120 degrees and a magnetic needle which aligns itself with the resultant field. Such a needle would indicate directly the desired azimuth angle. The only ambiguity is 180 degrees, which for cross fixes is no ambiguity at all.

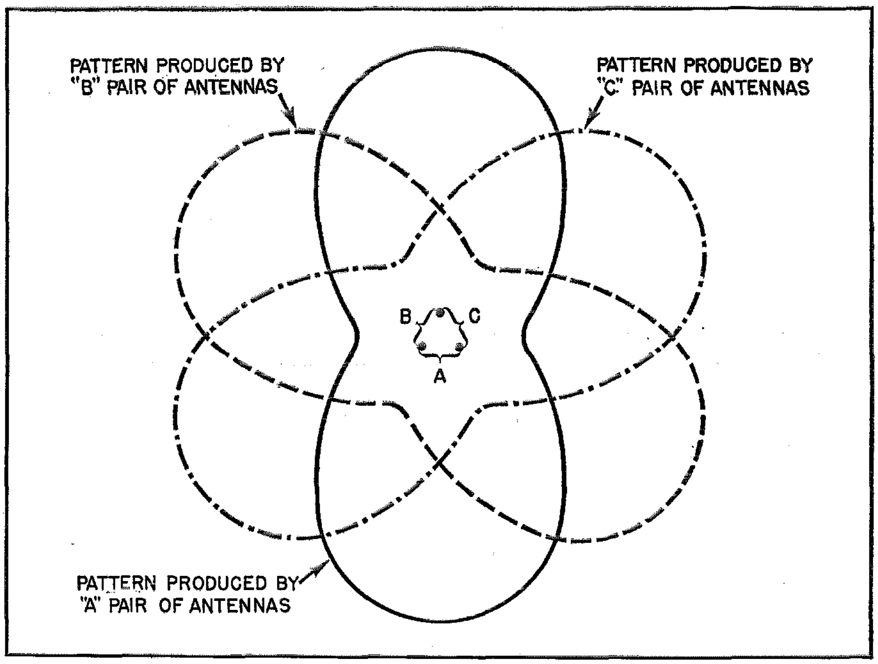


Fig. 5—Radiation patterns for standard Navaglobe.

To insure reliable operation under conditions of severe noise, the receiver bandwidth is made extremely narrow, preferably of the order of 20 cycles total; and in addition, the signals may be integrated over a period of several seconds to average out the effects of noise. *In such a case, the effective accuracy is equal to that which would be attained with a bandwidth of the order of 0.3 to 0.15 cycle per second.* Both the azimuth and automatic-direction-finder meters consequently may be somewhat sluggish in their operation under worst atmospheric conditions and it is estimated that these meters may require approximately 10 seconds to come to rest in position for taking a reading. It is believed that this sluggishness is a very small price to pay for the exceptionally high reliability which the Navaglobe system promises to provide.

Part II—Navar for Traffic Control Around Airports

2.1 Basic Philosophy

It is generally recognized that the problem of traffic control and navigation around airports is the most pressing of the whole aerial navigation field, and that at least the more urgent aspects of this problem must be solved as soon as possible.

On the other hand, it is clear that serious future difficulties will result if we continue any longer with the wartime practice of satisfying each need as it arises on a purely stop-gap basis, without regard to any ultimate co-ordinated goal.

Federal's basic conception is that these conflicting requirements can best be met by setting up as the ultimate goal a fairly definite, reasonably well-co-ordinated, system composed of certain basic units and additional auxiliary units associated therewith. Even the earliest steps taken for satisfying immediate needs should be controlled so as to fit in with this ultimately planned system.

For such procedure to be feasible, it is essential that the ultimate system set up as a goal should have the following 4 characteristics:

a. It must be capable of gradual adoption; the various functions which are regarded as ultimately desirable being capable of successive adoption by the addition of corresponding auxiliary units.
b. The order in which the several functions are designed to be adopted must correspond to the relative urgencies of the existing needs, so that the more urgent operational requirements can be immediately solved without departing from the outlines of the system.
c. The equipment proposed for solution of the more urgent problems, in accordance with the planned system, should be of an immediately available type using known and proved technique and developments and amounting to no more than the redesign of apparatus previously built.
d. The ultimate goal should be sufficiently ambitious to satisfy the requirements for at least 5 or 10 years, insofar as these can be foreseen.

Out of this fundamental philosophy certain specific conclusions may be drawn:

It is clear that the most important aid immediately available to traffic control is the ground surveillance radar; and it therefore follows that the system set up as a pattern for present and future action should make use of ground surveillance radar of conventional pulse type as its basic element.

Second, it appears that the most useful single step for improving a ground surveillance radar is the general adoption of high-performance responder beacons in all aircraft flying under instrument conditions. Accordingly, it appears that one of the earliest functions required in airborne equipments of the planned system should be the provision of responder-beacon service.

The provision of surveillance radars on the ground and responder beacons in the airplane, which can be foreseen as early and inevitable steps, would provide reasonably good ground information. However, they would not provide information in the airplane. To meet this requirement it probably will be necessary, in a comparatively early second stage, that some sort of distance meter and some sort of azimuth meter be provided in the airplane. The very-high-frequency omnirange proposed by the Civil Aeronautics Administration will probably be used for azimuth, although Federal believes that ultimately more-accurate azimuth indications may be conveniently obtained in the region around a surveillance radar from the very narrow rotating beam inherently provided by such radar. Distance indicators of various types have already been developed at various frequencies. It seems certain that some such distance indicators will be adopted at an early stage. Whatever the frequency ultimately decided on for such a distance indicator, it appears extremely desirable to consolidate this with the frequency used for the airborne responder beacon. These 2 equipments could then be combined with a consequent great reduction in the total amount of airborne apparatus.

Thus it appears reasonably certain that the first 2 steps which must be taken are (a) the general use of ground surveillance radars with the adoption of airborne responder beacons to improve such radar service; and (b) the provision of some sort of azimuth meter and some sort of distance indicator in the cockpit. (Preferably the responders of (*a*) and the distance indicator of (*b*) should be combined.)

It is clear that the ultimate goal envisaged should involve considerably more complete service than the mere provision of beacon-assisted radar displays on the ground, and distance and azimuth indications in the airplane. A series of additional functions beginning to be recognized as ultimately desirable, is the automatic reporting of such data as identity and altitude to supplement the plan-position information provided by the responder-assisted surveillance radars on the ground.

There is general agreement that some sort of identification must be given. There is somewhat less agreement with respect to the extent of identification information which should be given; also, with respect to the question of whether altitude information could be given by responder beacons or be determined by height finders on the ground. Federal's position on this question is that the identification information should be given in a form capable of handling a very large number of different identification codes so that each airplane may have a permanently assigned identification code.

In respect to altitude information, it is felt that the desirable accuracies of altitude determination are of the order of 100 feet or so and, therefore, ultimately satisfactory control cannot be achieved at reasonable distances by unassisted height-finder techniques. It is accordingly believed to be necessary, ultimately, to provide some sort of altitude information by responder action.

In addition to providing the ground with the above-mentioned extra information, with respect to altitude and identity, it is believed that the ultimate goal should also include some means for producing a single integrated pictorial display. In such a display the plan-position information from the plan-position-indicator (PPI) scopes, and the altitude and identification information transmitted by the responder beacons, are combined in a simple readily readable form. This information should additionally be made available for controlling, computing, recording, tabulating, and predicting mechanisms of various types not yet clearly foreseen. Hence, it appears desirable to add the requirement that the information on the ground should not only be displayed in an integrated pictorial form, but should also be translated into the form of positive "tele-control" signals such as telegraph or selsyn signals which are readily adaptable for remote transmission and for controlling electromagnetic mechanisms.

Thus it is our belief that after the completion of the early steps (*a*) and (*b*), a group of additional functions (*c*) must be provided to give really complete aid to the ground controllers. These should include the automatic reporting of altitude and identity information by the airplane, as well as the integration of this information plus the plan-position information and flight-direction information, all combined into a single clearly readable display, and including its translation into a positive "tele-control" form of signal.

A principle, which has been strongly urged by Federal for the last 2 years, is that of pictorial display of information not only on the ground, but also in the air.

Because of the known shortcomings of radar plan-position-indicator oscilloscopes, Federal's earlier proposals, made in the spring of 1944, suggested a synthetic form of pictorial display showing only the airplane's own position with a separate low-resolution display showing other airplanes within the altitude layer of interest. Successively, later proposals during the same year presented by Federal for comments and criticisms expanded the principle of the pictorial display to include in one picture not only the airplane's own position, but the position of other surrounding aircraft. Regardless of the details, however, Federal has consistently urged that the ultimate cockpit presentation should be in the form of a picture showing a map of the region to be flown, a representation in contrasting colors of the pilot's own airplane, also, possibly, other airplanes in the same altitude layer. It is believed that this concept is now becoming recognized as a desirable and ultimately achievable goal toward which planning should be directed.

This does not mean, however, that a good cockpit scope is now available, nor that the probability of perfecting such a scope reasonably soon justifies the abandonment of presently available solutions to immediate needs, filled partially by distance and azimuth meters in the cockpit.

In summation, Federal feels the fundamental need to be a system capable of piecemeal adoption so as to satisfy early needs quickly, yet capable of extension toward a more ambitious ultimate goal. Progressively, the steps which can be fairly definitely foreseen are:

a. The provision of ground surveillance radar and airborne responder beacons.
b. The provision of distance and azimuth indications in the cockpit.

Later stages of the development should include:

c. Some means for giving the ground additional information as to identity and altitude, as well as some equipment for integrating all the information into a convenient single pictorial display. Also means of translating all this information into a positive "tele-control" form suitable for transmission to a distant point and for operating tabulating, computing, and other mechanisms.
d. Some means for giving each airplane extra information as to the positions of other aircraft; in a convenient pictorial form of display of all given information.

2.2 *Description of Functions Performed by Navar*

The above analysis of basic requirements, worked out during the past 2 years with the assistance and advice of many agencies, leads to the conclusion that the most essential functions that must be performed by any system of traffic control and navigation around airports are:

a. To provide a radar surveillance function on the ground and at least a minimum responder-beacon operation in each airplane.
b. To give each airplane at least distance and azimuth information.
c. To give the ground extra information and a better form of display—particularly information as to the identities and altitudes of the airplanes shown by the surveillance radars. A display showing all available information in convenient integrated pictorial form, also making this information available in a positive "tele-control" form suitable for recording, computing, statiscal tabulation, and remote transmission.
d. To give each airplane additional information and a better form of display—particularly including information as to the positions of other aircraft of interest to the pilot—all in a convenient, integrated, pictorial form.

The group of equipments described in this section, under the name of the Navar system, performs all these essential functions (except for the provision of the convenient integrated pictorial form of ground display), showing altitudes, identities, and giving a "tele-control" form of signal. The system of integrated pictorial ground display can best be performed by an auxiliary installation, described later in Part IV under the title Navascreen. Even the ground displays given by the Navar system alone, however, are believed to be substantially more convenient and more suitable for operational needs than previously known or proposed ground radar displays.

The Navar system, moreover, is designed so that the more urgent types of functions can be provided for immediately, without waiting until all the ultimately planned extra functions and refinements are ready for adoption. Thus, if the

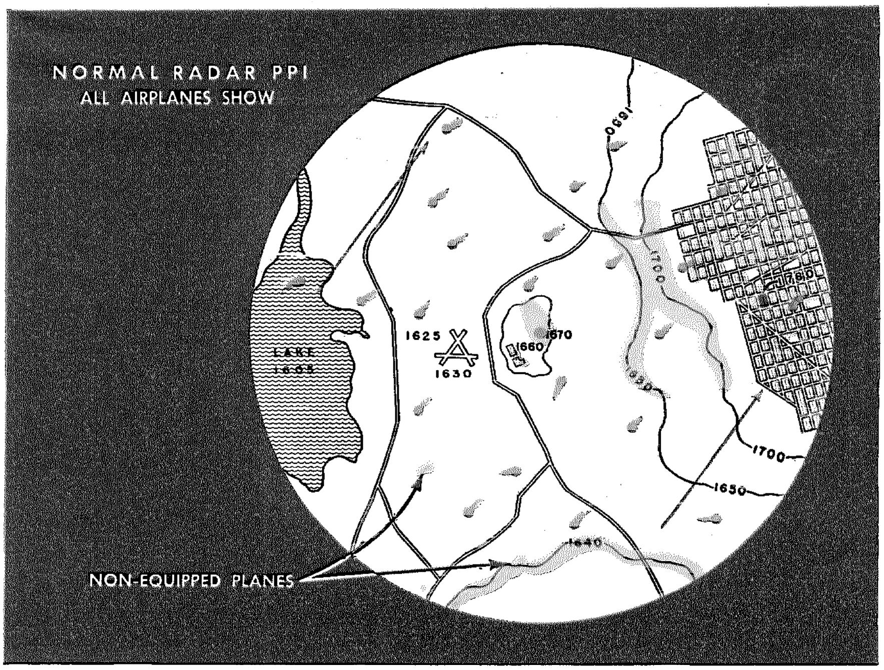


Fig. 6—Normal radar plan-position indicator.

perfection of the Navascope airborne oscilloscope display requires a year or 2, this need not delay the adoption of the simple distance-azimuth meters (which give the pilot at least the minimum essential knowledge of his own position). Similarly, should there be some delay in developing and putting into operation the Navascreen system, which combines several kinds of data in integrated form and also translates these data into "tele-control" form, this need not prevent early adoption of the ground radar and airborne responder-beacon equipments with their immediately useful plan-position-indicator displays.

To exemplify clearly this capability of successive adoption of functions in the order of their urgency, a description of the Navar system might well be separated into 5 or 6 successive steps, describing in this first step only the most urgent functions and the manner of performing them with the least development and minimum amount of initial equipment, and then describing in each successive step the manner of providing for the next most urgent functions. In the interests of brevity and clarity, however, the following description considers the Navar system as a whole. The order in which the different functions are discussed may depart somewhat from the order in which these would actually be put to use.

The 8 most important functions of the complete Navar system are summarized in Fig. 14.

As shown in the figure, the first 3 functions all serve to provide ground radar plan-position-indicator displays of the positions of airplanes within the effective radius of the ground station, i.e., within 75 or 100 miles. These 3 displays, however, differ from each other in certain respects which are believed to be of great practical importance from an operational standpoint.

2.2.1 Function I (Normal Radar Plan-Position Indicator)

The first display in Fig. 14 is a conventional plan-position-indicator display produced by a normal S-band radar unassisted by any airborne responder beacons. It is subject to ground clutter and to direct hash from other radar sets, as well as having an appreciable noise background. It is less clear and less easy to read and interpret than either of the other 2 ground displays; but it is useful because it shows even those airplanes which are not equipped with any responder equipment or whose responder equipment is not operating (hereafter called "stranger" airplanes).

2.2.2 Function II (Comprehensive Beacon-Radar Plan-Position Indicator)

The second display in Fig. 14 is a plan-position indicator produced by a so-called beacon radar, i.e., a radar which depends on the responses of airborne responder beacons (on another frequency) rather than on the natural reflections from the airplane's wings and fuselage. Such radars are free of ground clutter and have less noise background and less hash from other radar sets.

The comprehensive beacon-radar plan-position indicator would show all airplanes having working responder beacons. If suitable regulations compel all airplanes having "instrument ratings" to carry at least crude responder beacons (and to limit all others to contact flying), then in instrument weather practically all airplanes would be shown on this comprehensive beacon-radar plan-position indicator. All those that were shown, would be clearly and plainly seen without expert study. A map of different color from the spots representing airplanes is optically superposed on this display by means of a glass plate used as a transparent mirror.

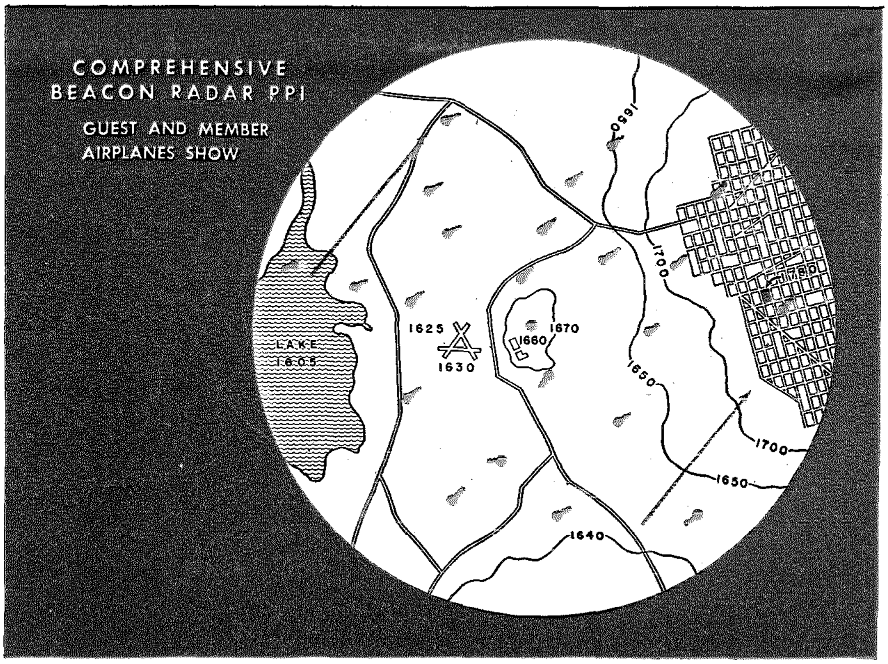


Fig. 7—Comprehensive beacon radar plan-position indicator.

This display may also include a layer-blanking feature by which the operator can blank out or erase the spots representing airplanes within any selected altitude layer of adjustable thickness. Assuming that the layer thickness has been adjusted to 1600 feet (i.e., 800 feet above and below the nominal center altitude of the layer), then if the operator turns on the blanking control and sets his altitude dial to a nominal height of 5000 feet, this will blank out all the spots representing airplanes within 800 feet of this nominal height (i.e., all spots representing airplanes between about 4200 and 5800 feet). Alternatively, the selected layer may be brightened or defocused, or may even be the only one shown.

It is assumed that the traffic controller will use mainly the clear readable indications of the *comprehensive* beacon-radar plan-position indicator and that the principal duty of the operator at the *normal* radar plan-position indicator will be to check continuously, to be sure there are no "stranger" airplanes in the region (i.e., airplanes without working responder beacons, which show on the normal radar but not on the comprehensive beacon-radar plan-position indicator). To facilitate this task, the Navar displays are arranged so that the normal radar plan-position indicator is yellow in color and has optically superimposed on it an orange image of the comprehensive beacon-radar plan-position indicator. This will be more clearly seen by comparing Figs. 6 and 7 which show these 2 displays as they would actually appear.

2.2.3 Function III (Selective Beacon-Radar Plan-Position Indicator)

The third display of Fig. 14 is the selective beacon-radar plan-position indicator which is shown more clearly in Fig. 8. (The circle and radial line shown in Fig. 8 is used for another feature hereafter described and may be disregarded at this time). This is also a clutter-free display of the beacon-assisted type, but differs from the display of Fig. 7 in that it selectively shows only those airplanes whose responder beacons are *tuned-in to the Navar ground equipment of the particular airport in question*, (e.g.,

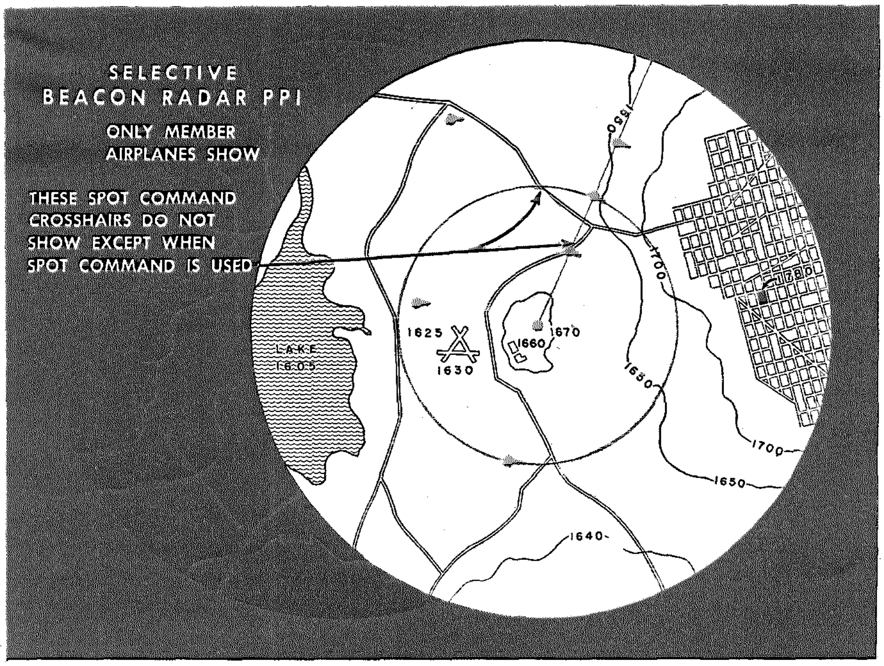


Fig. 8—Selective beacon radar plan-position indicator.

Idlewild Airport). These tuned-in airplanes, hereinafter called "member" airplanes, will be those 10 to 30 airplanes that are scheduled to land at Idlewild Airport. The many other airplanes—perhaps 100 to 250 in number—which are merely passing through the coverage region of the Idlewild radar station (and scheduled for landing at LaGuardia, Newark, Westchester, Mitchel, Roosevelt, Floyd Bennett, or other airfields) will not appear on the selective plan-position indicator of the Idlewild display.

This separate display of only member airplanes is important if, as we expect, the function of accurately scheduling arrivals (and of requesting time-saving increased speed or time-wasting fishtail flight for exactly adjusting a number of arrivals so as to mesh properly for successive landings) is to be handled somewhat separately from the purely safety function of imposing negative limitations on all airplane movements, as required for collision-prevention purposes.

This display also has an optically superposed map of contrasting color and may also be equipped with the layer-blanking control previously described.

2.2.4 Advantages and Shortcomings of Functions I, II, III

The 3 displays corresponding to the first 3 functions of Fig. 14 have many advantages over the plan-position-indicator displays heretofore used or proposed. The superposition of the comprehensive beacon-radar display on top of the normal radar plan-position indicator, but with a clearly distinguishable orange color, greatly facilitates the problem of picking out any "stranger" airplane so that this can be specially handled. The layer-blanking feature is useful in giving a rough check on altitudes. The provision of fixed maps of contrasting colors optically superposed on all displays is much more convenient than the use of arbitrary grids or maps produced by injected video signals, because the latter are necessarily of the same color as the spots representing airplanes. As compared with transparent maps physically placed over the plan-position-indicator screens, the optically superposed maps are much less subject to parallax error and can be more accurately registered.

Most important of all is the separate provision of 3 displays: one showing only *"member" airplanes* (those tuned to the station in question); another showing *all beacon-equipped airplanes*, both "guests" (those equipped with beacons but tuned to some other station) and "members" (as above defined); and a third, showing *all airplanes* whether "members," "guests" or "strangers" (with the previously mentioned superposed image to make the strangers easily distinguishable).

The principal shortcomings of the 3 Navar ground displays may be summed up by the statement that each display gives clearly only the plan-positions of the airplanes shown thereon, but does not properly combine with these any clear convenient display of altitude, identity, and direction of flight. This is because of the limitation of radar plan-position-indicator scopes which cannot yet be made to show several different colors nor to reproduce legibly hundreds of small letters and numbers.

It is, of course, possible to display much more information by the use of more than one oscilloscope but this defeats the main principle—that of providing all information needed for one controller on one integrated display.

For a truly complete ground display, it is believed essential to provide one integrated display showing continuously not only altitudes, but also directions of flight and identity in convenient and easily readable form. This is proposed to be accomplished along with several other important functions by the Navascreen installation described in Article IV.

2.2.5 Functions IV and V (Distance-Azimuth Meter)

The fourth and fifth displays shown in Fig. 14 represent, respectively, distance and azimuth meters in the cockpit of the airplane. These would preferably be combined in one instrument as shown in Fig. 9. For radial flight toward or away from the ground station, it is merely necessary to keep the azimuth constant, while for orbiting around this station, the distance should be kept constant. For flying a straight path which is offset with respect to the station, however, rather complex mental calculations would be necessary.

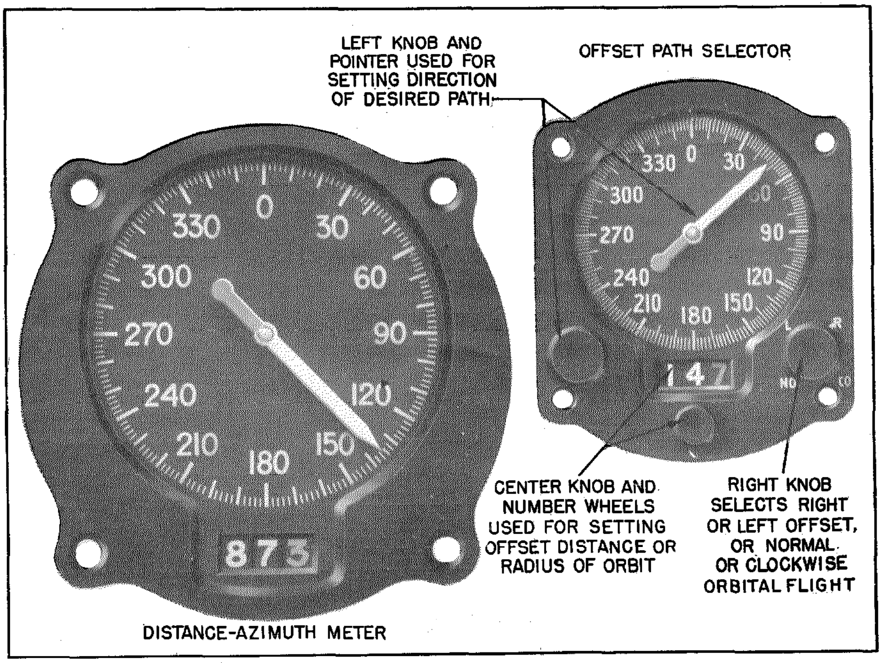


Fig. 9—Navar distance-azimuth meter and offset-path selector.

To make it practical to fly such offset paths (as well as to increase the convenience of radial and orbital flights), an offset controller may be provided. As illustrated in Fig. 9, such controller has 2 knobs for setting-in the desired direction of flight of a desired offset flight path, and the amount of offset of such flight path from the ground station. A third knob determines whether this offset is to the right or the left. For radial flight the settings are similar, except that the offset distance is set to 0. For orbital flight the radius of the orbit is set as desired and the third knob is set for "normal orbiting" or "clockwise orbiting" as desired. When this offset-path controller is thus set to preselect a desired path, it makes available a control voltage which may be applied to the left-right needle of the usual cross-pointer (see Fig. 15) or to an automatic pilot. Thus, manual or automatic flight along the preselected path or orbit may be carried out just as in the case of flight along a range or localizer beam.

2.2.6 Function VI (Navascope)

The sixth function, schematically represented in Fig. 14, is an airborne pictorial type of display referred to as the Navascope. This Navascope

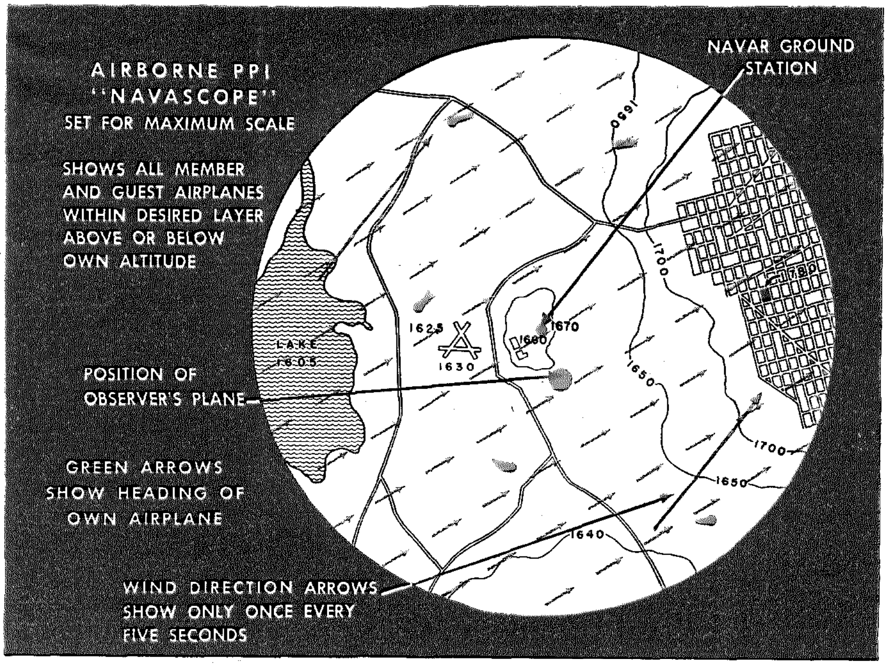


Fig. 10—Airborne Navascope.

shows the position of the pilot's own airplane as well as the position of other airplanes in relation to a printed map of contrasting color which is represented in Fig. 10. A series of such maps representing the regions around different airports are printed on transparent cards which can be readily snapped in place over the face of the Navascope. A grid of fine green arrows representing the heading of the airplane is also superposed on the Navascope display and is controlled from a suitable magnetic compass.

The spot representing the pilot's own airplane is distinctively marked by a bright halo and is instantly distinguishable from others. The identification of this spot does not depend merely on azimuth but on both azimuth and distance. Thus, even if one or more airplanes are flying at the same azimuth as the pilot's own airplane, no possible error in identification will result; Fig. 10, for example, shows a condition where one other airplane happens to be at the same azimuth as the pilot's own airplane. In spite of this condition the identification of the pilot's own airplane is clear and unmistakable.

Another important feature of the Navascope display is that it shows only airplanes that are approximately at the same altitude as the pilot's own airplane, avoiding the confusion which would result from showing 100 to 200 airplanes in the cockpit display. The purpose of this layer display is to show only those airplanes which are flying within a certain layer of altitude. This layer is usually set at approximately 1600 feet thick. It is automatically shifted as the airplane moves up and down, so that the layer shown is at all times properly centered with respect to the airplane's position.

Fig. 11 clearly shows how the altitude of the layer follows that of the airplane as the latter ascends or descends. The 4 small diagrams in the upper portion of this figure show the pilot's own airplane descending successively through altitudes of 8200 feet, 8000 feet, 7800 feet, and 7500 feet, respectively. These diagrams also indicate how the layer of vision of this airplane moves down *gradually and continuously* with the movement of the airplane. Thus when the airplane is at 8200 feet altitude, the layer within which other airplanes are shown extends 800 feet both above and below the airplane itself. Later when the airplane has descended to 8000 feet it will be seen that its layer of vision is correspondingly lowered so as to extend from 8800 feet to 7200 feet. Similarly, as the airplane descends to still lower altitudes, its layer of vision descends smoothly with it so that this layer always continues to extend 800 feet both above and below the altitude of the airplane.

The lower portion of Fig. 11 shows how the thickness of the layer can be adjusted. It is assumed that this layer will usually be set at a thickness of 1600 feet, i.e., 800 feet above and 800 feet below the airplane, but if desired this layer can be made thicker or thinner as shown in the lower portion of the same figure.

2.2.7 Functions VII and VIII (Selective Spotting-Reporter and Annunciator)

The last 2 functions summarized in Fig. 14 are closely associated with each other, but are separately shown, since in other systems these are usually offered independently. It is possible by means of one of these functions for a ground controller to pick out individually one particular airplane, which he sees as a spot on his display, and to obtain, by an automatic reporting method, detailed and accurate information as to the identity and altitude of such airplane. The other function enables the ground controller to send simple visually displayed commands to a particular airplane.

Both of these features depend on positively spotting or picking out a particular one of the 100 or more airplanes shown on the ground display. Ordinarily the controller will not know the identity or name of the airplane which he wishes to pick out but will only see it as a spot. To select this one particular airplane, therefore, it is necessary for him to set a pair of cross hairs to intersect the spot in which he is interested. Of these cross hairs, one has the form of a straight radial line which may be swung around to any angle by a suitable control, while the other has the form of a circle which may be expanded or contracted to any desired radius. These cross hairs are illustrated in Fig. 8.

Assume that the ground controller wishes to ascertain the identity and accurate altitude of a particular airplane which he sees on the selective beacon-radar display of Fig. 8. He first throws a switch to make the cross hairs visible, then rotates 2 hand wheels to adjust the 2 cross hairs so that they intersect on the spot in question. Finally he presses an interrogation button which causes the airplane to report

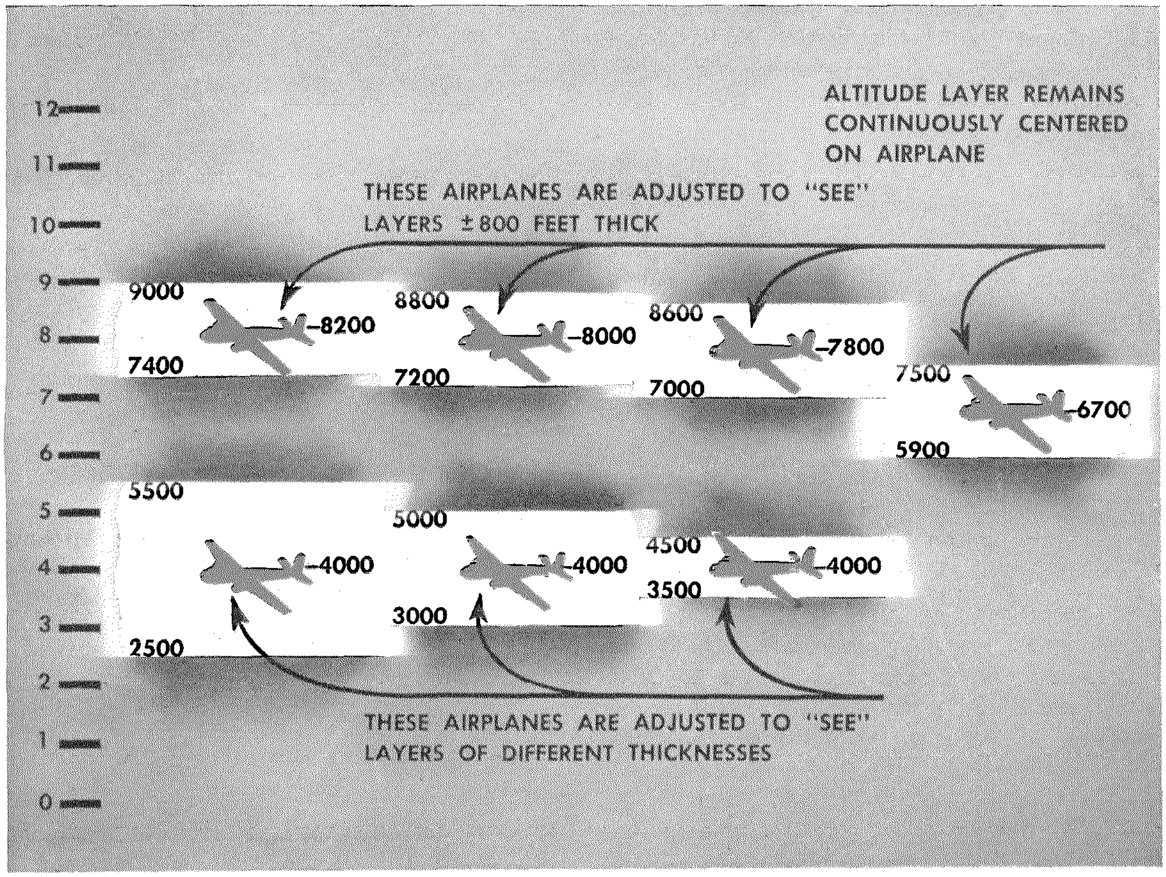


Fig. 11—Variation of layer displayed.

automatically its altitude and identity. Almost immediately this altitude and identity are displayed on a meter and set of number wheels. Fig. 14 illustrates this function.

If the controller's purpose is to send some simple command to the airplane instead of to interrogate it for automatic altitude and identity reporting, he sets the cross hairs as previously described but, instead of pressing the interrogation button, he presses one of several command buttons. This instantly causes the corresponding command to appear in front of the pilot on an annunciator (see Fig. 14). These commands may indicate simple flight instructions such as "Descend 1000 feet," "Climb 1000 feet," "Turn right 15 degrees," "Turn left 15 degrees."

Alternatively, the commands provided on the annunciator may be arranged to facilitate the establishment of communication between the tower and the airplane. Thus a few simple commands such as "Answer on channel A," "Answer on channel B," "Answer on channel C," etc., might be provided. This method of setting up speech communications would eliminate the annoying feature encountered when a common guard channel is made use of for publicly announcing to all pilots which channel is being assigned to a certain pilot for communication with the tower. Furthermore, this method appears to be the quickest way of establishing communication with a particular unidentified plane seen as a spot on the ground display.

If the selective annunciator is used in this way for assigning speech channels and giving very simple flight instructions, the more complex flight instructions could conveniently be given by means of speech. Normally, this would be done by spotting the airplane with the cross hairs and visually instructing the pilots to "Answer on channel B," for example. The detailed flight instructions could then be given over channel B.

In emergencies, when quick action necessitates giving instructions over the common guard channel, the selective reporter would still be extremely useful since it would enable the controller to determine precisely the identity of the spot representing the airplane in danger. The controller would merely set his cross hairs on the airplane in question, causing its identification number to be displayed almost immediately. The instructions could then be given in the usual way over the common guard channel to which all airplanes are normally tuned. The knowledge of the airplane's identity provided by the selective reporter in such a case is the quickest possible way of insuring that the command is directed to the proper airplane.

In cases where the airplane's communication set was temporarily tuned away from the guard channel for the purpose of conversation with the ground station or other airplanes, a special indication would be given on the selective annunciator such as "Emergency! Answer on guard channel!"

2.3 *Principles of Operation of Navar Functions*

The basic principles of operation of the Navar functions summarized in Fig. 14 are extremely simple and may be outlined in a few paragraphs.

2.3.1 Functions I, II, III, (Ground Displays)

The first ground display known as the normal radar plan-position indicator is merely the usual display given by a conventional search radar, except that it has superposed on it in orange color a representation of the comprehensive beacon-radar display to facilitate picking out the so called "stranger" airplanes. The second display of Fig. 14 is merely a conventional beacon-assisted radar display, except that the receiver which receives the response signals from the airplanes is adjusted to accept a whole group of channels simultaneously so that the response of every airplane will be heard regardless of the particular channel on which such response is given. The third display of Fig. 14 is an ordinary beacon-assisted radar display whose receiver is conventionally adjusted to cover only one channel; this display includes only the "member" aircraft tuned to that particular channel. All 3 displays make use of the same radar transmitter, so that all 3 can be provided by one conventional radar set, by merely adding 2 extra receivers.

2.3.2 Function IV (Distance Indicator)

The distance indication is given by conventional principles, successfully used by the U. S. Navy and independently by the National Re-

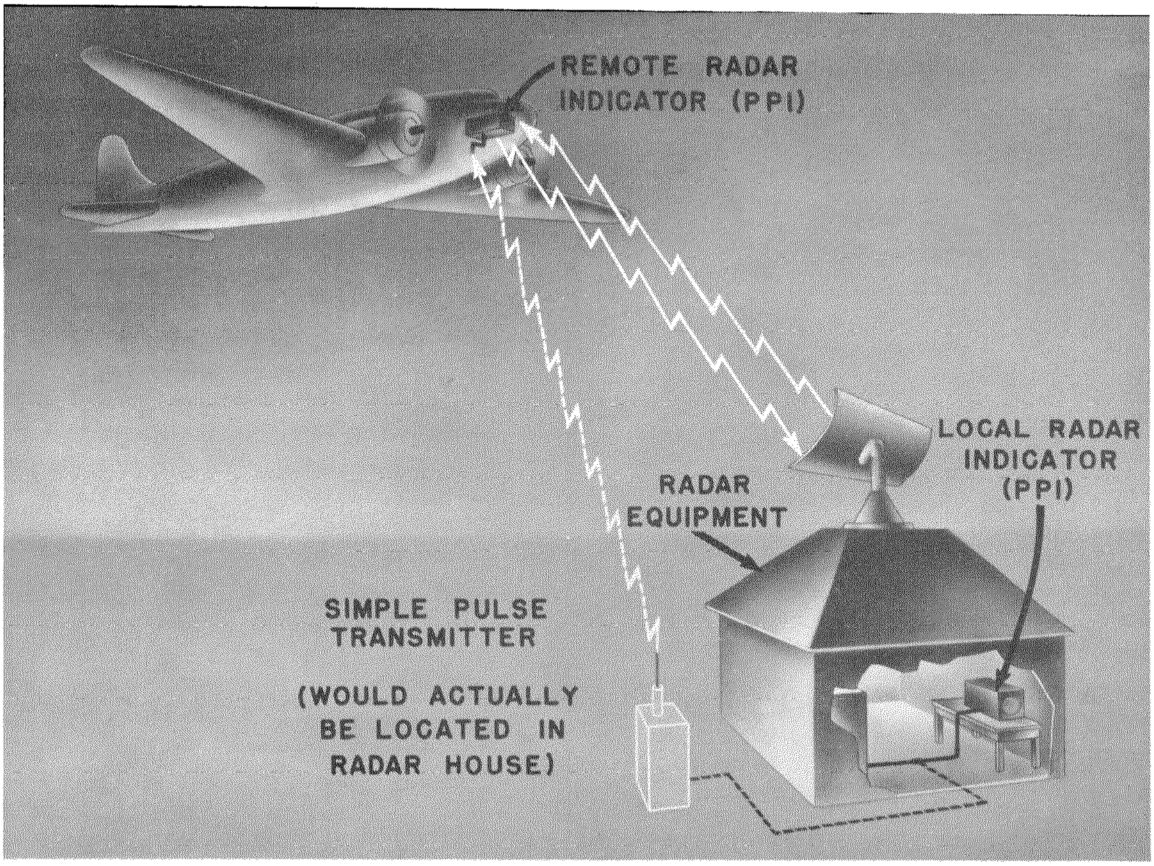


Fig. 12—Basic principle of Navascope display.

search Council in Canada. Pulses are transmitted at random from the airplane to the ground station where a responder sends these pulses back to the airplane on a different frequency, as shown by the arrows in Fig. 14. An automatic mechanism on the airplane measures the time elapsed between such transmissions and responses, directly giving the distance of the airplane from the ground station.

2.3.3 Function V (Azimuth-Indicating Principle)

This principle is the same as that used for many years in rotating ranges in Europe and during the war in this country. The accuracy is, however, improved by using the beam of the ground radar, its extreme sharpness making the azimuth indications much more accurate and less susceptible to errors caused by reflecting objects. Basically, the principle is that the rotating radar beam (shown as a dotted streak in the fifth small sketch of Fig. 14) sweeps around once per second so as to strike first one airplane and then another. A "North" signal is sent out in all directions, at a convenient lower frequency, each time that the rotating radar beam swings through north (represented by the solid streak in the same sketch). If an airplane happens to be north of the station, the North signal is received at the same time that the rotating radar beam is received. If the airplane is east of the station (i.e., a quarter of a turn beyond north) the North signal will be received and then one quarter of a second later, the rotating radar beam will swing past the airplane and be received. The time elapsed between the 2 signals is always proportional to the airplane's azimuth angle. The aircraft will only require a timing device to measure the interval between the 2 signals; this directly gives the azimuth angle of the airplane with respect to north.

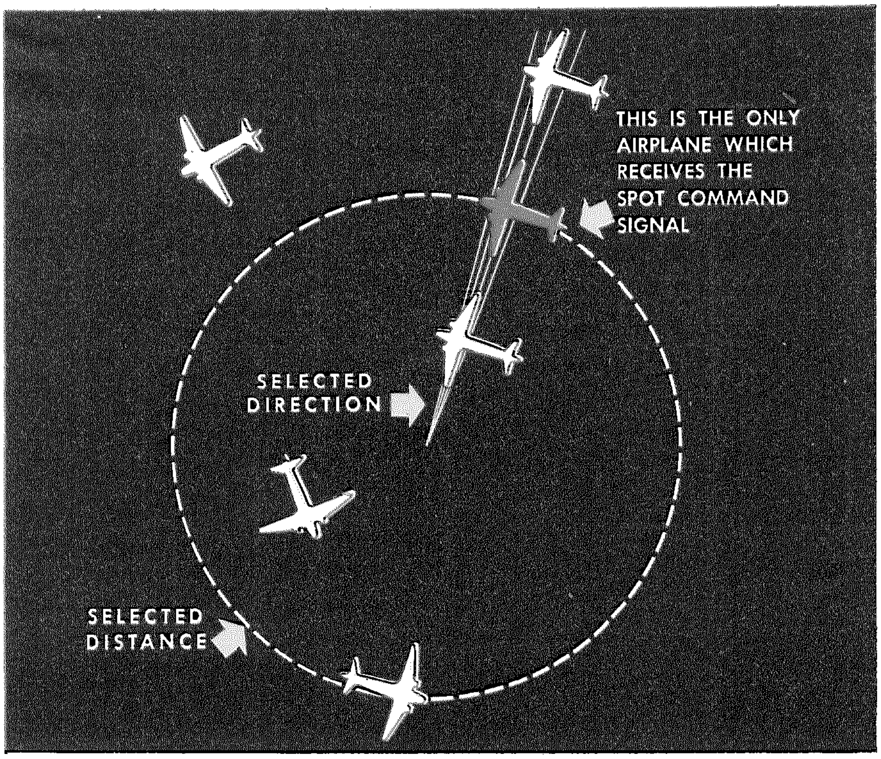


Fig. 13—Illustrating selective spotting functions.

to the plan-position indicator. The plan-position indicator in the airplane receives exactly the same pulse signals and synchronizing signals as does the plan-position indicator in the ground radar set. Therefore, exactly the same form of display is produced in the airplane as on the ground.

It will be noted that the airborne equipment involves only a simple receiver and a plan-position indicator. On the ground the only thing added to the conventional radar set is the pulse transmitter, which is keyed by the various signals normally applied to the ground plan-position indicator.

2.3.4 Function VI (Navascope)

The basic principle employed for producing the Navascope pictorial display in the airplane is almost equally simple. As shown in Fig. 12, a radar equipment (only the rotating reflector and the plan-position indicator are visible) determines the position of every airplane in the usual manner and transmits this information to its plan-position indicator in the usual form of a set of video pulses, together with appropriate synchronizing signals for controlling the rotary and radial sweeps of the indicating unit. *This much is merely the normal operation of a conventional radar.* The added ground equipment, for giving the airborne Navascope display, consists merely of a simple pulse transmitter which is keyed on and off by the same signals usually transmitted to the ground plan-position indicator, and which acts to retransmit these signals omnidirectionally to all aircraft in the vicinity. Each aircraft is then provided with a *simple plan-position indicator and with a receiver* for taking the signals from the pulse transmitter and applying them

2.3.5 Functions VII and VIII (Selective Reporter and Annunciator)

The 2 functions collectively known as the selective spotting function consist merely of straightforward signalling, to a specific airplane, for selectively operating one of a few annunciators on the airplane, and for triggering the airplane equipment to make it send out an automatic report signal. A new principle (illustrated in Fig. 13) makes it possible to single out one specific airplane and have only this airplane receive the various transmitted signals. Since each airplane is provided with an indication of its own distance from the ground station (see Function IV), it is a simple matter to provide a double pulse gate on each airplane which will pass a pair of pulses only if they are spaced apart by a suitable time interval to correspond to the airplane's distance from the ground station. The signals sent out from the ground are then simply made up of pulse pairs having the correct spacing. These signals can only be received by airplanes flying at the selected distance from the ground station. When the ground controller adjusts the circular cross hair shown in Fig. 8, the movement of the control knob also adjusts the spacing of the pulse pairs of the transmitted signal so as to be receivable only by airplanes at the corresponding distance (represented by the dotted circle in Fig. 13). Even if there is another airplane on this dotted circle as shown in Fig. 13 only the desired one will receive the signals, because these signals are sent out on a narrow beam. This beaming is attained by means of a directive antenna, controlled by the same knob that adjusts the radial cross hair. Thus, by setting the circular and radial cross hairs to intersect on a particular airplane, the spacing of the pulse pairs of the transmitted signals and the direction in which they are beamed are simultaneously adjusted so as to influence only the one airplane desired (shown in solid red in Fig. 13).

2.4 *Advantages of the Navar System*

Apart from the basic advantages of flexibility, capability of progressive adoption, and incorporation of those existing elements whose adoption in the near future is a virtual certainty, the Navar system is characterized by maximum simplicity of operation for each of the functions provided. It is true that in the complete form above described the Navar system incorporates a large number of functions. However, every one of these functions is performed in the simplest possible manner. The principle used for spotting a particular airplane with 2 cross hairs (illustrated in Figs. 8 and 13) is thought to be the simplest principle to achieve this result reliably while the principle used for the Navascope is believed to be the simplest possible for giving a pictorial display in the cockpit.

The principle (shown in Fig. 12) which is used for providing the Navascope display in every airplane, was independently invented by Federal. It corresponds quite closely to principles previously developed, and actually made use of, by the Radiation Laboratories of the Office of Scientific Research and Development in Cambridge. These principles have been time tried and proved. This principle not only requires a

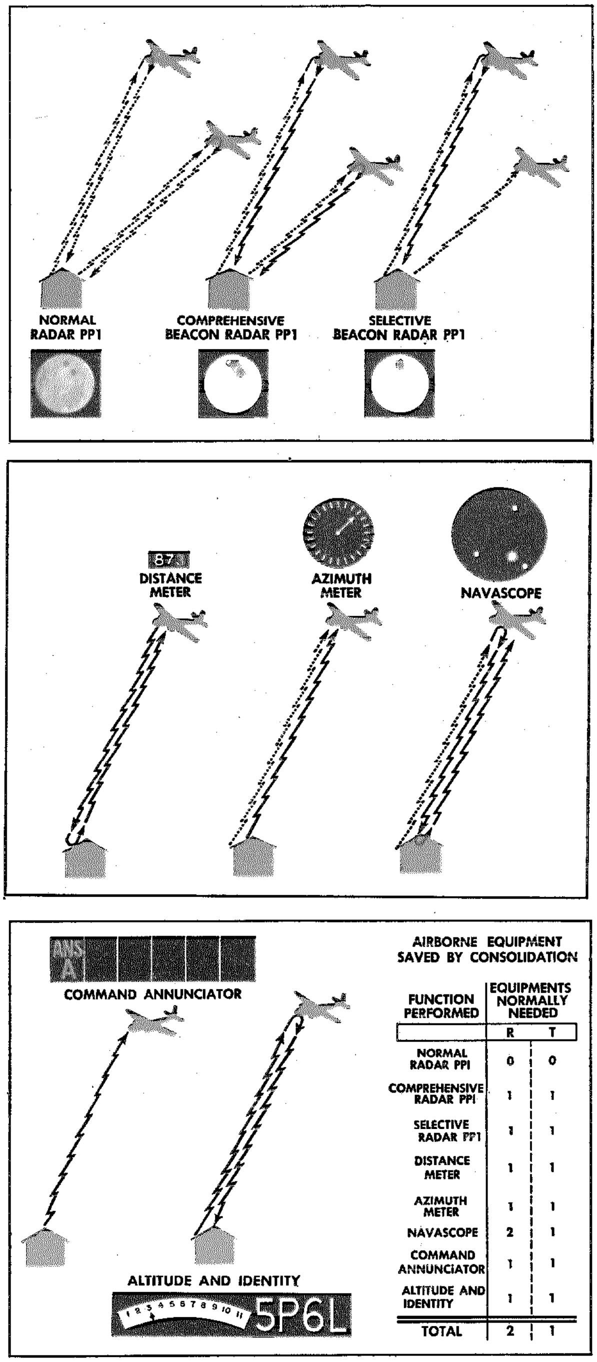


Fig. 14—Summary of principal Navar features.

minimum of ground and air equipment, but also has certain important tactical advantages in *saving bandwidth* and preserving the *full definition* of the *plan-position-indicator* display. Moreover, if any special codings are included in the radar signals sent back from the airplane to the ground radar set, these *special codings will not be lost in the process of retransmitting the signals to the airplane.*

This preservation of the coding of the airplane responses is the factor that makes possible the accurate layer display of the Navascope. If it were not for this factor, it would be much more difficult to make the layer of visibility move up and down continuously to correspond with the vertical movements of the airplane.

Despite the fact that the Navar system is a flexible one, permitting the progressive adoption of different features on a practical basis, a considerable measure of consolidation has nevertheless been achieved. The tabulation shown at the right of Fig. 14 indicates that if each of the 8 functions therein summarized were independently performed, the total number of receivers and transmitters in the airplane would amount to 7 and 8, respectively. By virtue of combining the various functions, the *total number of transmitters is reduced to 1* and the *total number of receivers is reduced to 2.* This consolidation in no way affects the flexibility of the system.

Except for this consolidated use of one transmitter and 2 receivers, the different functions are for the most part quite separate; they can be added independently in almost any sequence likely to be desired. The performance of several different functions is achieved by taking advantage of a simple pulse-width selector developed and used by Federal during the war. Thus it is conveniently possible to separate several different kinds of signals passing through a single receiver and to route them to different auxiliary units. The airborne transmitter is also required to transmit 2 different widths of pulses, to perform different functions without interference.

Because of the essential lightness and inexpensiveness of the electronic equipments working at video or lower frequencies, each of the auxiliary equipments provided for the separate functions is almost negligible in size, weight, and cost, compared with the 2 receivers and the transmitter which must operate at high radio frequencies. Accordingly, it can be definitely stated that a very large measure of consolidation is achieved in the Navar system while still providing separate auxiliary units for most of the individual functions.

A further advantage resulting from the consolidation of the radio-frequency units is that they can be better engineered and better constructed than would be possible if a larger number of receivers and transmitters were provided. Thus the transmitter and one of the receivers are arranged for multichannel operation with *crystal-stabilized frequency and push-button channel selection.* This attainment of crystal-stabilized multichannel operation provides great advantages in respect to many of the functions.

The use of a multichannel transmitter for the responder function makes it possible, for example, to provide the separate selective beacon-radar display which shows only the "member" airplanes scheduled to land at an airport. The provision of a tunable receiver also makes it possible, for a ground station remote from the airplane, to obtain responses therefrom under adverse conditions. This applies even when the airplane is flying so close to another ground station that conventional responder equipments would cease to operate.

In respect to the distance-indicator function, the multichannel feature provides a service considerably superior to that offered by most distance indicators. The usual type of distance indicator merely indicates the distance to the nearest ground station, whether or not this ground station is the one in which the pilot is interested and to which his azimuth indicator is tuned. The Navar type distance indicator, with its push-button-tuned crystal-controlled transmitter and receiver, is capable of indicating selectively the distance and azimuth to that one of the ground stations in which the pilot is interested. This is operationally very significant.

Suppose, for example, that a pilot were flying toward Floyd Bennett Field from Bridgeport, Connecticut, with a conventional distance indicator. His meters might successively show him his distance from Westchester Airport, LaGuardia Field, and from Idlewild, even though the station in which he was interested, and to which his azimuth meter was tuned throughout the flight, was Floyd Bennett. The Navar distance and azimuth indicators would, in such case, enable him to select the Floyd Bennett station as soon as he came within approximately 80 miles thereof. These meters thereafter, would continuously display his distance and azimuth with respect to Floyd Bennett only.

The following is a partial listing of the important features of the Navar system benefiting pilots and aircraft operating agencies:

a. A normal responder feature which responds to all S-band radars in the usual way, thus avoiding the need for carrying a separate responder beacon.
b. Member airplane responder feature which responds only to the selected Navar station at which a landing is scheduled.
c. Distance-indicator feature which gives the aircraft a continuous indication of its distance to a Navar ground station.[3]
d. A precision azimuth feature giving azimuth by the use of a sharp directive pattern from an S-band radar.[4]
e. Automatic pilot controls for automatically controlling radial or orbital flight; even flight along an offset line passing to the right or to the left of the selected ground station.
f. Cross-pointer controls for applying "fly-left" and "fly-right" signals to the standard cross-pointer meter to facilitate instrument flight along radial, orbital, or offset paths.
g. The pictorial presentation of the airplane's own position provided by the Navascope.
h. The superposition of a clear map of contrasting color which cannot confuse the other indications of the Navascope.
i. The heading indication superimposed in still another color on the Navascope display, to facilitate flying along desired paths.
j. The anticollision feature showing on the same Navascope display the positions of other airplanes which must be avoided.
k. The altitude-layering feature which restricts the Navascope display so as to show only those aircraft in the same general level as the airplane in question.[5]
l. The selective reporter which relieves the pilot of the necessity of verbally reporting his altitude and identity.
m. The selective annunciator feature which visually presents to the pilot the more common types of flight instructions and which conveniently informs him when a special channel is assigned for his use in conversing with the tower.[6]

A partial listing of features benefiting flight controllers and other ground personnel follows:

a. Normal radar display of all aircraft.
b. Beacon-assisted clutter-free display of all aircraft having S-band responders (all aircraft permitted to operate under instrument flying conditions).
c. The optical superposition of the above-mentioned beacon-assisted display on the above-mentioned normal radar display which facilitates picking out the "stranger" airplanes (those not equipped with responder beacons or those whose responder beacons are not operating properly).
d. A selective "Member" airplane display showing separately those aircraft which are tuned to the particular ground station.[7]
e. The layer-blanking control which permits a rough determination of the altitudes of any airplanes shown on either of the beacon-assisted displays.
f. The selective reporter feature enabling almost instantaneous determination of the identity and *exact* altitude of any airplane seen as a spot on the beacon-assisted displays.
g. The selective annunciator feature which enables simple commands to be transmitted automatically to any particular airplane shown as a spot on the beacon-assisted displays.[8]

[3] A very great increase in utility results from the selective feature of the distance indication which permits the pilot to choose the ground station with respect to which distance indications are desired.

[4] Added utility results from the fact that this azimuth feature is ganged with the distance-indicator feature so that both indications are always given with respect to the same ground station.

[5] This layering is particularly advantageous because of its property of *continuously* following the vertical movement of the airplane, remaining accurately centered about this airplane.

[6] A factor which will probably render this feature particularly attractive to experienced airline pilots is the possibility of thereby eliminating much of the annoying chatter which otherwise takes place on the stand-by or "guard" channel and to which he is normally required to listen for many hours.

[7] By proper regulations, it can be arranged that the aircraft shown will be those scheduled to land at the airport in question.

[8] The possibility of using this feature for assigning individual channels to aircrafts makes it especially convenient. Also, of great importance is the possibility of using this feature for rapidly communicating with a desired aircraft in emergencies, whether such aircraft is listening on a stand-by channel or not.

Part III—Navaglide for Instrument Landing and Automatic Landing

The least urgent major requirement of the aerial navigation field is the development of a new and modernized system of instrument landing.

Present plans call for the continued use, for several years, of an instrument approach system essentially like the SCS-51 system. This system includes a 110-megacycle localizer transmitter, a 330-megacycle glide-path transmitter, and 3 75-megacycle marker transmitters, as well as 3 corresponding receivers in each aircraft. The SCS-51 system was developed by Federal (initially for the Civil Aeronautics Authority and in later stages for the Armed Services). With some redesign to render it more suitable for permanent installation rather than mobile wartime installation (and with probable alteration in the form of modulation employed), this system should provide satisfaction for many years.

Ultimately, however, it appears desirable to supplant this system by one making use of a single frequency for glide path and localizer and having certain other modifications to fit it better for use with the traffic-control systems which will probably be in use within a few years.

To be prepared to meet such demands when they finally arise, Federal has commenced development of a microwave system for instrument landing and automatic landing. Most of the principal features and characteristics thereof have already been determined.

This new microwave system, which may be referred to as the Navaglide, will provide not only the conventional directional signals, such as "fly-left," "fly-right," "fly-up" and "fly-down," but will additionally include a distance responder for giving distance signals which continuously and accurately indicate the distance to the point of contact.

A single receiver operating in the same general frequency range as the tunable aircraft receiver of the Navar system will be used for receiving all 4 directional signals. The principle of time sharing will be made use of to transmit these 4 signals in succession instead of simultaneously. The transmission will take place sufficiently frequently to provide suitable control for an automatic pilot.

The same time-sharing feature will make possible the use of a number of such Navaglide installations at one airport. All such installations at an airport will operate on one carrier frequency, but the various signals will be distinguished by super-audible tones. Ultimately, it is possible that the single receiver required for the 4 directional signals of the Navaglide system may be consolidated with the tunable Navar receiver. This, however, has not yet been definitely determined.

The continuous distance signals will be provided by a pulse responder located on the ground at an adjacent point. This responder on the ground will be suitable for co-ordination with the distance indicator incorporated in the Navar system, but will be set to operate on a different channel from that used by the Navar ground equipment at the same airport. No increase in the number of channels of the Navar receiver will be necessitated by this arrangement, since the directivity and low power of the responder located at the touch-down point will render it feasible to operate this responder on one of the channels assigned to some other airport between 100 and 250 miles away.

The same simple beam principles employed in the SCS-51 will be used in the Navaglide system. Because of the anticipated provision of some traffic-control system similar to Navar, a 360-degree angle of coverage will no longer be required. The beams of the localizer and glide-path systems of the Navaglide system will be, therefore, restricted to a narrow angle of 35 degrees or less. Because of the use of microwave frequencies, the pattern sharpness can be increased readily to the point where bends caused by reflections from nearby obstacles will be greatly reduced. The narrowed beam width and, if necessary, the use of a wider frequency spectrum will further reduce such bends to the point where they are wholly inappreciable.

Engineering calculations and experiments are being carried on to investigate the possibility of relocating the localizer antennas at a position closer to the touch-down point on the runway. It has not yet been determined whether the possible gains of such relocation are sufficient to

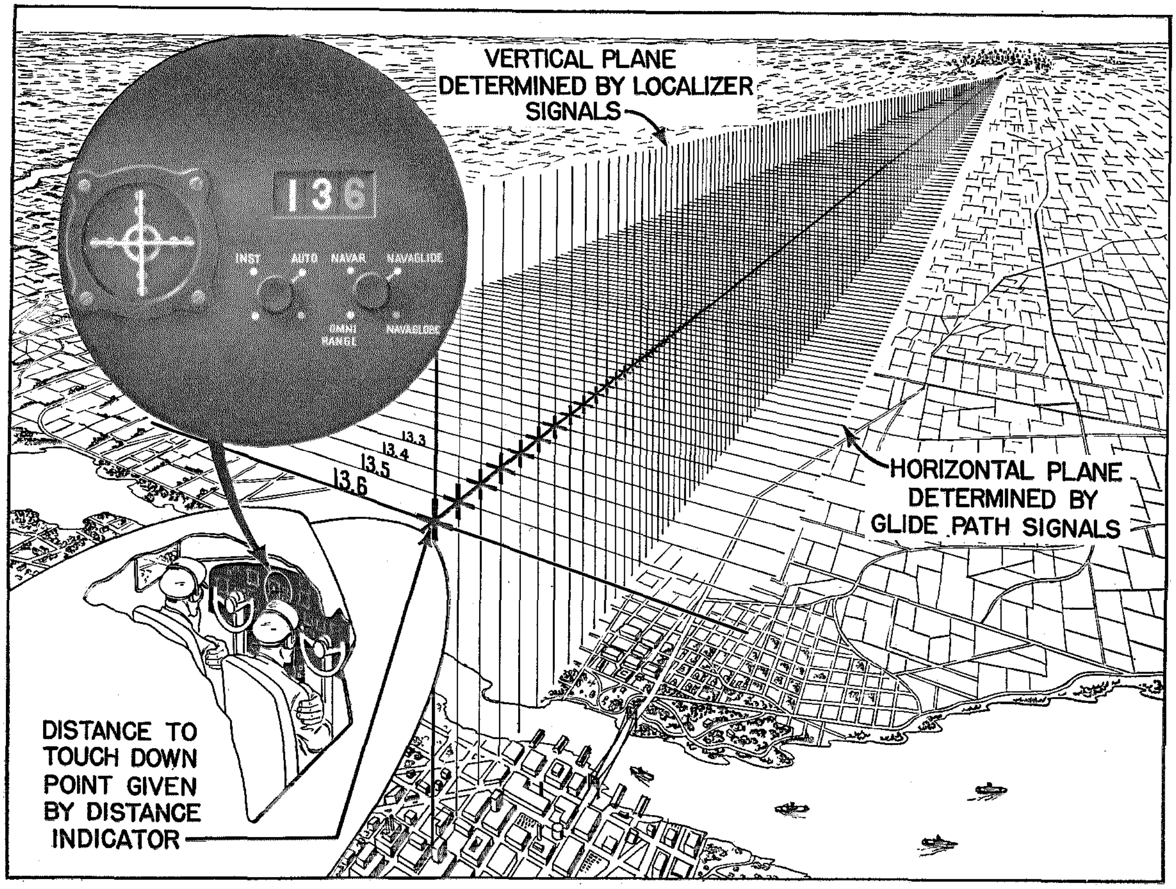


Fig. 15—Illustrating principles and features of Navaglide.

justify the abandonment of the substantial advantages provided by the present location of the SCS-51 localizers.

Fig. 15 illustrates in highly schematic form the operation of the future Navaglide system as it is now foreseen. It may be expected that considerably more information will be available with respect to this system within a year.

Part IV—Navascreen for Displaying and Computing Traffic-Control Data

4.1 Basic Philosophy

It is clear to all that even with present methods of collecting information as to airplane positions, altitudes, identities, and movements, the amount of data available is already sufficient to tax severely the present facilities for handling and co-ordinating such information. Many suggestions have been made in respect to new operational methods and new equipments to handle this problem. Basically most of the suggestions fall into 3 classes:

a. Those proposing to take data directly from radar displays, projecting it without essential change in the form of a larger more brilliant display. This classification may also be considered to include those suggestions which propose to add altitude information (obtained by height-finding radar procedures or by coded airborne beacon responses) to the normal plan-position-indicator display, then project it in 3-dimensional form.

b. Those based on the assumption that the available information is already in the form of positive "tele-control" signals, such as telegraph or selsyn signals which are readily adaptable for remote transmission and for controlling electromagnetic mechanisms, and which merely concern themselves with various forms of posting, displaying, computing, and tabulating equipments for handling these data.

c. Those based on the assumption that all airplanes requiring ground control will always fly along a limited number of fixed airways so as to pass regularly over certain fixed points at reasonable intervals throughout their flight. Based on such an assumption, a network of automatic reporting stations is suggested for automatic reception of the required data in reasonably positive form and for remote transmission to a center where it can be handled by conventional signaling means, similar to those used for railway block systems or automobile traffic-light systems.

After some study of the matter, Federal has come to the following conclusions:

a. That a system suitable for general use must be capable of handling data from a number of different kinds of sources.

b. That one of the very important sources of information—and ultimately by far the most important—is the ground surveillance radar.

c. That in spite of this expected growth in importance of radar, the data-handling system must for many years be capable also of accepting information from other sources and handling such information in the same manner as that obtained from radar.

d. That for a very considerable period much of the available information will come from the so-called "primary radar" plan-position indicators, i.e., from the plan-position indicators of radars unassisted by airborne responder beacons; and that the ground clutter, hash, and background noise will make it unfeasable to use a simple magnified projection thereof as an operational display to be referred to by the traffic controllers.

e. That whether the information arrives from telephone calls, from radar displays, or from some source directly giving positive "tele-control" signals, all this information must be combined and handled in 2 separate ways as follows:

1st. By integrating all the information into a large-scale, clearly readable display, showing position, altitude, identity, and direction of flight of every airplane at every instant as accurately as the basic source of information will permit.

2nd. By translating into the form of positive "tele-control" signals all informtaion not initially arriving in such form (as well as that information which is already in a "tele-control" form differing from the standard signals used in the system). Such translation of all signals into one standard "tele-control" form makes it possible to take full advantage of the various existing and proposed tabulating, recording, predicting, computing, and interlocking equipment offered by the proponents of the 2 types of systems previously classified as (b) and (c).

Another important point of this company's basic philosophy is the belief that every possible safeguard and double check should be provided to prevent errors when taking data from any source requiring human interpretation, such as telephone calls, screens of primary radars (and probably during the next few years even the screens of secondary or beacon-assisted radars).

The above are the basic tenets of Federal's philosophy with respect to the characteristics and features required for handling all the various types of information which will have to be dealt with for proper ground control of aircraft during the next decade. Certain additional minor points may be noted.

It is also felt that the need for transmission of data from one point to another will increase considerably as networks of radars and other information-gathering sources increase in complexity. Satisfying these requirements appears perfectly possible in the case of radars by television or facsimile transmission means, or somewhat more simply, by radar relaying techniques similar to those used in producing the Navascope display described in Part II. Nevertheless, it seems somewhat uneconomical and unjustifiable to forward radar data in this manner for the total amount of information required could very simply be transmitted in positive "tele-control" form over a narrow-bandwidth channel, with substantially reduced possibility of error.

Based on our belief that all information should be translated into "tele-control" form so as to be readily handled by predicting, computing, and statistical data-handling machinery, it appears much more logical in most instances to perform such translation at or near the point where the data are first received, and then to transmit the information in this form to other points where it may be required. Perhaps in a few cases the direct transmission of untranslated data in the form of radar displays may be justified to eliminate the cost of a separate installation and of additional operators who would perform the translation at the point where the information is originally derived. It is believed, however, that the greater part of the transmission of information between points many miles apart should take place in a standardized "tele-control" form such as teletype code, selsyn control voltages, or other equivalent signals.

Another specific point, carefully considered, is the question of whether radar data can most safely be translated into "tele-control" signals by mechanical or human agencies. It is believed that most persons will agree that a purely automatic translation would not be sufficiently reliable for the purpose of traffic control, at least in the case of normal radar signals (signals from radars unassisted by beacons). Federal believes that even in the case of beacon-assisted radars a purely automatic "reading-out" of the information would not be sufficiently safe until much better tracking methods have been perfected and tested over a considerable period of time.

Perhaps for the very best performance, regardless of practical considerations such as cost and complexity, the reading-out of information from beacon-assisted radars should take place automatically with some sort of monitoring or double checking by an operator. In the case of normal radar unassisted by beacons, however, it is believed that such an arrangement would be unsatisfactory. Hence, in view of the desirability of handling all radar information in a similar manner, and in view of the amount of delay which would be necessitated by an attempt to develop such a monitored automatic tracking system, Federal has temporarily discarded this possibility.

Another obvious possibility is to rely wholly on human operators to perform the translation of the data without any mechanical assistance. Not only would this require a very large force of operators but also the possibility of error would, in our opinion, be dangerously great.

It is our conclusion therefore that the best method of reading-out the information from a radar screen and translating it into positive "tele-control" signals is by the use of the "aided-tracking" principle employed so successfully for the operation of drift meters, bomb sights, and visually controlled gun-sighting equipments. It is believed that this not only increases the number of airplanes which can be handled by one operator from 1 or 2 to 4, 5, or even more, but also decreases the possibility of gross errors.

4.2 General Description of Navascreen System

The Navascreen system is believed to meet satisfactorily those requirements which Federal considers to be essential as set forth in Section 4.1.

The general appearance of a Navascreen installation is illustrated in Fig. 16. Such an installation requires a semilighted room in which the controller's display is presented; and which is large enough for several controls as well as the teletype and telephone operators who handle the controllers' messages and instructions. Separated from this controller's room by a translucent screen is a comparatively dark room in which are located the projectors for producing the Navascreen display and a number of consoles for the read-out operators. These operators read out the data from plan-position-indicator screens or from positive "tele-control" signals by manipulating an appropriate number of dials on their consoles.

The projectors are arranged in a compact bank in the center of the projector room (Fig. 16). For convenience of maintenance, and to simplify the installation, these projectors are placed upright and direct their beams upward, an inclined mirror being provided to reflect the beams toward the large screen which forms the main display. By an arrangement similar to the so-called "camera obscura" the display thus produced on the screen is projected back and optically superposed on the screen of each of the plan-position-indicator consoles.

The appearance of the Navascreen display, as viewed from the controller's room, is shown in Fig. 17. As will be seen from this figure, each airplane shown on this display is represented by a 2-symbol identification character together with an arrow.

Each of the characters of the airplane identification symbol may be a letter or a figure, so that a total of more than 1000 identification symbols is available. Ultimately a large number of characters could be employed for each symbol to increase the number of possible identifications.

The arrow associated with each identification symbol represents direction of flight of the corresponding airplane. The color of the arrow indicates the approximate altitude of the airplane in steps of 5000 feet. Thus a red arrow indicates a plane between 1000 and 5000 feet altitude, a violet arrow indicates a plane between 5000 and 10,000 feet, a blue arrow represents the 10,000- to 15,000-foot region, etc. The color of the identification symbol indicates the specific altitude within this general layer. Thus the 2 colors of the identification symbol and arrow together represent the airplane's altitude to the nearest 1000-foot level. By the use of 5 clearly distinguishable colors, 25 different levels of altitude may be represented. To facilitate reading of the identity symbols, they are arranged to remain upright regardless of rotation of the associated arrows representing the direction of flight.

The representations of the different airplanes move bodily in the directions indicated by the arrows and at appropriate speeds. Each such representation, therefore, continuously indicates

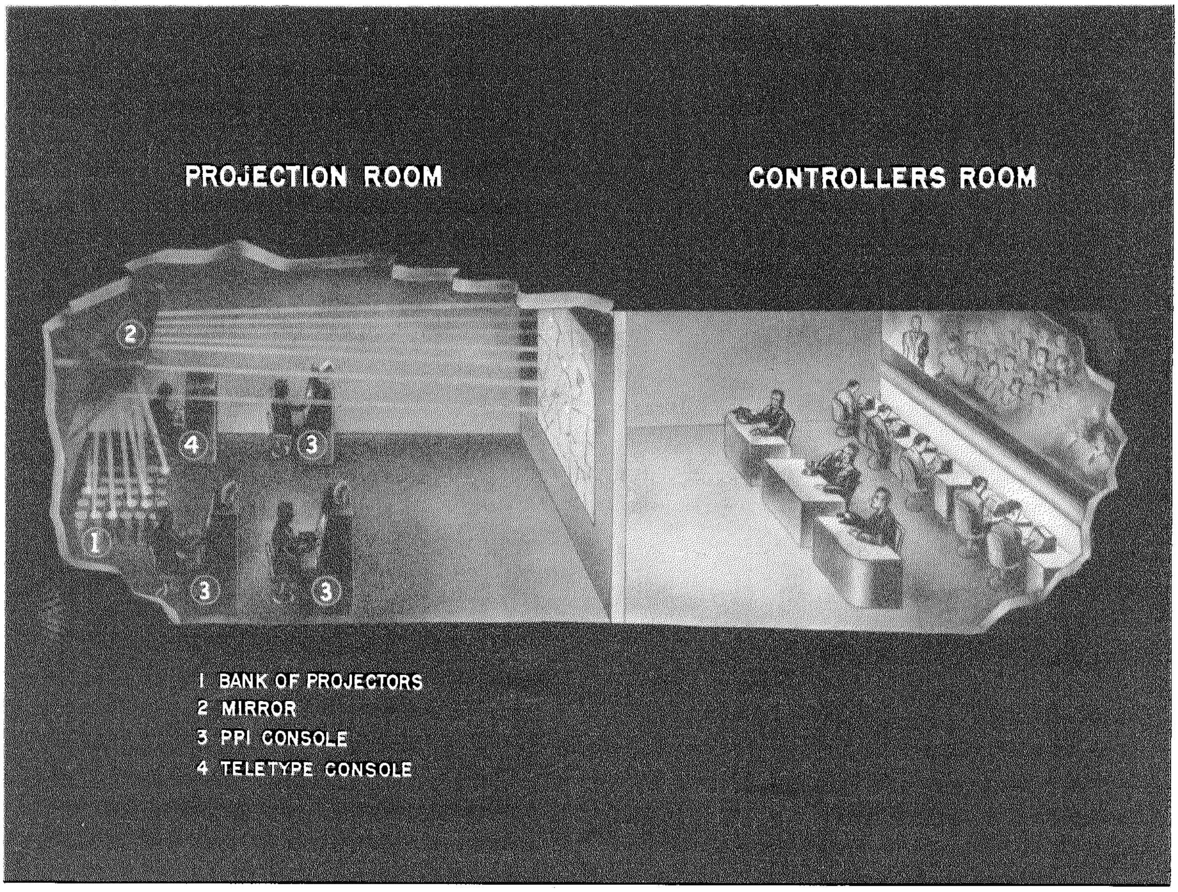


Fig. 16—Installation of Navascreen.

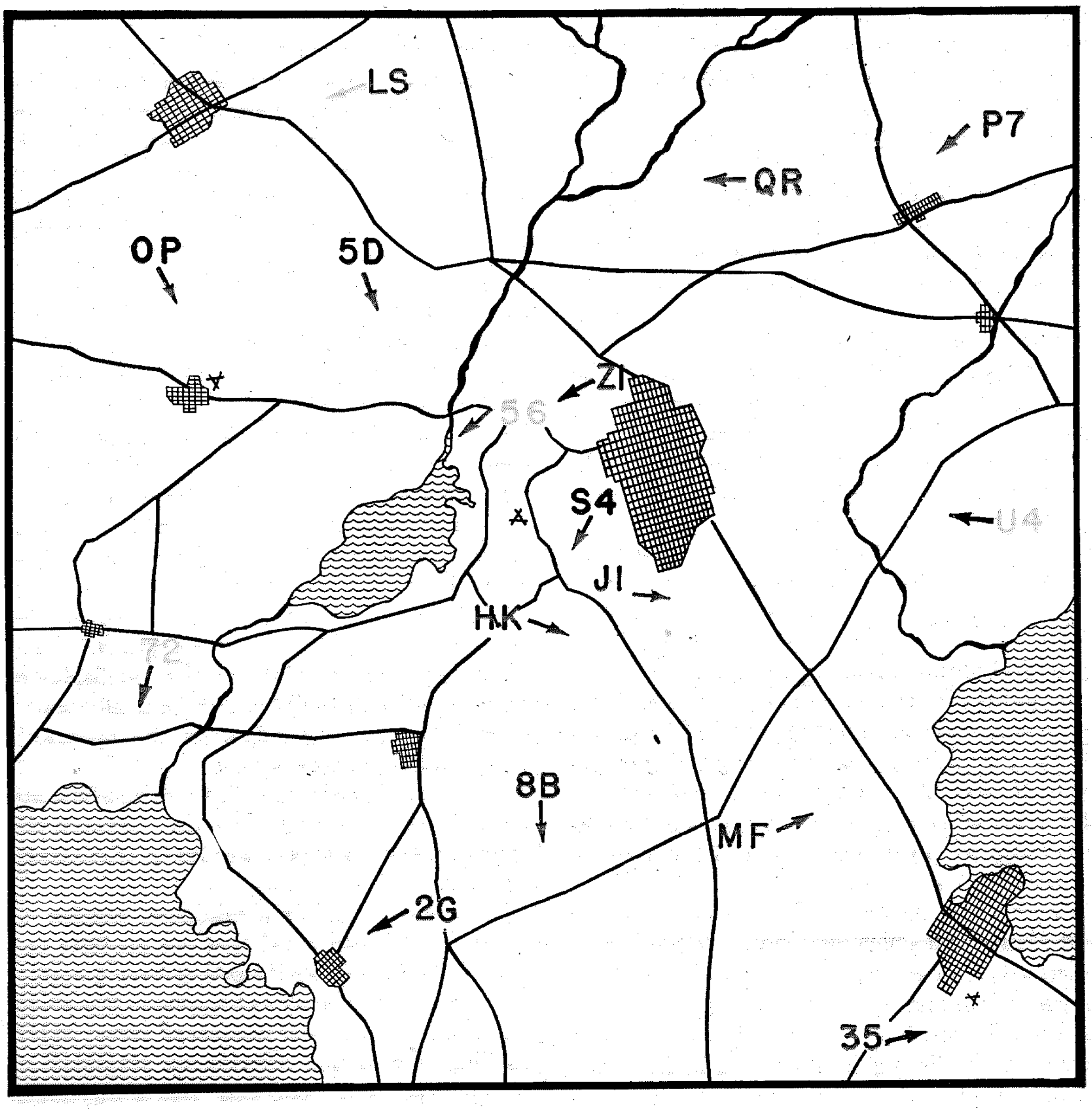


Fig. 17—Appearance of Navascreen display.

at all times the positions of all aircraft relative to a map which is printed on the screen.

If desired, aircraft whose positions are not definitely known may be specially marked by an intermittent flashing of their symbol.

No streaks, hash, or background marks are shown on the display screen since this is produced synthetically from the positive "telecontrol" signals into which the various console operators translate their primary data.

A valuable feature is the possibility of producing the effect of accelerated time or reversed time. This is done in the same general way as in a planetarium where the stars are frequently made to assume positions corresponding to the year 1, 2000 A.D., etc. The accelerated-time feature of the Navascreen, however, is provided for the practical purpose of enabling the controllers quickly to predict factors such as the number of aircraft which will arrive at a given airport in the next 10 minutes, or the relation between times of passage of several airplanes through some intersection point where collisions may be feared.

The exact arrangement of the controls used by the operators at the plan-position-indicator consoles and other consoles is not illustrated, because some changes in this arrangement are still under consideration. In one form of the Navascreen system which has been previously described, and which is now being designed for manufacture, the controls are laid out on the basis of polar co-ordinates. The azimuth is set by one control and another control sets radial distance to bring the identification symbol and arrow to a point hereafter called the origin. This origin usually corresponds to the airplane's present reported position.

A further set of controls, also based on polar co-ordinates, produces a superposed motion. It may be either a linear motion in any desired direction from the origin previously present or an orbital motion about each origin.

In addition to these 2 sets of polar co-ordinate controls, 2 other controls are provided for selecting the altitude color code and the speed of movement. No special control for setting the direction of the arrow is required since this is automatically adjusted by the controls which determine the motion of the spot.

Another arrangement of controls, which is under study and which may supersede the above-described arrangement, involves essentially similar controls but arranged on the basis of rectangular co-ordinates. This might facilitate the shift of axes which is required when data from one Navascreen installation is transmitted to a remote point and used for automatically controlling another similar Navascreen installation.

4.3 *Advantages of Navascreen System*

This system is capable of operating with data derived from telephone or teletype messages, from normal or beacon-assisted radar screens, or in fact from any sources.

The method used for translating the data from radar screens into "tele-control" form is based on the principle of aided tracking for the reasons explained in the foregoing sub-section.

This same method is also used in the case of data received from intermittent telephone calls or teletype reports, and in such case presents the very great advantage that the automatic motion of the aided-tracking mechanism serves to show continuously as accurately as possible from the available data the probable position of the airplane. Even if such probable position is not wholly accurate it is certainly much better than the usual records which merely show the last-reported position, the then-reported direction and speed of flight, and the time at which such report was received. Obviously this latter form of record necessitates a mental computation which is usually performed much less accurately than could be done by the aided-tracking mechanism.

The Navascreen also provides an extremely convenient arrangement for double checking information derived from a radar screen. This is accomplished by taking the "tele-control" signals which the operator has produced by the above-mentioned aided-tracking principle and converting them back into a synthetic display of airplane position, which is then optically superposed in contrasting colors on the operator's plan-position-indicator screen.

Thus any inaccuracies make themselves apparent in the form of a divergence between the radar spot and the superposed image of contrasting color.

The system requires a minimum number of operators. It is estimated that one operator can handle 4 or 5 airplanes if working from a normal radar screen or as many as 6 airplanes if working from a screen of a beacon-assisted radar. When handling information arriving by telephone or teletype reports, it seems clear that a very much greater number of airplanes can be handled by one operator, assuming that the reports arrive at the rate of 5 or 6 reports per hour for each airplane handled. Data arriving from another similar Navascreen system at a remote point can at first be handled manually, but in the near future can be handled automatically with a high degree of reliability and safety.

The form of display provided for the use of the controllers is large enough to be viewed by a number of persons at a time and shows in an easily readable integrated pictorial form the plan-positions, altitudes, directions of flight, and identities of as many airplanes as desired.

The system is constructed of a number of interchangeable units, together with a small amount of common equipment; and none of the equipment need be specially designed for a particular airport. Thus the cost and difficulty of installation is greatly reduced. It is readily possible to add to the system many sorts of recording, computing, tabulating, and data-analyzing machines, so that the wealth of features offered in the field of tabulation and business machines is made immediately available for the handling of traffic-control data.

Frequency, Power, and Modulation for a Long-Range Radio Navigation System

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1 Introduction

THE purpose of this study is to determine which band of radio frequencies is most suitable for a long-range transoceanic radio navigation system. There are 2 requirements considered to be basic.

The first requirement is that the radio system must be capable of extension so as to cover all oceanic regions of the globe. This implies that aircraft anywhere in such regions must be within range of at least 2 ground stations to make a cross-fix possible. Examination of the globe leads to the conclusion that sufficient coastal or island sites are available for such world-wide double coverage provided the ground stations have a minimum range of 1500 miles.

The second basic requirement is that of reliability. All aircraft within the prescribed range of the radio transmitter must be able to receive useful signals regardless of weather, time of day, season, year, direction, and distance.

It is recognized that the distance range of 1500 miles immediately limits the choice of frequencies, roughly, to those below about 300 kilocycles per second or to those between about 2 megacycles per second and 30 megacycles per second. Between about 300 kilocycles and 2 megacycles, daylight transmissions suffer great absorption; transmission above about 30 megacycles begins to be limited to line-of-sight distances.*

As between the 2 frequency bands which may be used, it is approximately true that for equal *power radiated*, the *average* received signal intensities at long distances are of the same order of magnitude for both high-frequency and low-frequency transmissions;[28,35] but other factors determine the relative suitability of the 2 bands. These general factors are discussed from the point of view of navigation system requirements in the following 2 sections of this paper. The remaining sections are concerned with a detailed analysis of the important factors for low frequencies, to arrive at specific engineering conclusions.

2 High-Frequency Transmission

Because of greater antenna efficiency, high-frequency installations are less expensive to construct and to operate than are low-frequency equipments of equal radiation power. High-frequency installations offer other apparent advantages: antenna directivity is more easily obtained, static intensity is lower, and there is room in the available block of frequencies for more or wider channels. Certain peculiarities in high-frequency transmission, on the other hand, constitute obstacles to its application to a navigation system. The requirements of a long-range navigation service are so exacting that this apparent economy cannot be realized.

2.1 Frequency Complexities

Low-frequency transmission is dependable at all distances intermediate to its extreme range, and in all directions. High-frequency transmission, however, proceeds through "single- or multiple-hop" paths which depend on conditions in the various ionized layers of the upper atmosphere. These conditions are subject to irregular hourly, seasonal, and yearly variations. Because of these conditions, and because the ground wave is so rapidly attenuated with distance, there are zones in which there is no dependable service. Commercial high-frequency communication is therefore made feasible only by having available a number of frequency channels from which a suitable selection can be made as dictated by:

a. Time of day,
b. Direction of transmission,
c. Season of the year,

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* Numbered references will be found on page 156. See reference 49, Fig. 9; and reference 35, Fig. 5.

d. Relation of the year to the solar-activity cycle, and
e. Distance to the receiving station.

For dependable transatlantic radiotelephone communication between 2 fixed points, it is necessary to select at various times one of 3 (sometimes 4) assigned frequencies.[35, 54, 68]

Because transmission by a navigation-system station must be dependably received at all distances to 1500 miles, and in all compass directions, at all times of the day or season, the transmission requirements are more stringent than for a point-to-point communication system. Dependable service would require simultaneous transmission by a ground station at 3 different frequencies chosen on the basis of prevailing conditions. For each station, a group of 6 to 10 frequency channels would be required, and this suggests the problem of providing enough distinct channels for all ground stations within possible mutual-interference range.

The radio operator on the aircraft (or some other person in an emergency) would not know definitely on which frequency signals would be received, and might be obliged to try all. Considering the high speeds of aircraft, the time consumed in doing this for 2 different stations to establish a complete fix would be a serious disadvantage.

2.2 Fading

High-frequency reception at long distances is particularly subject to fading, or to irregular fluctuations, which may be violent and frequent.[28, 33, 37] The slower fluctuations are perhaps not serious, because their effects are mitigated by automatic volume control, and distortion is less damaging in a navigation system than in radiotelephone service. The short-period intensity changes, however, might affect accuracy of navigation in those systems which depend on observations of null values (direction finders, rotating beacons) or which depend on a comparison of successive intensities (radio range type of system). This would be particularly true if a very narrow bandwidth and hence slow operation were used. It should be noted also that at high frequencies airborne direction finders are susceptible to the worst kind of "night effect" and to polarization changes.[28, 34]

2.3 Fade-Outs

High-frequency transmission is particularly susceptible to complete "fade-outs" of rather long duration during periods of solar disturbances or magnetic storms; these periods constitute an even more serious disadvantage than does fading. Fade-outs are related to the sunspot cycle and are often but not always coincident with magnetic storms.[28] Because fade-outs affect all high-frequency channels, and are apparently the result of increased attenuation[39] rather than a change in optimum distance for a given frequency, a change of frequency would not improve matters.

The effect is not the same for different circuit paths, and is worse[35] in the latitudes where greatest transatlantic flight activity is expected, than at the equator.[28]* The most important and difficult problem in high-frequency transatlantic communication is maintenance of service through magnetic storms;[35] at times not even a heterodyne note can be detected. Cosmic disturbances may either prevent high-frequency communication completely[37] or may attenuate it severely. In 1930, a poor year for high-frequency transatlantic commercial signals, there were periods during which none of *3 available* high-frequency circuits provided serviceable transmission.†

These nonuseful periods accounted in the aggregate for approximately 15 percent of total time. Even when magnetic storms have not been exceptionally severe, it has at times been impossible, with high transmitter powers, directive antennas, and high-gain receivers, to hear even a heterodyne note of the transatlantic signals.[39]

Other tabulated data[58] demonstrate that during a magnetically disturbed year, low-power high-frequency transmitters would provide uncertain means of communication across the North Atlantic. Data for 1930 are given in Table I.

Between February and October of 1928,[28] there were about 10 periods when high-frequency stations faded out. From October, 1927, to

* Reference 39, Fig. 14.
† Reference 39, Fig. 13.

October, 1928, the number of occasions per station (reception in England) when high-frequency signals were appreciably below normal because of fade-outs was:

Transmissions from Montreal	49
Transmissions from New York	32

TABLE I

Duration and Number of Interruptions—1930

Duration of Interruptions of Service (Hours)	Number of Interruptions
0.5	300
1.5	200
2.5	55
3.5	40
4.5	30
5.5	15
6.5	7

Other sources[13, 30] report a period in October, 1926, when *high-frequency communication the world over broke down,* and service between Canada and England was completely blocked by a magnetic storm. On July 8, 1928, the 18-megacycle transatlantic signal dropped to 1/30 of its normal value, or to 30 decibels below 1 microvolt per meter, and did not recover completely until the end of 7 days, during which considerable fading and instability occurred.[29] Other difficult periods recorded in 1928 were on May 27, July 7, October 18, and October 24,[25] when poor reception was encountered over periods of several hours. The year 1927 was also one of maximum disturbance, with difficulty encountered on 83 days.[25]

2.3.1 *Significance of Fade-Outs*

The data quoted have been applicable chiefly to reception of telephone signals at distances up to 3500 miles. Since the distance range for a navigation system is shorter and the permissible signal-to-noise ratio is smaller than that required for communication, these data may not be entirely indicative of conditions to be expected in the operation of a navigation system. While the dates mentioned represent periods of extreme conditions, it appears reasonable to expect from 10 to 20 difficult days in a year of minimum disturbance,[25] whereas a radio navigation system must be capable of maintaining reliable service even on those few bad days. Interruption in the operation of a communication system involves only delay in transmission and loss of revenue, whereas interruption of navigation service can result in loss of life.

2.4 Cost of Reliability of High Frequencies

The commercial services have examined the question of costs. One study[48] presents data on lost time in radio broadcast relaying by high frequencies, and concludes that several frequency channels must be available and transmitter powers as high as 50 kilowatts are required for satisfactory service. The other[35] deals with experience in high-frequency transatlantic radiotelephone communication. The general conclusion is that, with a frequency chosen to suit the particular transmission conditions, for 80 percent reliability, a transmitter power of 500 kilowatts would be required; for 90 percent reliability, 5000 kilowatts; and *for 95 percent reliability, 50,000 kilowatts!*

Unless a radio navigation system can guarantee a degree of reliability considerably greater than does celestial navigation, its existence is not justified. A system which could provide 99.9 percent reliability would be worth while, because it would place transoceanic air transportation in the same category, as far as risk is concerned, with other types of transportation.

2.5 Summary of the Disadvantages of High Frequencies

a. Plurality of frequency channels (up to 3) required for simultaneous operation by one transmitter,

b. Plurality of frequency channels (6 to 10) required for permanent assignment to each transmitter,

c. Duplication of equipment at transmitting station because of plurality of channels,

d. Inconvenience at receiver (airplane) in selecting the proper channel,

e. Disturbances to direction-finding readings caused by fading and polarization changes,

f. Nonreliability because of complete fade-outs during magnetic storms, and

g. Excessive power required for reliable service.

3 *Low-Frequency Transmission Characteristics*

Evidence shows[56] that long-distance low-frequency transmission is also affected by the sky wave, but is much less sensitive to changes in the upper atmosphere. According to available data,[7, 14, 25, 30, 35, 42, 43, 69, 70] long-distance transmission at frequencies between 10 kilocycles and 150 kilocycles is almost entirely stable except for certain diurnal and seasonal variations. There is no well-defined skip distance, and no fading; all changes in signal strength are gradual. Night signals are usually stronger but more variable than daylight signals. The moderate seasonal and yearly variations are not troublesome. Above 150 kilocycles, conditions become less favorable.[70]

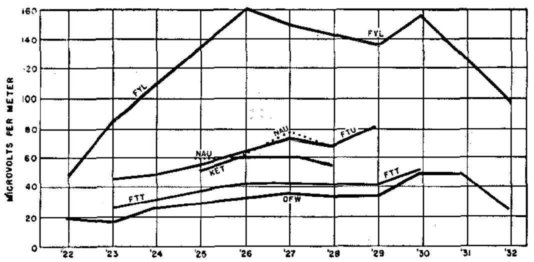

Fig. 1—Recorded annual average field strengths for 6 selected stations.

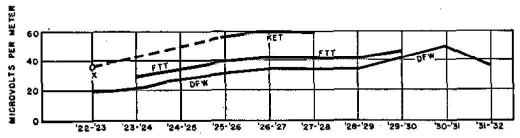

Fig 2—Smoothed curves for 15-kilocycle stations only. These curves from Fig. 1 have been smoothed by use of moving 2-year averages. The dashed curve is estimated by eye from the other 2 curves. A point for 1922–1923 for KET, estimated from the 1925–1928 ratios of KET to DFW, is shown at X.

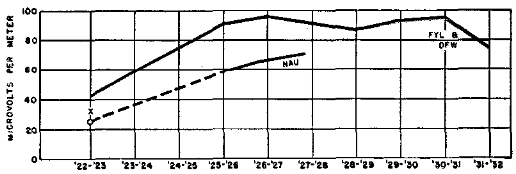

Fig. 3—Smoothed curve of arithmetic mean values of field strengths of FYL and DFW compared with similar values for NAU. The dashed curve is estimated by eye and the point X is computed from the ratio of the respective field strengths during 1925–1928.

3.1 Diurnal Variations

A "sunset dip" occurs when the sunset line on the earth is about midway between the transmitting and receiving stations.* The dips are very deep, but also of such short duration[17, 50] that the safety of flight is not endangered. The time of their occurrence is accurately predictable, and the brief interruption can be anticipated. When an aircraft is within a few hundred miles of its destination, where perhaps a 20-minute interruption of navigation service would be serious, the sunset dip is much less pronounced, or even non-existent.[3, 18]

3.2 Absence of Fade-Outs

Evidence indicates that magnetic disturbances cause daylight signal strength to increase, and night signal strength to decrease to about the normal daylight value.[7, 25, 30, 42, 43, 69] During the high-frequency breakdown of October, 1926, low-frequency reception was hardly affected.[14, 30]

3.3 Cost of Reliability of Low Frequencies

Although there are known to be some years during which average signal strength is low, and isolated days when it is abnormally low, there is no published information as to the percentage of lost time in commercial low-frequency transmission. Neither are there estimates of power required for a given degree of reliability. One report[35] states that the reduction in time lost through fading and fade-outs offsets the disadvantages of low frequencies with respect to lower radiation efficiency and higher static intensity.

The remaining sections of this study represent an attempt to answer these questions by determining, for the 1500-mile oceanic range, what the most promising low-frequency carrier may be as regards reliability and economy. Factors that must be taken into account include the variation in signal and static strengths at different frequencies, the degree to which signal and noise strengths fluctuate from the average values at different times and places, and the variation in antenna radiating efficiency at different frequencies.

* Reference 7, Figs. 6 and 8.

4 Signal Field Strength

In the design of a reliable system, it is necessary first to determine a criterion of significant minimum field strength which can be expected at different frequencies for a given radiated power. A *quasi-minimum* field strength which does not give undue weight to isolated days of extremely low signal strength is defined as the monthly average of signal strength measured at the worst hour of the day during the worst month of the worst year. For the frequencies between 40 and 60 kilocycles, the lowest point of each monthly curve is replaced by the next lowest hourly value, to avoid giving undue weight to the brief sunset dip, which is very marked at those frequencies.

Data from stations FYL, FTU, FTT, DFW, KET, and NAU[12, 15, 21, 32, 36, 42, 52] were used as a basis for the estimation of quasi-minimum field strengths at 15, 23, and 34 kilocycles. The results of the computations are shown in Table II. Figs. 1, 2, and 3 show the original data and indicate the adjustments and interpolation required.

The best data available in the 50- to 60-kilocycle range were those for 2XS operating on 57 kilocycles.[7] The value of 1.5 microvolts per meter was estimated from these figures.

Table III shows the final estimated values of the quasi-minimum field strengths and the ratio of each to the theoretical average field strengths as predicted by the Bell Laboratories formula

TABLE II

ESTIMATED QUASI-MINIMUM FIELD STRENGTHS

Transmitter Call Letters, Frequency, and City	Recorded 3 P.M. Fields at Washington, D.C. during 1925–1928			Ratio of Low Monthly Average to Annual Average in Same Year	Lowest Annual Average of 3 P.M. Fields at Washington, D.C.			Lowest Monthly Average of 3 P.M. Field Estimated by Lowest Ratio
	Year	Annual Average	Lowest Monthly Average		Years on Record	Low Year	Average in Low Year	
FYL	1925	132	Aug. 73	0.55				
previously LY	1926	161	Aug. 96	0.60				
16 kc	1927	150	July 76	0.51				
Bordeaux	1928	141	July 74	0.52	1922–1932	1922	48	24
	Av'g			0.55				
FTU	1925	55	June 24	0.44				
previously FU	1926	64	Aug. 40	0.62				
15 kc	1927	75	July 46	0.61				
Paris	1928	—	—	—	1923–1929	1923	46	20
	Av'g			0.56				
FTT	1925	37	June 19	0.51				
previously FT	1926	41	June 21	0.51				
21 kc	1927	42	July 24	0.57				
Paris	1928	40	May 23	0.57	1923–1930	1923	26	13.3
	Av'g			0.54				
DFW	1925	28	June 16	0.57				
previously AGS	1926	32	July 17	0.53				
23 kc	1927	36	May 26	0.61				
	1928	34	June 21	0.62	1922–1932	1923	16	8.5
	Av'g			0.58				
KET	1925	51	June 23	0.45				
23 kc	1926	62	July 36	0.58				
San Francisco	1927	60	July 43	0.72		22–23		
	1928	56	July 39	0.70	1925–1928	Est	33?	15?
	Av'g			0.61				
NAU	1925	72	Apr. 55	0.75				
34 kc	1926	60	July 41	0.68				
Puerto Rico	1927	76	Aug. 61	0.80		22–23		
	1928	66	July 48	0.73	1925–1928	Est	29?	20?
	Av'g			0.74				

TABLE III

CORRELATION OF ESTIMATED QUASI-MINIMUM FIELD STRENGTHS WITH VARIOUS FORMULAS

Call Letters and City	Frequency Kc	Distance to Receiver Kilometers	Estimated Quasi-Minimum Field μv/m	Ratio of Quasi-Minimum Field to Formulas Indicated		
				Bell	Austin-Cohen	Compromise
FTU Paris	15	6200 to Washington	20	0.16	0.32	0.226
FYL Bordeaux	16	6160 to Washington	24	0.17	0.35	0.244
FTT Paris	21	6200 to Washington	13.3	0.14	0.27	0.195
DFW Berlin	23	6650 to Washington	8.5	0.15	0.29	0.209
KET San Francisco	23	3920 to Washington	15	0.13	0.19	0.157
NAU Puerto Rico	34	2490 to Washington	20	0.15	0.16	0.155
2XS Rocky Point	57	5480 to New Southgate, England	1.5	0.19	0.10	0.138

and the Austin-Cohen formula,[10] from the known radiated power and transmission distance in each case. These ratios are hereafter termed "stability factors." Because of the original data used in deriving the two formulas, it is believed that the Bell Laboratories formula best represents conditions between 17 and 57 kilocycles for distances of 3500 miles,[7,17,23,35] while the Austin-Cohen formula conforms best to observations at frequencies above 60 kilocycles. For that reason a compromise formula was set up, whose values are the geometric means of those in the Bell Laboratories and the Austin-Cohen formulas for frequencies between 15 and 60 kilocycles, but which gradually approach the Austin-Cohen values for frequencies above 60 kilocycles. Table III lists also the ratios of the quasi-minimum values to the average values as computed by this compromise formula.

TABLE IV

POINTS FOR QUASI-MINIMUM FIELD-STRENGTH CURVE AT 1500 MILES

Frequency Kc	Average Field, Compromise Curve D	Stability Factor, Table III	Quasi-Minimum Value for Curve E (μv/m)
15	80	0.226	18
34	53.5	0.155	8.1
57	33	0.138	4.5
217	5.15	0.084	0.43

The systematic decrease of these stability factors with increasing frequency is a reflection of the observed fact that at higher frequencies (within the low-frequency band) fluctuations of signal strength below the average level become more pronounced.

4.1 EXTENSION TO 1500-MILE DISTANCE AND TO OTHER FREQUENCIES

Curve D of Fig. 4 is the average field-strength curve for a distance of 1500 miles as computed by the compromise formula. Curve E, estimated quasi-minimum field strength, was computed by multiplying the values from curve D by the appropriate stability factors at the different frequencies. Table IV shows this operation in detail.

Curve C represents average ground-wave strength computed by Norton's method for the same transmission conditions. The similarity between curve C and curve E is striking.

4.2 SUMMARY

Curve D of Fig. 4 is considered, all in all, the best estimate of average daylight signal strength at 1500 miles over sea water from an antenna radiating 1 kilowatt of power at various frequencies. It is based on the most applicable experimental measurements available, extended to the particular transmission conditions by means of a compromise between the 2 most widely used and tested transmission formulas.

Curve E of Fig. 4, the final result of this section, is considered the best estimate of quasi-minimum signal strength at 1500 miles from an antenna radiating 1 kilowatt of power at various frequencies. It was derived from curve D of Fig. 4, the average daylight signal strength curve, by reference to stability factors based on actual observations at various frequencies.

5 *Signal-to-Noise Relationships*

As in the case of signal strength, it is not the average static intensity which is of importance for the engineering of a reliable radio navigation system, but the most unfavorable value to be expected. The term "quasi-maximum value of static" will be used for that value which is exceeded very rarely. Because the signal-to-noise ratio is the determining factor, it is important to determine to what extent periods of maximum static coincide with periods of minimum signal strength. The term "quasi-maximum significant static intensity" will be used for that value which is exceeded very rarely *at any time and place where the useful signal is likely to have its quasi-minimum field strength.*

A considerable mass of statistical data is available[7] with respect to static conditions observed at Belfast, Maine, and Riverhead, New York. At Belfast, worst static usually occurred at 10 p.m. during the month of June, and the general level was at about its highest in 1922, 1923, and 1924. Accordingly the averages for 10 p.m. in June, 1924,[12,52] were used.

The data for Riverhead did not show June averages of 10 p.m. static, but comparison of the curves* showed that the values were approximately double those for Belfast for the period when static levels for both locations were recorded. Values for 10 p.m. at Riverhead were estimated on that basis. Data for Washington, District of Columbia, were less complete than for either Belfast or Riverhead, and it was necessary to obtain the required values by a series of estimates based on ratios applied to available data.[12,15,21,32,36,42,52] The values finally used for the 3 locations are given in Table V.

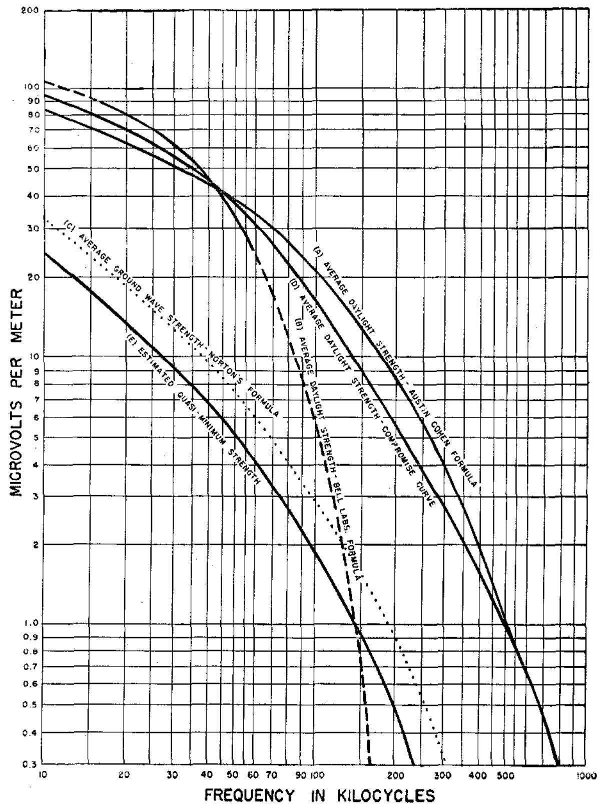

Fig. 4—Average daylight and quasi-minimum-signal field-strength values based on a radiated power of 1 kilowatt for a distance of 2414 kilometers (1500 miles) over sea water.

Since it is generally agreed by all authorities that nighttime static varies inversely as the frequency,[7,47,53,69] the values shown were modified to conform with such inverse-frequency curve; the resulting values were in some instances greater and in some instances less than the originally

TABLE V

QUASI-MAXIMUM STATIC LEVELS

City	Effective Value of Static in Microvolts per Meter Measured by the "Warbler" Method			
	15 Kc	23–24 Kc	33–36 Kc	52 Kc
Belfast	400	130	80	48
Riverhead	800	260	160	96
Washington	1290	680	450	—

* Reference 7, Fig. 16.

estimated values. Furthermore, since it is recognized that months of unusually high static disturbances will occur, it appeared reasonable to multiply the idealized values by a factor of 1.4 to determine a conservative quasi-maximum value for 10 p.m. static during the worst periods. Table VI gives such values, extrapolated for convenience to the 100-kilocycle frequency by means of the inverse-frequency law.

TABLE VI

QUASI-MAXIMUM STATIC LEVELS AT 100 KILOCYCLES

Belfast	56 μv/m
Riverhead	112 μv/m
Washington	224 μv/m

5.1 Static in the Tropics

All authorities agree that a large portion of the static observed at middle latitudes originates in tropical or semitropical regions.[6, 8, 12, 27, 38, 65, 68] Unfortunately, however, few quantitative data are available. Static increases as a receiver approaches the tropics, as indicated by the progressive increase from Belfast to Washington, but it is not reasonable to expect that it will continue to rise until a maximum is reached at the equator, because the sources of static lie in the whole tropic and subtropic belt, rather than on the equator alone. It may be expected therefore that (but for a few exceptional regions of limited area) maximum static intensity will occur at about the latitude of the southern portion of the United States. It has appeared conservative to assume that tropical quasi-maximum static intensity is approximately 4 times that at Washington.

5.2 Quasi-Maximum Significant Static Strength

Because the significant factor which governs reliability of signals is neither signal strength nor static strength alone, but rather the signal-to-noise ratio, it is not logical to consider quasi-minimum signal strength and quasi-maximum static strength together when the time and places of their occurrence may never coincide. This time relationship depends on a number of factors, including latitude, time of day, and direction of transmission.

5.3 Middle-Latitude Conditions

Analysis of experimental data[7] shows that in the middle latitudes, 10 p.m. static values are in general highest, but also that they are not substantially lower for a period of several hours before and after 10 p.m. Lowest signal strength coincides with the sunset dip, which is at about 3 p.m. for North Atlantic transmissions from east to west; this is far removed from the hour of worst static. For transmission from west to east, however, sunset-dip time at the receiving point is about 8 p.m., when nighttime static is near its peak. Conditions show seasonal variation, with the most unfavorable occurring in the summer. For the shorter distance of 1500 miles there is some improvement, but it is still possible for quasi-maximum static to coincide with quasi-minimum signals. Although such coincidence will not occur at all in fall, winter, and spring, and will occur only for certain directions of propagation and at certain times of day, even in summer, the worst combination must be assumed as a test of reliable service. Consequently, the quasi-maximum static levels previously stated must be used also as the quasi-maximum significant static levels in middle and higher latitudes.

5.4 Tropical Conditions

Near the equator the time of worst signal reception is about 6:45 p.m. at all seasons, while estimates of static intensity at the same time indicate a reduction factor of about one half compared to 10 p.m. values.

The fact that sources of most low-frequency static are located over land masses within the equatorial belt[6] results in a further important reduction of significant static values as compared with the high absolute values. In the higher latitudes, static heard would be approximately the same whether the aircraft receiver were near land or at midsea. On a flight in the tropical belt, however, static at midsea would be relatively weaker because the attenuation increases with distance from the source. The amount of this reduction is estimated as at least 50 percent. Near land it is true that the static would approach the higher values above assumed as the quasi-maxima, but the aircraft would be nearer to the ground transmitting station, and the increased signal strength would compensate for the increased static.

It appears reasonable to assume from these 2 and other factors that in the tropics the quasi-maximum significant static is appreciably less than the quasi-maximum static taken without regard to time and place; a factor of $\frac{1}{4}$ has been used as a conservative estimate. Since the absolute value of quasi-maximum tropical static has been previously estimated to be 4 times that of Washington static, quasi-maximum significant static has been assigned the same value for the tropics as for Washington.

5.5 Summary

The estimated effective monthly average values of static, at the hour and place of the worst signal-to-noise ratio, during the worst month of the worst year, giving effect to the described estimated values for static and assuming the validity of the inverse-frequency law, are given in Table VII.

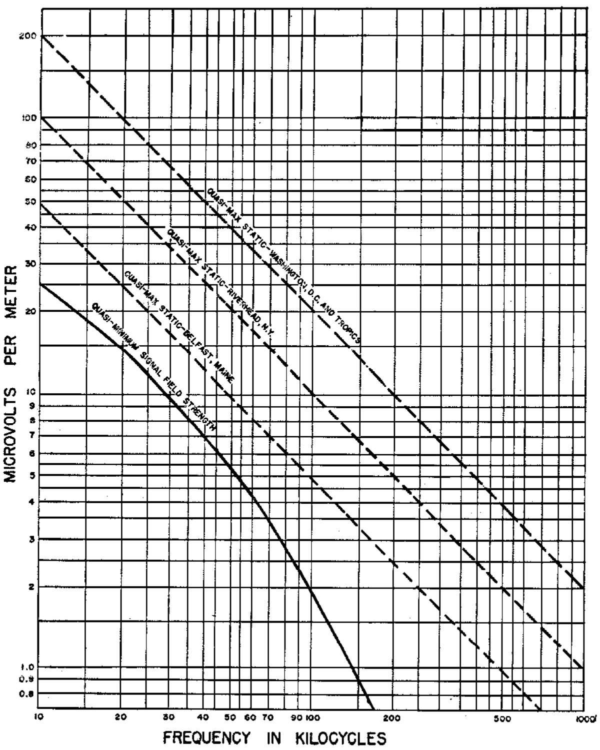

Fig. 5—Quasi-maximum (significant) field-strength values based on a bandwidth of 20 cycles. The quasi-minimum-signal field-strength curve is based on a radiated power of 1 kilowatt for a distance of 2414 kilometers (1500 miles) over sea water.

TABLE VII

Static under Worst Conditions

	Static in μv/m f = frequency in kilocycles
Belfast	5,600/f
Riverhead	11,200/f
Washington	22,400/f
Tropics	22,400/f

5.6 Over-all Reliability on the Basis of Quasi-Extreme Values

It may be expected that these estimated static values will be exceeded in a period of about 33 years (i.e., 3 sunspot cycles) for periods of an hour or more on about 30 to 60 days of the 3 summer months of the worst year of the worst cycle, and on 25 to 75 days of the summer months of the worst years of other cycles; perhaps also on 25 to 75 other summer days. The worst months for signal propagation will in general coincide with the worst months for static, but there is no evidence of coincidence of the individual days or hours of weak propagation with those of strong static. Thus signal-to-noise ratios worse than those predicted will probably not be observed more than 6 to 12 days during the summer of the worst year of the worst cycle, and perhaps on 6 to 12 other days in all other summers. This would mean that during about 12 to 24 days out of 12,050 (about 0.1 to 0.2 percent of total days) there would be periods of more than 1 hour when navigation would be interrupted in a system designed on the basis of the estimates stated. These figures are, of course, only rough guesses presented to give an idea of the order of magnitude of anticipated reliability.

5.7 Values for Various Bandwidths

The receiver acceptance band used as a basis for these estimates is approximately 2700 cycles wide, i.e., carrier ±1350 cycles. The "warbler" method of measurement has been taken as standard.

For one form of navigation system under consideration, it appears that a bandwidth as low as 20 or 10 cycles will be satisfactory. Received static intensity is proportional to the square root of receiver bandwidth.[5, 69, 70] To obtain values applicable to such a system, the static values of the last tabulation have been multiplied by 0.086 (the square root of 20/2700) and the resulting values of quasi-maximum static have been plotted in Fig. 5. For any system using a bandwidth other than 20 cycles, the power estimates derived later need merely be modified by the appropriate factor.

6 Radiation Efficiency

From Fig. 5 it appears that the frequency at which the highest quasi-minimum-signal-to-noise ratio is produced at 1500 miles for a given amount of *radiated* power is about 35 kilocycles. It is, however, *input* power which is of economic interest, and that depends on radiation efficiency. Efficiency is defined as the ratio of watts radiated by the antenna to total input watts to the antenna; in equivalent form it is the ratio of radiation resistance to total resistance.

Radiation resistance is computed by the well-known formula:

$$R = 1580(h/\lambda)^2$$

in which h is effective height, and λ is wavelength, both measured in meters. Effective height is usually between $\frac{1}{2}$ and $\frac{2}{3}$ of actual height. Because of cost and construction difficulties, the height of antennas has been assumed to have a practical limit of about 400 feet (123 meters) and an effective height of about 85 meters.

Antenna radiation efficiency depends not only on radiation resistance, which can be fairly well predicted from a knowledge of antenna size and operating frequency, but also on the resistance of the antenna conductors, tuning coils, and ground circuits. These factors cannot be accurately predicted, and yet are critical in determining the radiation efficiency of antennas at low frequencies, where radiation resistance is very small.

Therefore, dependable figures on radiation efficiency should be based on actual measurements of signal strength at a known distance in comparison with the measured input power, using the fundamental inverse law.[22,46,69]

On the basis of available data of this sort, the curves in Fig. 6 are considered the best estimates of the radiation efficiencies practicably obtainable for a standard 400-foot antenna at various frequencies. The curves are to some degree uncertain because of necessary interpolations. The points plotted were calculated on the basis of data given in the references mentioned in Fig. 6.

In some instances[1,23] measured radiation efficiencies of actual 400-foot antennas were quoted. In other cases[22,55,67] sufficient experimental data, such as field strength at a known distance, input power, radiation pattern, etc., were given, from which it was possible to calculate the radiation efficiencies of the particular antennas, and to calculate what the efficiencies would be if all

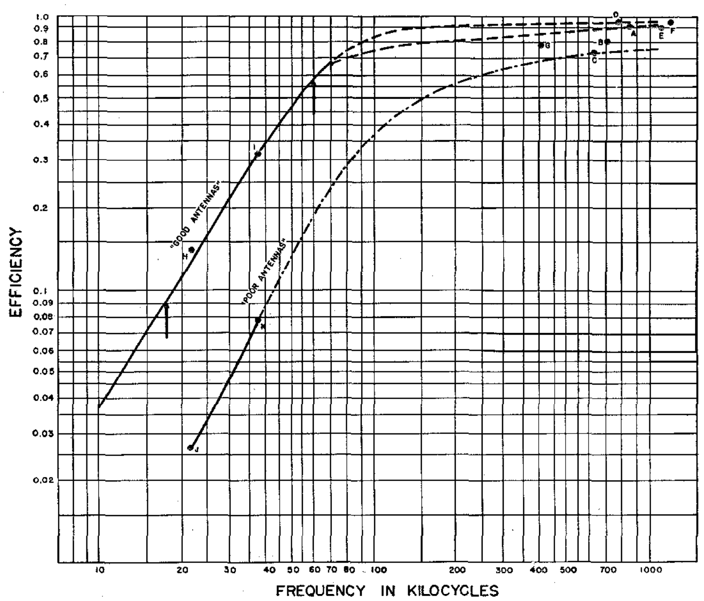

Fig. 6—Radiation efficiencies. The "good antennas" curve is for the 400-foot antenna of reference 23. The upper and lower estimates of extrapolation are dashed lines. The "poor antennas" solid curve is for the 400-foot antenna of reference 1 with estimated values in dash-dot curve.

A, B, C, D, E—Reference 22, modified to an antenna height of 400 feet.
F—Reference 55, WCAU 500-foot antenna.
G—Reference 67, modified to an antenna height of 400 feet.
H—Reference 1, New Brunswick 400-foot antenna.
I—Reference 1, estimated New Brunswick antenna.
J, K—Reference 1, New Brunswick antenna without multiple tuning.

Arrows denote frequencies mentioned in reference 23 as the basis for the curve.

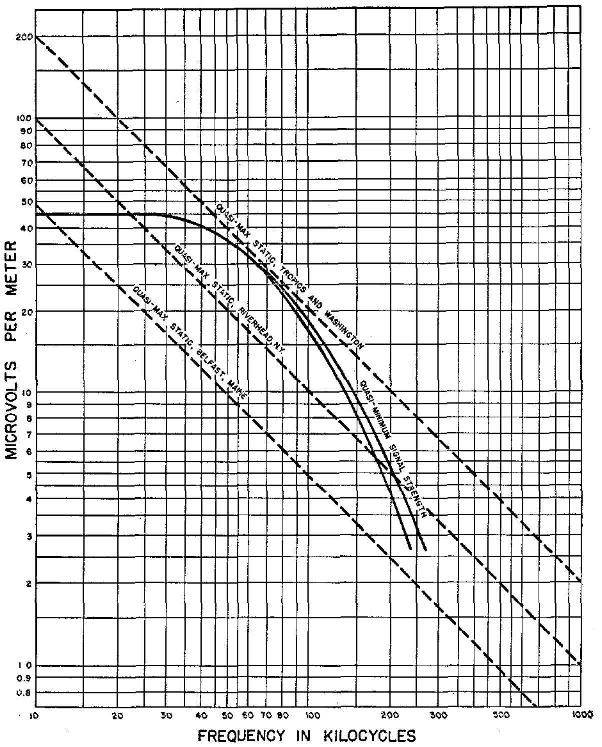

Fig. 7—Signal and static strengths based on an input power of 100 kilowatts, "good antenna" efficiencies, a 1500-mile sea-water path, and a 20-cycle bandwidth.

factors were the same except that the heights were changed to 400 feet.

7 Optimum Frequency and Power

Fig. 7 gives the same information as Fig. 5, except that in Fig. 7 the curve of quasi-minimum signal strength has been changed to the basis of constant *input* power by taking into account the radiation efficiency curve for a "good antenna" from Fig. 6. Since signal strength is proportional to the square root of radiated power, the signal strength for each frequency was multiplied by the square root of efficiency. (To facilitate plotting, signal strengths were multiplied by 10, which implies an increase in power from 1 to 100 kilowatts.)

TABLE VIII

INPUT POWER TO PRODUCE QUASI-MINIMUM-SIGNAL-TO-NOISE RATIO OF 1/1 AT OCEANIC DISTANCE OF 1500 MILES, USING EFFICIENT ANTENNAS AND A BANDWIDTH OF 20 CYCLES AT OPTIMUM FREQUENCY OF 70 KILOCYCLES

Static Condition at	Input Power in Kilowatts
Belfast	7
Riverhead	25
Washington	100
Tropics	100

According to Fig. 7, at a distance of 1500 miles over sea water, with constant input power, the highest quasi-minimum-signal-to-noise ratio is obtainable with a transmission frequency of about 70 kilocycles. Expressed in other words (and as shown in Fig. 8) any desired signal-to-noise ratio is obtained, for the same transmission conditions, with least power input at 70 kilocycles.

Various published articles[4, 9, 11, 23, 31, 40] estimate optimum frequencies for communication service as about 44 kilocycles for transatlantic service, and between 60 and 100 kilocycles for a range of about 1500 miles. The derivations of the latter estimates are not clearly stated; they appear to be more or less "rule of thumb."

Fig. 8 was plotted on the basis of a 1/1 signal-to-noise ratio, which is assumed as the low limit for worst conditions. It is evident that the minimum power requirement is at 70 kilocycles and is about 26 kilowatts. By virtue of the relation between static levels at various locations, the power requirement is about 6.5 kilowatts for Belfast and 105 kilowatts for Washington and tropical conditions.

7.1 SUMMARY

Rounding off the numbers gives Table VIII.

The power requirement for obtaining the same signal-to-noise ratio is directly proportional to the ratio of the bandwidth to 20 cycles.

Under most conditions the stated power requirements will be greater than necessary for navigation service. It might be advisable for at least the higher-powered ground stations to operate at reduced power except when full power is required; a considerable saving would be effected even though efficiency would be lower. Alternatively, each station might have 2 or more transmitters to be operated in parallel only when conditions require. The power stated is believed adequate to assure a usable signal under most unfavorable conditions except at very rare and negligible times.

8 Corona and Modulation

The values given for estimating the power required are based on continuous-wave radiation at 70 kilocycles. The size of the antenna is partly determined by the condition that its capacitance must be of such value that the peak sine-wave voltage to which it is charged by the antenna current shall not exceed the critical corona voltage. In judging the feasibility of a method of modulation for a given average radiated power, the highest working voltage allowed by corona considerations will determine the greatest peak-to-average power that may be used.

Antenna current has been computed for each chosen antenna power on the basis of an assumed effective height of 85 meters (which means a radiation resistance of 0.55 ohm) and an assumed efficiency of 66 percent (from Fig. 6). These values are listed in Table IX, together with the capacitances of 3 sizes of antennas, and the *peak* sine-wave voltage computed for each antenna.

Antenna (1) is of a physical size which may represent the economical limit for a 2-mast antenna, and which will probably suffice for most of the proposed radio navigation stations. The assumptions are: Height, 160 meters; sag of 40 meters at the center; mean height, 120 meters; length and breadth of flat-top portion, 240 meters and 15 meters, respectively.[2]

A larger antenna (2) was next chosen because such an antenna may be necessary for some stations where high powers are required. That chosen for (2) is the Pearl Harbor antenna,

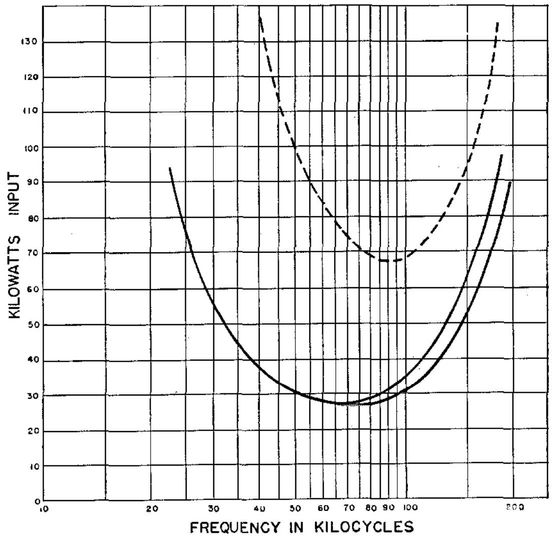

Fig. 8—Input power required as a function of frequency based on a 1/1 ratio of quasi-minimum signal to Riverhead static for a 1500-mile sea-water path, and a 20-cycle bandwidth. The dashed curve is for "poor antennas" and the solid curve for "good antennas." The branched part of the solid curve is based on high and low estimates of radiation efficiency.

which consists of 3 towers, 600 feet high, at the corners of a triangle 1100 feet on each side.

Finally, and merely as an indication of extremes in antenna size, the Radio Central[4] antenna has been selected as (3).

TABLE IX

FULL POWER IN SINGLE ANTENNA

Static Conditions at	Antenna Power, Continuous-Wave, in Kilowatts	Antenna Current Amperes	Antenna Capacitance in μf	Antenna Voltage Continuous-Wave Peak in Kilovolts
Belfast	7	92	(1) 0.003	90
			(2) 0.017	16
			(3) 0.053	5
Riverhead	25	173	(1) 0.003	170
			(2) 0.017	30
			(3) 0.053	9
Washington and Tropics	100	346	(1) 0.003	340
			(2) 0.017	60
			(3) 0.053	19

The voltages at which corona losses may be expected to occur were computed* on the assumption of unfavorable but expected extremes; temperature 50 degrees centigrade and barometer 70 centimeters of mercury. Stranded cables, $\frac{1}{4}$ inch, $\frac{1}{2}$ inch, and 1 inch in diameter, were separately considered; each at a height of 160 meters above ground. Values are tabulated in Table X.

TABLE X

CORONA LIMIT (PEAK VOLTAGE)

Cable Diameter in Inches	Fair Weather (Kilovolts)	Stormy Weather (Kilovolts)
$\frac{1}{4}$	74	59
$\frac{1}{2}$	138	110
1	257	206

8.1 CONCLUSIONS

8.1.1 Full Power in Single Antenna

A comparison of Tables IX and X leads to the conclusion that antenna (1) with a conductor diameter of $\frac{1}{2}$ inch would be safe for Belfast conditions; with a conductor diameter of 1 inch, for Riverhead conditions. For Washington and tropical conditions antenna (1) would not be suitable unless the diameter of the conductors exceeds 1 inch. These conclusions are for continuous-wave radiation; any form of modulation which involves a higher peak voltage would require a corresponding increase in antenna size.

* Reference 24, formula (35′).

8.1.2 Full Power Divided Between 2 Antennas

In certain navigation systems under consideration, a directional pattern is created by phased excitation of 2 spaced antennas. In this case, the full station power would be the same as mentioned before but would be divided equally between 2 antennas. The current in each antenna would be 0.707 times the value listed in Table IX. Table XI shows the antenna voltages to be expected in this case for the same 3 sizes of antenna.

TABLE XI

FULL POWER DIVIDED BETWEEN 2 ANTENNAS

Static Conditions at	Antenna Power, Continuous Waves, Kilowatts	Antenna Current Amperes	Antenna Capacitance μf	Antenna Voltage Peak, Continuous Waves, Kilovolts
Belfast	3.5	65	(1) 0.003 (2) 0.017 (3) 0.053	64 11 4
Riverhead	12.5	122	(1) 0.003 (2) 0.017 (3) 0.053	120 21 7
Washington	50	245	(1) 0.003 (2) 0.017 (3) 0.053	240 43 13

Comparison of Tables X and XI leads to the conclusion that antenna (1) would be safe for Belfast conditions with a conductor diameter of ¼ inch, or a smaller antenna could be used with ½-inch conductor diameter. Antenna (1) with conductors of ½-inch diameter would be safe for Riverhead conditions. For Washington and tropical conditions, an antenna slightly larger than (1) would be required, unless the conductor diameter exceeds 1 inch.

Preliminary calculations indicate that the powers here listed could be handled by antennas of the single-mast umbrella loaded type of heights around 500 to 600 feet, in which the capacitance is great enough to allow modest-sized conductors to be used without danger of corona, and in which the improvement in effective height, at the cost of greater tower height, allows a reduction in input power.

8.1.3 Other Bandwidths

Power requirements, and consequently antenna requirements, depend on the bandwidth of the receiver, because signal-to-noise ratios are the determining factors. For ½ the bandwidth, or 10 cycles, antenna power would be halved and antenna current and peak voltage are reduced by a factor of 0.707.

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Summary

Radio propagation implications of a long-range radio navigation system are discussed. The transmission frequency or range of frequencies most suitable for such a system is considered. A basic requirement laid down is that radio reception be assured within a radius of 1500 miles from each ground transmitting station regardless of hour, season, weather, or location, so that the navigator of an aircraft may always be able to determine his geographical position. The high- and low-frequency bands are first discussed generally. Consideration of various disadvantages of high frequencies for the exacting requirements of a navigation service leads to a detailed analysis of the low-frequency bands.

A study of compiled experimental data and consideration of all factors involved, including signal and static strengths and fluctuations, and antenna efficiency, leads to the conclusion that, for a maximum distance of 1500 miles, assured reception can be obtained with least power input at a transmission frequency of about 70 kilocycles. Estimates are presented of power requirements for several locations, and the sizes of antennas for handling such power without corona are discussed.

Pulse-Time-Modulated Multiplex Radio Relay System–Terminal Equipment*

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1 Introduction

PREVIOUS to the war, several types of single-channel and point-to-point radio links were operated successfully and in many cases they were used for commercial purposes.[1] On the lower frequencies it has been common practice to receive transoceanic telegraph or broadcast signals, and relay them on different frequencies to terminating stations. A few links combining several telegraph or facsimile printers with narrow-band transmission have been put into operation.[2] Other links for both single and multichannel telephone trunk-line operation in the ultra-high-frequency region have been limited to single-hop operation.[3,4] In addition, experimental short-distance pick-up-point-to-transmitter and transmitter-to-studio links have been used for television relaying.[5]

Until recently, however, most of these links were for narrow-band transmission, single-channel operation, or for short distances and did not utilize repeaters. Their limitations were mainly technical and specific facilities were lacking for wide-band multiplex operation on long radio relays.

With the development of special systems of transmission, such as frequency modulation and the newer pulse modulation, the ability to generate practical amounts of power at frequencies as high as 30,000 megacycles per second, and the progress in radar-pulse technique, the major difficulties have been overcome; it is now possible to design such multiplex radio relay systems for practical operation. This paper will describe terminal equipment for a 24-channel radio relay system, utilizing pulse-time modulation and time-division multiplexing, which takes advantage of these latest transmission techniques.

Pulse-time modulation (PTM) as used in this equipment employs narrow pulses transmitted at a supersonic rate, the time interval between successive pulses varying with the amplitude of the modulating signal, and the rate of change of the pulse displacement corresponding to the frequency of this signal. This type of modulation has been used in several equipments built during the war. Pulse-time modulation has been described in various restricted technical reports, and a few articles have also appeared in the technical literature.[6,7,8]

As narrow pulses are transmitted at a low repetition rate, compared to the width of these pulses, a relatively long time elapses between pulses. It is, therefore, possible to interleave several sets of pulses, each set providing a separate and independent signaling channel, resulting in what has been called time-division multiplexing, to distinguish it from conventional frequency-division-multiplex operation.

The multiplex pulse series, combining the signals of all channels, is transmitted at a common carrier frequency. At the receiver after detection, the individual pulse channels are separated and retranslated into their original audio-frequency signals. The method of radio transmission is optional and either amplitude or frequency keying of the carrier may be employed.

Pulse-time multiplexing offers many advantages over the conventional method of multiplexing. There is an improved signal-to-noise ratio which is characteristic of pulse modulation and wide-band transmission. Limiters and other noise-reducing devices may be utilized effectively since amplitude variation is not a parameter of the audio modulation. Constant average power being transmitted during modulation, the transmission circuit may be simplified and operated at maximum efficiency.

With frequency-division multiplexing, nonlinear circuits must be assiduously avoided to prevent cross talk between channels. For time-division multiplexing, these effects are avoided

* To be published in Proceedings of the I.R.E., and Waves and Electrons. Presented, Pittsburgh Section, Institute of Radio Engineers, March 11, 1946.

[1] Numbered references will be found on page 177.

as only a single signal is transmitted at any given instant of time. This results in minimum distortion and cross-talk effects which are essentially independent of the number of repeaters utilized to extend the range of transmission. The level of the output audio-frequency signal is likewise independent of the number of repeaters. Neither automatic volume control nor pilot channels are required for maintaining this level. The improvement in signal-to-noise ratio achieved with the pulse system, permits repeaters to be spaced farther apart or less power may be used.

There are additional characteristics of pulse transmission that make this system particularly advantageous for relaying. The discrete "on-off" type of operation permits transmission during periods of nonreception. Moreover, with transmission at radio frequencies, pulsing methods of modulation are particularly adaptable to the higher frequencies where such types of generators as magnetrons are used.

Of course a price must be paid for these advantages; pulse systems require a relatively large bandwidth compared to more conventional methods of modulation. This is not necessarily an excessive price, however, since at high frequencies the modulation bandwidth viewed as a percentage of the carrier frequency is as small or smaller than that for other modulation systems at lower frequencies. In addition, the geographical isolation offered by the directive ultra-high-frequency transmission utilized in relaying allows operation of other services on the same frequencies and thus decreases the interfering effects of wide-band transmission by a considerable factor.

2 *Operating Principles*

2.1 General

The multiplex terminal equipment comprises 3 main units: modulator, demodulator, and auxiliary equipment. It is intended for terminal operation over coaxial cable (4-wire system) or for subsequent modulation of a radio-frequency carrier. A total of 24 2-way audio-frequency channels are available with a modulation bandwidth of 2.8 megacycles per second, in each direction. The equipment has been designed primarily for telephone operation although any type of intelligence consistent with the frequency-band characteristics may be transmitted.

2.2 Modulation

The modulation method will best be understood by referring to Figs. 1 and 2. Basically the transmission for a channel consists of 2 sets of pulses of period T displaced in time with respect to each other by an average amount which depends on the channel placement. One set of pulses, called the marker pulses, are fixed in time. The instantaneous position of the second set of pulses, with reference to the marker pulses, depends on the instantaneous amplitude of the modulating signal.

Fig. 1 illustrates on a relative time scale the modulation method as applied to a single channel. The modulating wave form represents one component of a complex audio-frequency signal. Each pulse samples the modulating signal and takes up a position in time determined by the instantaneous amplitude of the sample of modulating signal. The pulse displacement from the

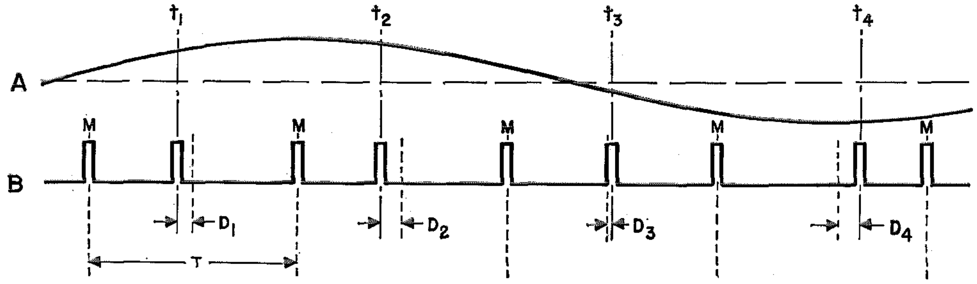

Fig. 1—Pulse modulation method. A is the modulating wave and B is the time-modulated pulse series derived from it. t_1, t_2, t_3, t_4 represent the time of sampling; D_1, D_2, D_3, D_4 are the relative time displacements of the pulses corresponding to the instantaneous amplitude of the modulating signal.

mean position, determined by the instantaneous amplitude of the sample of the modulating signal, is shown by the successive increments of

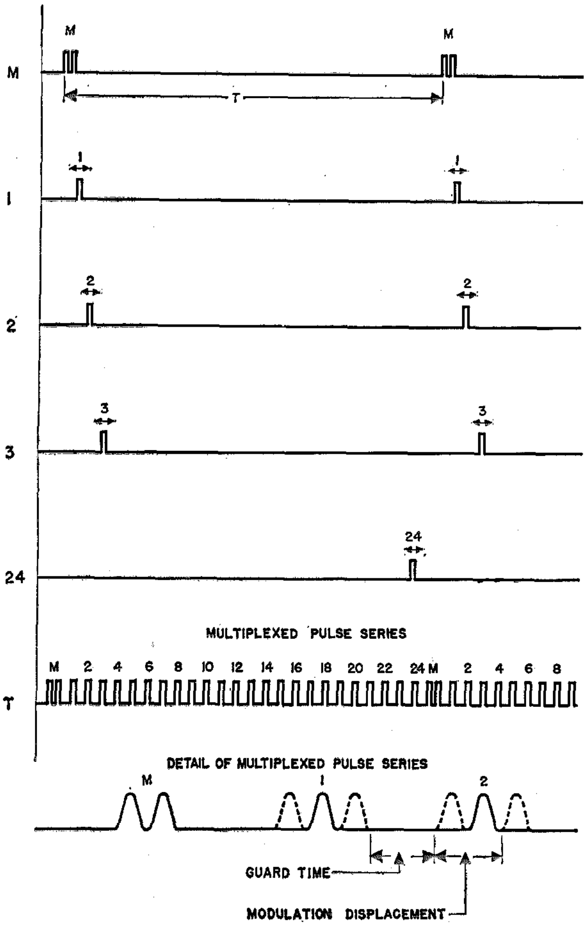

Fig. 2—Time-division pulse multiplex. Wave-form diagram illustrating the interleaving of the pulses of the various channels. M, 1, 2, 3, 24 are the separately generated pulses for the marker and channels 1, 2, 3, 24. T is the total of the marker and 24 channel pulses properly interleaved for the unmodulated condition. The displacement of the pulses under modulation is indicated by the dotted pulses in the lower drawing; the expanded time scale of this drawing shows the pulses actually to be rounded on top and with sloping sides.

D_1, D_2, D_3, D_4 at the scanning times t_1, t_2, t_3, t_4, respectively. The frequency of the modulating signal determines the rate of time displacement for the modulated-pulse series.

It is apparent that a sufficiently high repetition rate of pulses must be chosen to delineate adequately the modulating wave form. The pulse-repetition rate is a function of the highest modulating frequency, the maximum pulse displacement desired, and the maximum allowable spurious distortion. The relation between the required pulse-repetition rate and the highest modulating frequency can be determined by a Fourier analysis of the pulse series. For the particular modulation displacement used in the present equipment, the ratio between the two quantities is approximately 2.5:1 resulting in distortion from this cause alone of less than 1 percent.

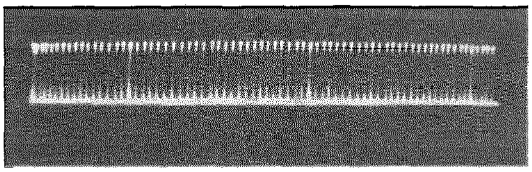

Fig. 3—Oscillograph of 24-channel pulse series. Two full cycles are shown. The brighter pulse is the marker and is made up of 2 closely spaced pulses.

It should be noted that the modulation displacement is only a fraction of the period T. During the remaining interval of time, pulse series carrying modulation for other channels are interleaved as illustrated by Fig. 2. A single series of marker pulses are used as the reference pulses for all channels. Generally the marker pulses are given a distinguishing separation or width characteristic as indicated in this figure to facilitate their removal. Fig. 3 shows an oscillograph of the 24 sets of interleaved channel pulses. The brighter pulse is the marker and is made up of 2 pulses, side by side, each similar to a channel pulse.

By limiting the maximum swing of modulation displacement, each channel is made independent of all others. Likewise by providing the proper frequency band, carry-over between adjacent pulses is avoided and thus cross talk between channels is minimized.

It should be noted that the build-up time of each pulse determines the bandwidth required; adding more channels does not increase this requirement. The improvement in the signal-to-noise ratio obtained with the system depends on the modulation displacement and also on the build-up time of the individual pulses. By decreasing the build-up time, an improvement in signal-to-noise ratio is obtained but a larger frequency band must be used. Alternatively, increasing the modulation displacement will improve the signal-to-noise ratio but fewer channels can be accommodated. Thus a practical compromise must be reached between the number of channels, the signal-to-noise ratio, and bandwidth.

The following steps are involved in the generation of a pulse-time-modulated multiplex wave form:

a. Generation of a series of pulses.
b. Production of pulses at proper time intervals to provide a series for each channel.
c. Modulation of each series of channel pulses by the respective audio-frequency signal.
d. Limitation of the audio-frequency modulating signal to prevent cross talk or "breakthrough" between channels.

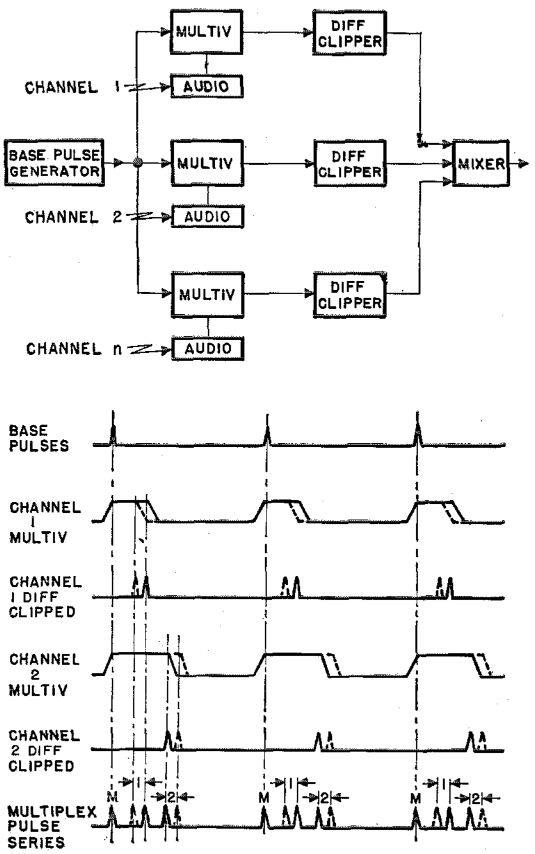

Fig. 4—Multiplex modulator, multivibrator type. The timing for each pulse series is established by the time constants of the multivibrator. Modulation is introduced by varying the output pulse widths and utilizing the trailing edges of these pulses. The dotted lines indicate relative positions for various conditions of modulation.

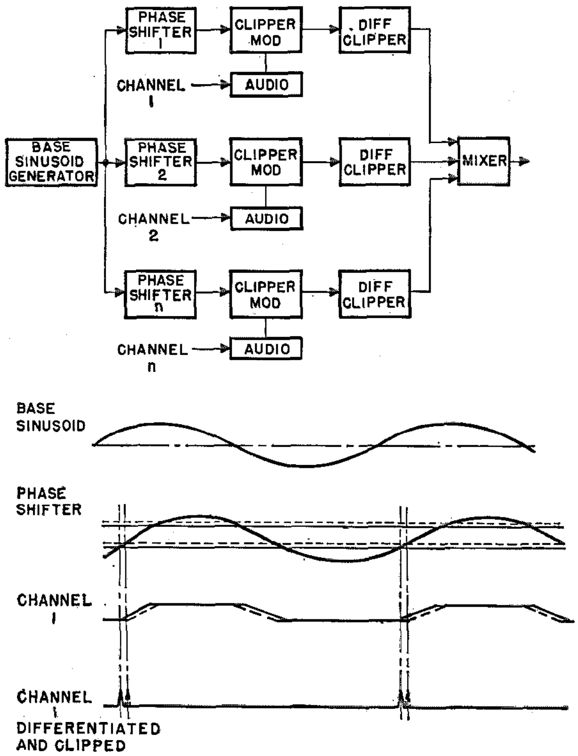

Fig. 5—Multiplex modulator, phase-shifter type. Pulse timing is obtained by the relative phase of the base sinusoids.

e. Generation of a marker pulse.
f. Final mixing of channel and marker pulses into one interleaved set.

2.2.1 *Multivibrator Modulator*

There are several methods of modulation possible. One such method involves the use of a series of multivibrators, one for each separate channel. The multivibrators are synchronized by pulses from a control oscillator and the timing of the pulse series for each channel is determined by the time constants of the multivibrator. Modulation may be effected by varying the width of the output pulses and utilizing the trailing edges of these pulses through differentiation and clipping. Fig. 4 illustrates this type of modulator.

2.2.2 *Phase-Shifter Modulator*

An alternative method used in early equipment is indicated in Fig. 5. The fundamental timing is obtained from a sinusoidal oscillator.

Phase shifters control the timing for each channel. A clipper-modulator removes a variable-width slice, corresponding to the audio-frequency modulation, from the sinusoid of a given channel. The leading or trailing edge of the resulting variable-width pulse is utilized to produce the time-modulated pulse series.

2.2.3 *Cyclophon Modulator*

In the present equipment, a simplified method of generating the base pulses utilizes a tube called the Cyclophon. This special tube includes in an evacuated envelope all the elements necessary for operation as a modulator and, with some modifications, as a demodulator. The Cyclophon provides considerable improvement in stability and simplicity over previous methods. The following description has particular reference to its use as a modulator.

The Cyclophon is based on the standard cathode-ray tube. It contains a gun structure producing a fine beam of electrons, horizontal and vertical deflecting plates, and a series of special electrodes to produce the multiplexing operation. Figs. 6 and 7 illustrate the general constructional details of the tube. Fig. 8 indicates the associated external circuits and details of the end-plate construction.

Electrodes 1, 2, 3, and 4 represent the conventional gun-and-deflecting-plate structure. This is followed by a "stopper" or aperture plate, 5, containing as many apertures as there are channels, plus marker. Dynode shoes, 6, are placed behind the aperture-plate openings. The aperture plate is operated at approximately anode potential, and the dynode shoes at a potential somewhat lower.

An oscillator generates a sinusoidal wave at the base frequency and the sinusoid produced is applied directly to one pair of deflecting plates and through a 90-degree phase-shifting stage to the other pair of plates. These potentials cause the electron beam to rotate around the end face of the tube at a rate equal to the frequency of the sinusoid.

The beam in scanning the aperture plate passes through each small aperture for a time interval determined by the window width, beam width, and the rotational speed. During this interval the beam strikes the dynode shoe, causing secondary electrons to be emitted from the dynode shoe, which in turn are collected by the aperture plate.

A pulse of current flows through the dynode load resistance R for each rotation of the electron beam. As the beam scans the apertures in succession, a series of pulses are produced in each

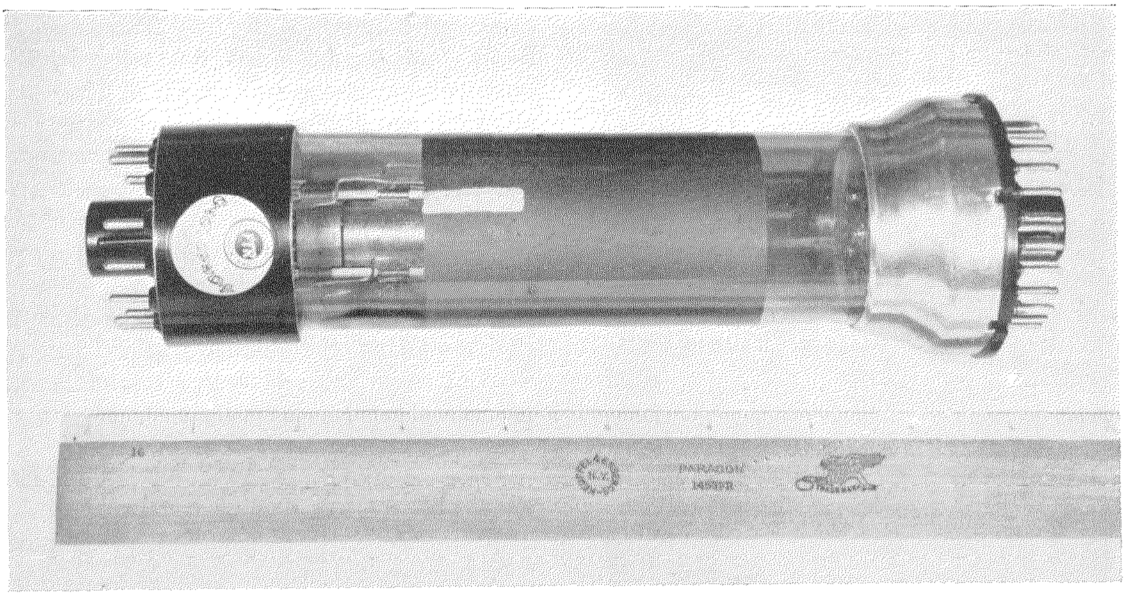

Fig. 6—Cyclophon tube. The output signals are obtained from the 26-prong base.

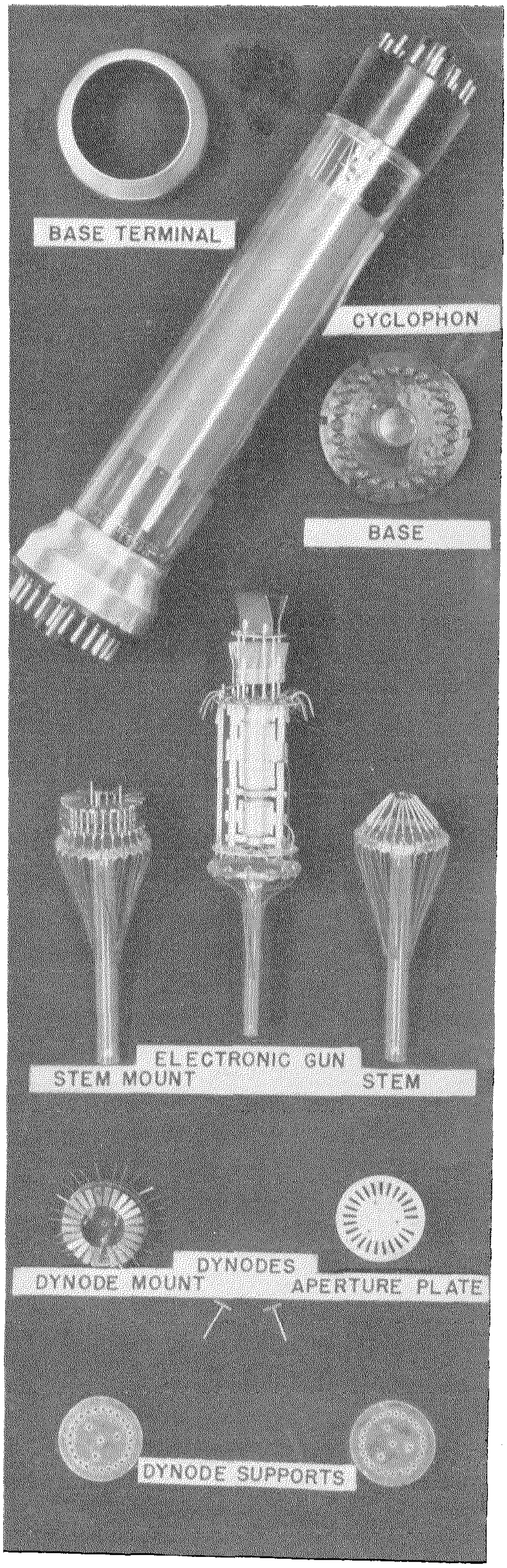

Fig. 7—Constructional details of the Cyclophon tube.

dynode load and are related in time to the pulse series in other dynode circuits by the relative mechanical placement of each window around the aperture plate. Each dynode load resistance is shunted by a capacitance C to obtain a pulse with a relatively slow but linear build-up time, rather than an abrupt steplike pulse.

The pulses produced by the Cyclophon are applied to individual channel modulators which generate the time-modulated pulses corresponding to the incoming audio-frequency signals. These channel modulators comprise essentially a double-gate clipper which is controlled by the modulating signal and which isolates a small slice of the simultaneously applied pulse, the width of each slice depending on the instantaneous amplitude level of the audio-frequency signal. By means of this process a series of width-modulated pulses are obtained which may be converted to a time-modulated series by the use of a simple differentiating and clipping circuit. Fig. 9 illustrates this sequence of wave processing for a single channel.

The time-modulated pulse series obtained from the channel modulators are combined to yield the composite pulse series. Fig. 2 shows the waveform diagrams corresponding to the addition of all channel pulses. To simplify the process this mixing is done in steps of 8 channels. Thus the pulses of 8 channels, every third channel apart, are added and then the 3 8-channel groups are combined to produce the final 24-channel pulse series. This arrangement not only minimizes cross talk but also gives a degree of flexibility by allowing a multiplex system in 8-channel steps to be developed. By adding 8-channel groups, an 8-, 16-, or 24-channel system can be achieved.

It will be noted that the marker pulse obtained by the Cyclophon is added to the composite pulse series after shaping to the required pulse characteristic by means of the marker-shaper unit. For producing the double marker pulse, the shaper may utilize a delay network and generate the second marker pulse by reflection from the open-ended network.

Also included in the individual channel modulators is a limiter which prevents the audio-frequency signal from exceeding a set amplitude. By this means the peak time displacement of each channel pulse is kept within prescribed limits and thus break-through between channels is prevented.

The resulting time-modulated multiplex wave form obtained from the final mixer is applied directly to the coaxial cable or radio-frequency terminal equipment through a low-impedance cathode follower. Further shaping of the multiplex pulse series to obtain constant or special shape characteristics are achieved by placing the appropriate shaping unit at this point in the circuit.

Fig. 9 shows a sequence of oscillograms illustrating the modulation process. The pulse series from one channel of the Cyclophon is shown at A. The corresponding output of the clipper-modulator indicating the translation of Cyclophon pulses to width-modulated pulses is shown at B. And the time-modulated pulses for one channel together with the addition of all channel pulses plus the marker are illustrated at C and D, respectively.

2.3 Demodulation

The sequence of operations necessary to retranslate the time-modulated multiplex pulse series into the individual audio-frequency channels after reception of the radio signals generally involves the following:

a. Removal of the marker pulse from the pulse series.
b. Separation of the individual-channel pulses from the combined pulse series.
c. Retranslation of the individual-channel time-modulated pulse series into the appropriate audio-frequency signal.
d. Amplification of the audio-frequency signal to the level required for use.

2.3.1 Multivibrator Demodulation

As in the case of the modulation process, there are many possible means of accomplishing the demodulation of the time-modulated pulse series. The marker pulse may be removed from the pulse sequence to control a multivibrator, which produces a pulse delayed to the proper channel pulse timing. This pulse may serve as a pedestal for separating the appropriate channel pulse.

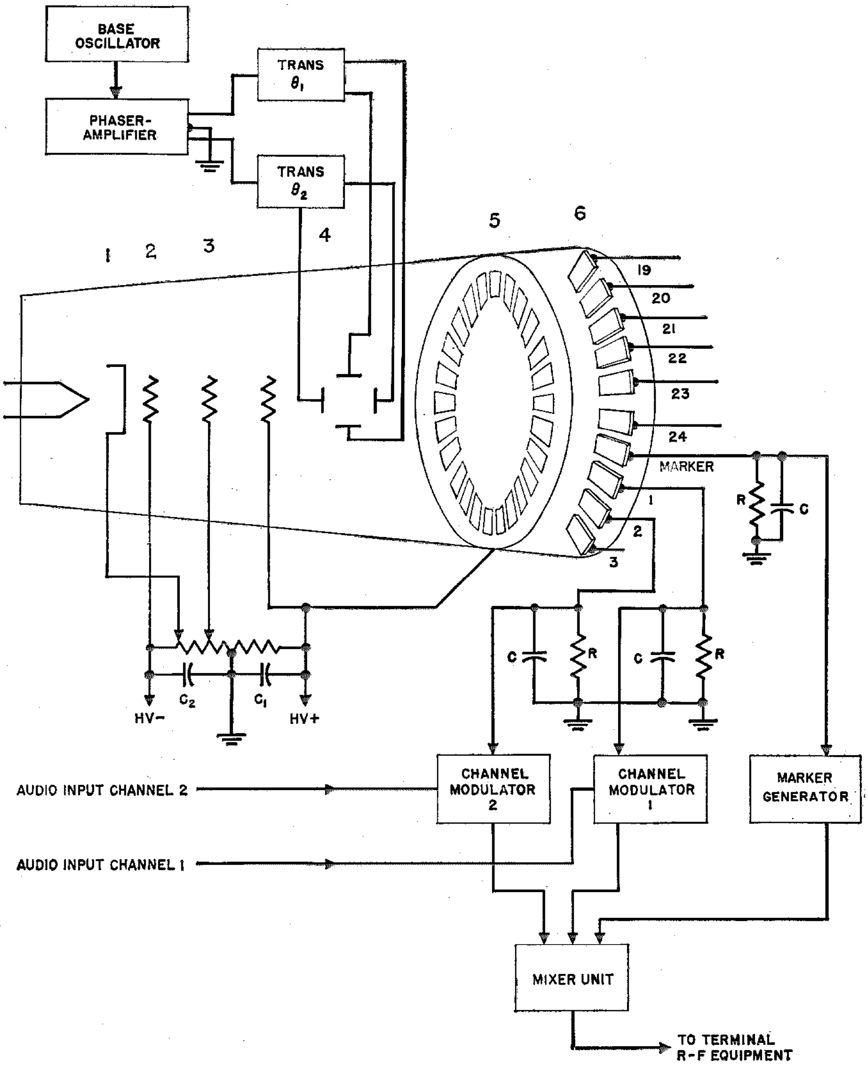

Fig. 8—Multiplex modulator, Cyclophon type. A detail of the dynode-aperture-plate construction is shown together with associated circuit elements. The pulse timing is obtained by the mechanical relationship of the Cyclophon apertures.

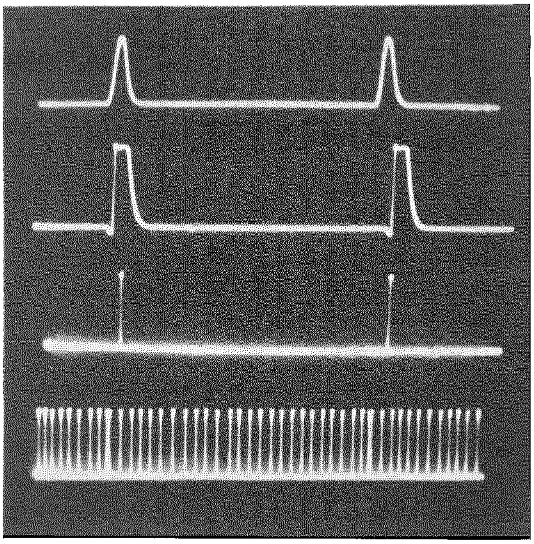

Fig. 9—Oscillogram of modulation sequence. A. Single-channel Cyclophon pulses. B. Width-modulated channel pulses. C. Time-modulated channel pulses. D. Addition of all pulse series, plus marker.

The single-channel time-modulated pulses can then be translated into amplitude-modulated pulses by utilizing the slope of the same pedestal pulses. All other channels are demodulated in the same manner by making use of appropriately timed pedestal pulses.

Fig. 10 illustrates one demodulation system of this type. Of course other circuit elements or combination of units may be substituted in place of those shown. For example a delay network can be utilized in place of the multivibrator or the pedestal pulse may be so spaced as simultaneously to remove and amplitude translate the channel pulses. Alternatively, the multivibrator may be made to respond to one pulse only depending on the internal time constants and likewise accomplish separation and translation simultaneously.

Unfortunately these methods present difficulties in the way of stability or complexity when applied to a large number of channels and for these reasons a demodulation method utilizing a version of the Cyclophon is incorporated in the multiplex equipment described.

2.3.2 Cyclophon Demodulation

Basically, the special multiplexing demodulator tube is similar in construction to the Cyclophon modulator tube with the exception that the equivalent of the series of collectors arranged in the circular pattern at the tube face, differ in general dimensions. The number of collectors correspond to the number of channels desired. The number may be N+1 if a marker collector is included. For practical purposes it is more convenient to use the aperture-dynode system which is the equivalent of collector plates. Fig. 11 indicates in a schematic way the arrangement of the tube together with the accompanying circuits. Figs. 6 and 7 apply also to the demodulator and illustrate the general mechanical features.

As in the case of the Cyclophon modulator, the tube structure consists of a diaphragm with a

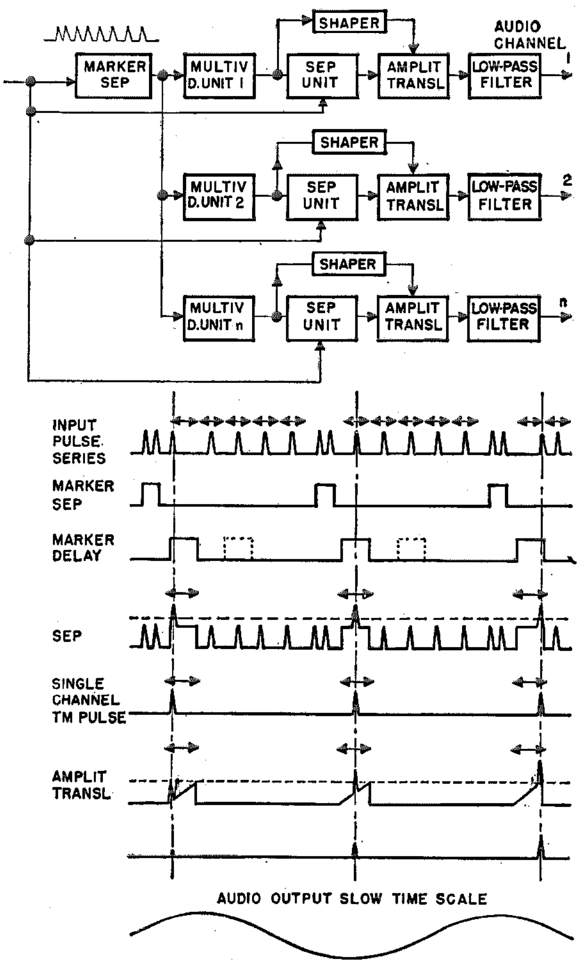

Fig. 10—Multiplex demodulator, multivibrator type. The channels are separated by the pedestal formed by the multivibrator pulses. This same pedestal pulse is also utilized for demodulating the time-modulated pulses.

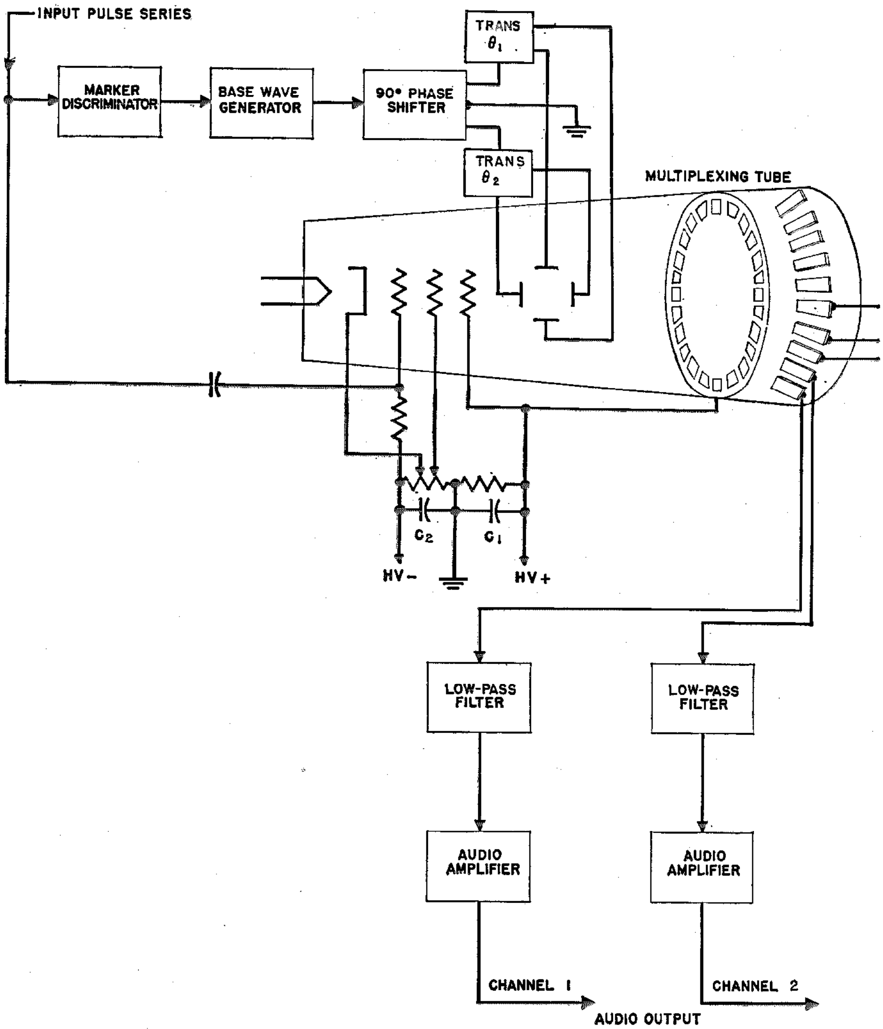

Fig. 11—Multiplex demodulator, Cyclophon type. The Cyclophon accomplishes both the separation and demodulation of the time-modulated pulse series.

series of apertures located around its circumference. These apertures are dimensioned in accordance with the characteristics of the modulation system which includes the time-modulation displacement, guard time, number of channels, etc. A dynode is placed behind each aperture and electrons striking this surface produce a secondary-emission current flow.

From the time-modulated series of pulses, the marker pulse is removed by a marker discriminator. A sinusoid at the base frequency is derived from the marker pulses which in turn is used as the deflection voltage and causes rotation of the scanning beam.

The grid of the demodulator tube is normally biased to cut-off so that the electron beam is extinguished in the absence of channel pulses applied to the grid. Depending on the time relation between the channel pulses and the base wave, the beam will be turned on more or less coincidentally with the particular channel aperture, producing a greater or lesser current flow in the dynode-aperture-plate circuit for that particular channel. The spatial relationship of the aperture with respect to the base wave serves to isolate the individual channels, while the relationship between channel aperture and the instantaneous time position of the beam produces the translation into an amplitude-modulated signal. Fig. 12 shows the specific actions occurring within the tube, with reference to this process. The resultant output wave form at the dynode will therefore consist of a series of amplitude-modulated pulses from which the original modulating signal may be obtained by means of a low-pass filter. The action occurring in all other channels will be similar and each channel in turn will be separated and demodulated.

It can be seen, therefore, that the special multiplex demodulator tube performs several of the functions previously set forth, i.e., separation of channels, demodulation of signals, and partial amplification of the individual channel outputs.

Fig. 13 shows a sequence of demodulation oscillograms for a single channel. The pulse series applied to the grid of the Cyclophon is shown at A. It should be noted that this series is for one channel whereas all channel pulses, interleaved, are normally applied to the grid. The base sinusoid obtained from the marker before application to the deflection plates is indicated at B together with the resulting amplitude-modulated pulses from one channel dynode at C. The final audio-frequency output following the low-pass filter is illustrated at D.

The method of separating the marker pulse channel, which establishes the base wave for use with the demodulator, utilizes passive circuits and controls synchronization in a reliable and straightforward manner. The received multiplexed pulse series are applied to an open-circuited delay line, the forward delay of which is equal to $\frac{1}{2}$ the timing between the 2 closely spaced marker pulses. A complete reflection of the pulse series without change of polarity occurs at the open end of the line resulting in an image pulse series appearing at the line input terminals. Since the total delay is equal to the time separation of the marker pulses, the resulting wave form will consist of a double set of pulses of uniform amplitude with the exception of the second marker pulse which will be twice the normal amplitude, as a result of the pedestal formed by the reflected marker pulse. This pulse is removed from the multiplexed series by a clipper tube and is applied directly to a tuned circuit for producing the base sinusoid. Fig. 14 shows an oscillogram illustrating the marker separation. At A is shown the input pulse series including the marker; B is taken at the delay-line terminals and shows the addition of the applied and reflected pulses; C shows the separated marker pulse after clipping.

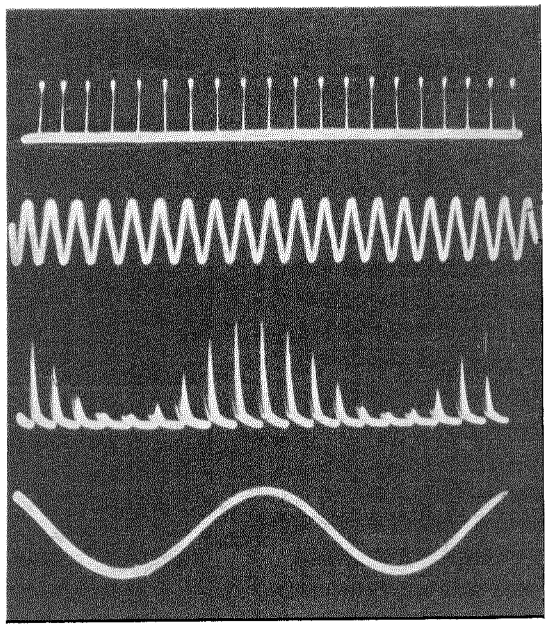

Fig. 13—Oscillogram of demodulation sequences. A. Single-channel time-modulated pulses. B. Base sinusoid. C. Output amplitude-modulated pulses. D. Output of low-pass filter.

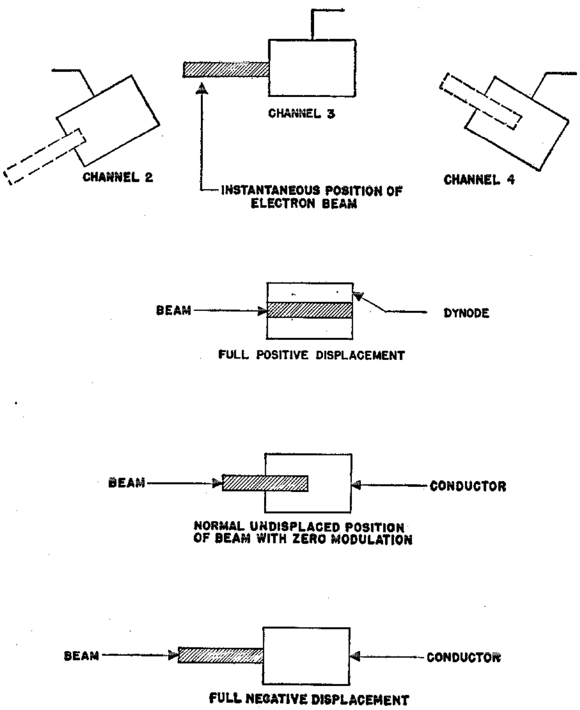

Fig. 12—Cyclophon tube demodulation process. Maximum pulse output is obtained with the beam full on the collector. Zero pulse is obtained for the beam completely off the collector.

2.4 Auxiliary Equipment

Where normal telephone operation is desired, ringing and dialing can be accomplished in an exceedingly simple manner. Inherently, direct current can be transmitted by varying the pulse position. Displacement of channel pulses in one direction is made to cause direct current to flow in the output circuit while displacement in the opposite direction interrupts this current.

Direct current applied to the input terminals of a channel closes a relay which by-passes the audio-frequency equipment and places a biasing voltage on the channel modulator. This causes the channel pulse to be displaced by a fixed amount from the original stand-by position. In the absence of the biasing voltage, i.e., when the direct current is removed from the input, the pulse returns to its stand-by position.

At the receiving demodulator, the stand-by position corresponds to the beam in the Cyclophon being just adjacent to the channel aperture; no current will flow in the local dynode circuit. For the direct-current condition, however, the pulse is displaced so that the beam partially covers the aperture, which is the position for normal demodulation action. Under these conditions, current will flow in the dynode circuit and operate a local relay which places a direct current of the proper magnitude on the output terminals. Modulation of the pulse does not disturb this direct-current condition as an average dynode current will flow during the dynamic-modulation displacement.

As far as the input and output terminals are concerned, the multiplex terminal behaves as a metallic line. Closing the circuit and placing direct current together with the telephone signals on the input results in the combination of an audio-frequency signal plus direct current in the output circuit. Interruption of the direct current at the input causes interruption of the direct current at the output. The normal ringing and dialing impulses can thus be applied directly to the input terminals and operate the corresponding automatic ringing, dialing, and line-finding equipment connected directly to the output terminals.

A 2-way radio relay is essentially a 4-wire system, and some method must be used for transforming a 4-wire into a 2-wire system if connection to the standard telephone lines is desired at the input and output ends of the link. This may be accomplished in the conventional manner by hybrid transformers. Usual precautions must, of course, be taken to prevent singing around the hybrid loop as well as the proper circuit arrangement for by-passing the hybrids during ringing or dialing.

2.5 Over-All Operation

The multiplex modulator and demodulator previously described perform the essential functions of multiplexing the various voice channels. The design of both these units must be such that the over-all distortion, frequency response, and cross talk meet the minimum requirements of a good communication system. The distortion and response-frequency characteristics are determined completely by the multiplex terminal equipment and are independent of the number and type of repeaters.

Cross talk can be introduced into the system by improper pulse carry-over characteristics which may be caused by either the terminals or the repeaters. However, proper utilization of the frequency band allocated to the system allows the reduction of this effect to the required degree. Theoretically it is also possible to obtain cross talk from multipath reflections of a radio wave. With proper antenna directivity, such effects can be minimized; operation of radio links has shown this factor to be of minor importance.

Limiting and differentiation are applied before demodulation to obtain the maximum signal-to-noise possibilities with a pulse system. The limiters remove the noise occurring between pulses as well as amplitude modulation of the pulses caused by noise. In addition, the limiters allow constancy of signal output independent of fading and other transmission vagaries. Differentiation further aids in reducing noise effects by removing variations of the shape and width characteristics of the individual pulses.

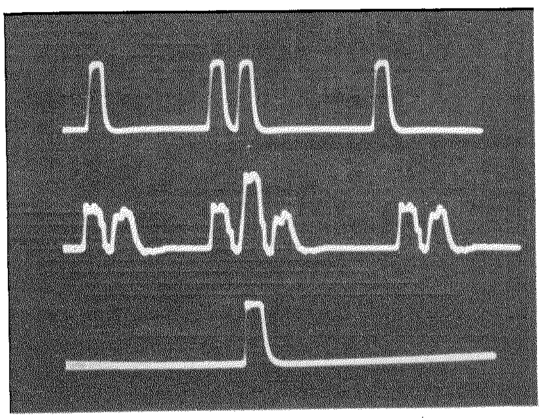

Fig. 14—Oscillogram of marker separation. A. Applied pulse series (expanded time scale). B. Addition of applied and reflected pulses. C. Separated marker pulse after clipping.

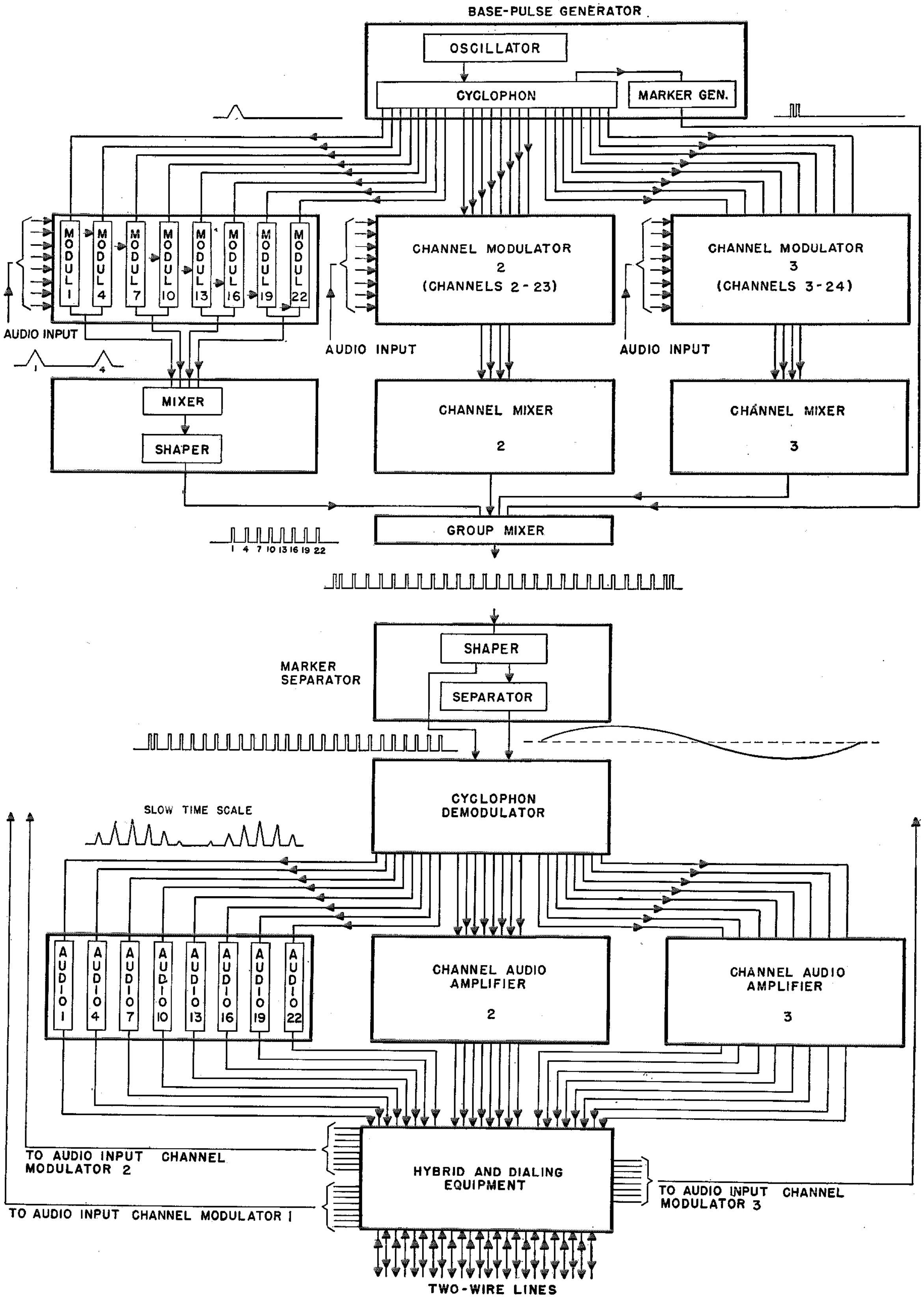

Fig. 15—Block diagram of terminal equipment. The subdivision of the common group units 2 and 3 are identical to the corresponding group-1 unit.

3 *Apparatus Description*

3.1 General

The principles of operation of a pulse-time-modulated multiplex system are described in the previous section. A description will now be given of the physical and electrical characteristics of the terminal equipment incorporated in an operating pulse-time-modulated multiplex radio relay system.

The multiplexing equipment, including modulator and demodulator, are combined in a single standard 19-inch by 80-inch relay rack which also mounts the hybriding and terminating apparatus. The auxiliary equipment with its alternating-current-operated power supplies and ringing and dialing apparatus is mounted in a second rack of the same dimensions. Wiring of all racks is self-contained and the placement of parts is such as to permit ease of servicing, replacement, and adjustment.

Fig. 15 shows the block diagram of the complete terminal equipment excluding the regulated power supplies. The location of the various units as well as the general appearance of the apparatus is indicated by Fig. 16.

The equipment is powered from 60-cycle alternating current at either 110 or 220 volts. A total of approximately 4.5 tubes per channel, excluding ringing and dialing, is required for the complete 2-way 24-channel terminal system. Table I lists the technical specifications of the equipment described.

For each channel, the response over an audio-frequency band from 200 to 3100 cycles per second is within ±1 decibel. An over-all audio-frequency distortion less than 3 percent can be obtained for terminal-to-terminal operation. The

TABLE I

Technical Specifications

Over-all System	
Number of channels	24 duplex voice-frequency channels, 1 marker channel
Audio-frequency band per channel	200–3100 cycles per second, level within ±1 decibel
Cross talk between channels (For terminal equipment)	Better than −60 decibels of peak modulation of adjacent channel
Audio-frequency input level	1 milliwatt in 600 ohms
Over-all audio-frequency distortion	Less than 3 percent
Audio-frequency output level	1 milliwatt in 600 ohms
Pulse frequency band	2.8 megacycles per second
Fundamental pulse rate (per channel)	8000 pulses per second
Total pulse rate (24 channels and 1 marker)	200,000 pulses per second
Modulation displacement	±1 microsecond
Guard time	2.5 microseconds, approximate value
Channel pulse shape	Trapezoidal, approximately
Channel pulse width (10 percent base)	0.5 microsecond, approximate value
Channel pulse build-up time	0.15 microsecond, approximate value
Channel pulse decay time	0.2 microsecond, approximate value
Equivalent square channel pulse	0.27 microsecond, approximate value
Marker-pulse shape	Trapezoidal, approximately
Marker-pulse width (10 percent base)	0.5 microsecond, approximate value
Marker-pulse build-up time	0.15 microsecond, approximate value
Marker-pulse decay time	0.2 microsecond, approximate value
Marker-pulse separation	1.3 microseconds, approximate value
Peak-to-average-power ratio	18, approximate value
Primary power	110–220 volts, 60 cycles, alternating current
Rack size	Standard 19-inch relay rack
Indoor cabinet	18 by 28 by 84 inches
Modulator	
Input audio-frequency level	1 milliwatt in 600 ohms (each channel)
Output level (pulse)	+5 volts, peak to peak
Output impedance	70 ohms
Tube complement	3.5 standard receiving tubes per channel per equipment, 1 multiplex modulator tube
Power consumption	500 watts per equipment
Weight (including stand-by equipment)	750 pounds.
Demodulator	
Input pulse level	+5 volts (from 70-ohm line)
Output audio-frequency level	1 milliwatt (each channel)
Output impedance	600 ohms
Tube complement	1.5 standard receiving tubes per channel per equipment, 1 multiplex demodulator tube
Power consumption	450 watts per equipment
Weight (including stand-by)	750 pounds
Auxiliary Equipment	
Ringing-dialing impulses	International standard
Dialing speed	Up to 20 cycles per second
Tube complement	2 per channel
Size	Standard rack or cabinet
Weight	350 pounds
Power consumption	300 watts

audio-frequency input and output levels are maintained at the standard 1 milliwatt in 600 ohms. Cross talk between channels is more than 60 decibels below the peak modulation level of the adjacent channels.

The pulse frequency band utilized in the system for 24 channels is 2.8 megacycles per second. The improvement in signal-to-noise ratio over an amplitude-modulated system with the same average power is of the order of 15 decibels.

As indicated by the block diagram of Fig. 15, the terminal equipment can be divided into the 2 basic classes of units, multiplex modulator and multiplex demodulator. The design features of this apparatus are given in the following paragraphs.

3.2 Multiplex Modulator

The multiplex modulator, which translates the individual voice channels into corresponding

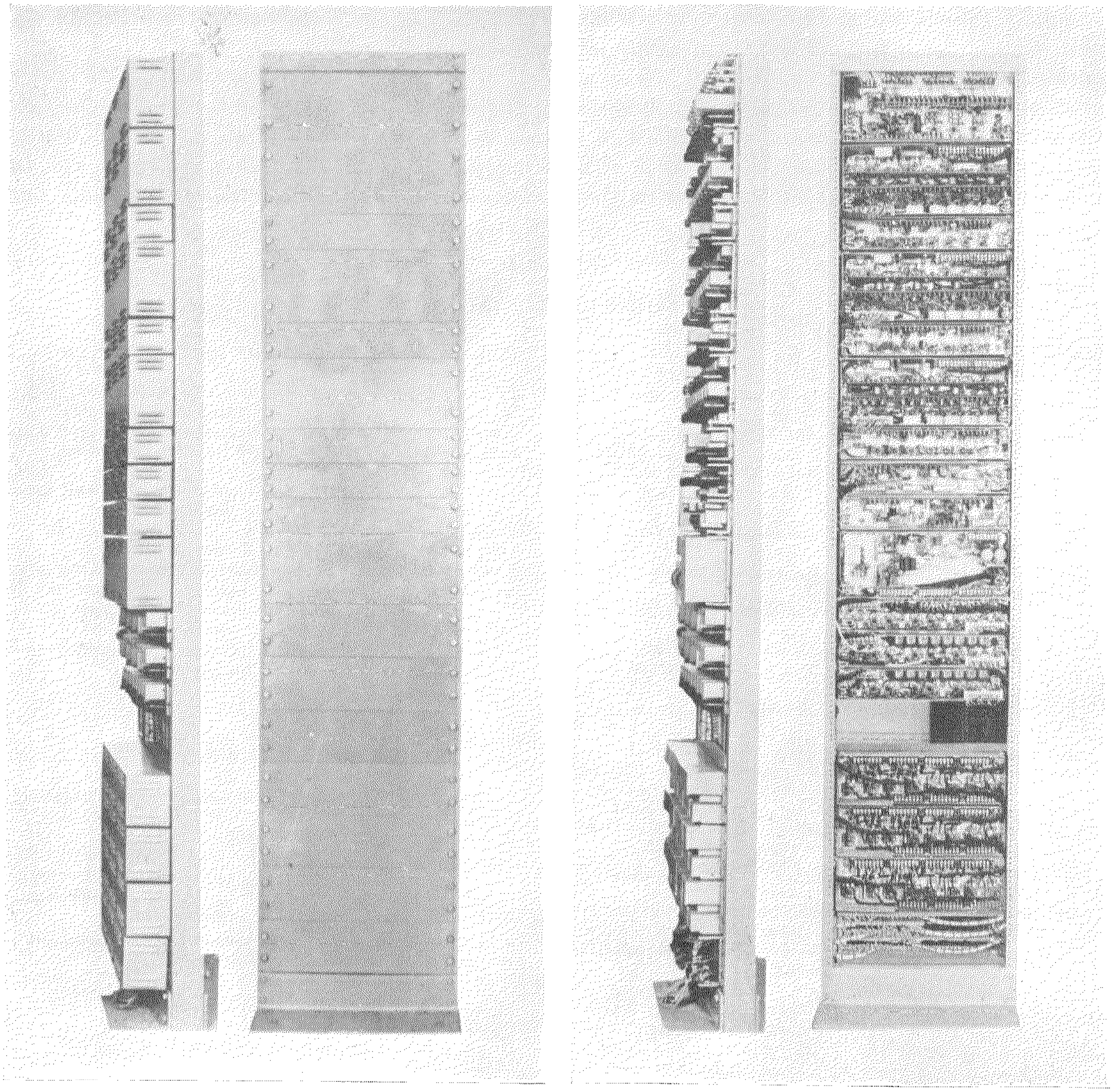

Fig. 16—Terminal equipment rack. Front and side views of multichannel rack are shown with and without dust covers and panels. The power supplies and auxiliary equipment are housed in a similar rack.

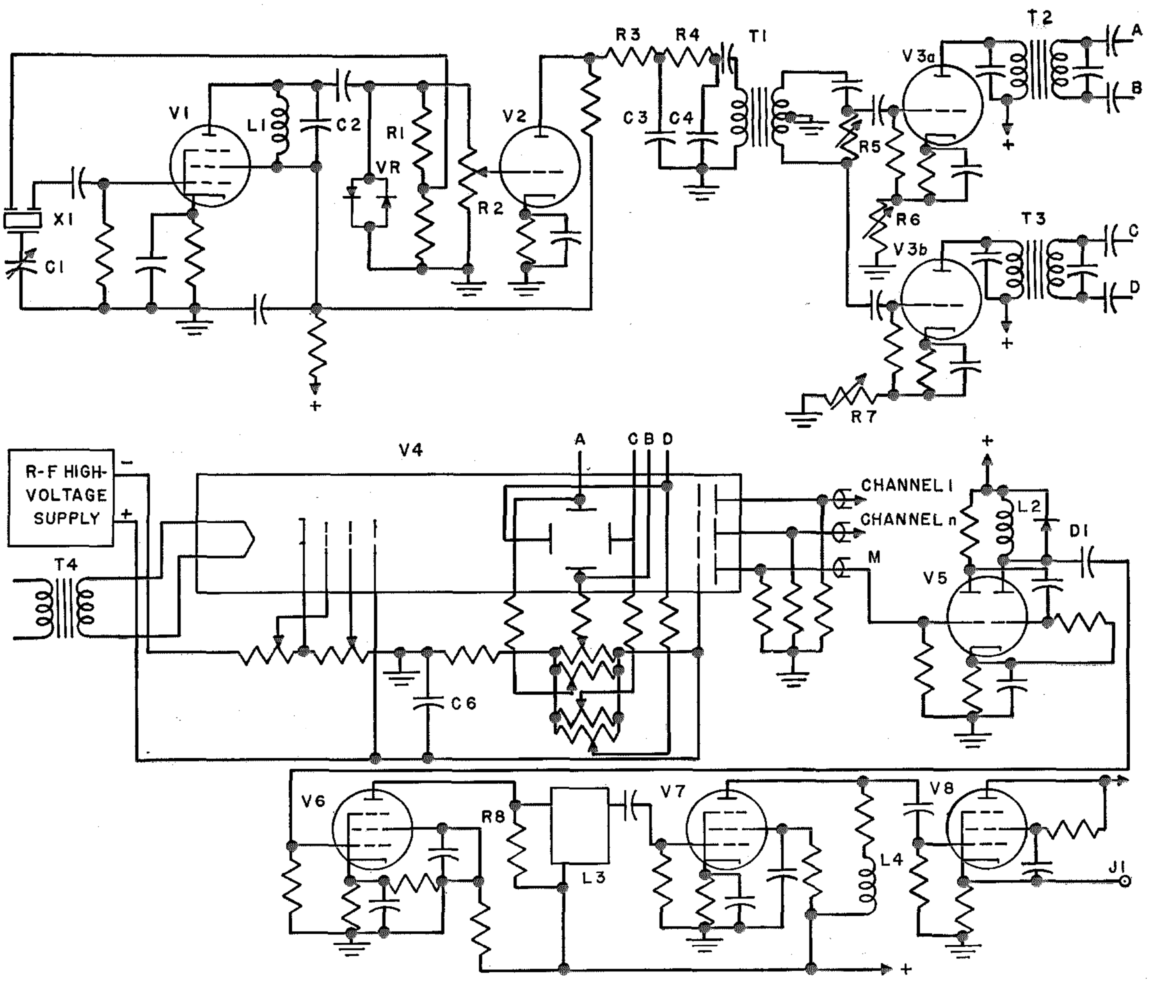

Fig. 17—Base pulse generator schematic. Includes oscillator, phase splitter, deflection amplifiers, and marker generator.

time-modulated pulse series, comprises essentially 4 types of circuit units, as follows:

a. Base pulse generator.
b. Channel modulators.
c. Channel mixers.
d. Group mixers.

3.2.1 Base Pulse Generator

A stable oscillator of the crystal type supplies the reference base frequency for the system. Special precautions against temperature changes and other extraneous effects are taken to insure maximum stability.

A schematic diagram of the base pulse generator is shown in Fig. 17. The circuit comprising V1 constitutes a bridge-stabilized crystal oscillator and supplies a base sinusoid to the phase-splitting circuits V3a and V3b. The circuits including V2 decouple the crystal oscillator and also serve as an amplifier for driving the conventional phase-splitting circuit. Tuned transformers insure maximum freedom from harmonic distortion. Quadrature voltages obtained from T2 and T3 are applied to the deflection plates of the Cyclophon at A, B, C, and D, respectively.

The circuit for the Cyclophon is similar to a standard cathode-ray-tube circuit with the usual accelerator and focusing voltages applied to the gun electrodes. With this tube, however, the aperture plate is at the same potential as the second anode and the dynode elements are operated at a somewhat lower potential. The output pulses for the various channels are obtained at channel 1, channel *n*, etc.

The base generator also includes the marker circuits which are shown in the schematic. The marker pulse obtained from the Cyclophon at *M* is applied to the grid of V5 which clips and shapes the pulse before application to the open-ended delay line L3 through tube V6. A combination of the input pulse and the reflected pulse at resistance R8 results in a double pulse marker with the separation between the individual pulses determined by the constants of the delay line. This marker is then further shaped by means of tubes V7 and V8 before application to the following group mixer. Tube V8 is also utilized as a common coupler for several other channels as well.

3.2.2 Channel Modulators

The pulses obtained from the base generator as well as the incoming voice signals are applied to the individual-channel modulators which produces a set of time-modulated pulses corresponding to the audio-frequency signal. The modulators contain the circuits which limit the maximum pulse displacement during modulation peaks. Each of 3 such units contains 8 single-channel modulators and provides for the total of 24 channels. It should be noted that the pulses produced by each single-channel modulator can be considerably wider than the ultimate transmitted pulse because of the staggering of channel pulses at this point.

Fig. 18 shows a representative schematic diagram of a single-channel modulator. The saw-tooth pulses obtained from the Cyclophon are applied through jack J1 to the clipper tube V2. The audio-frequency voltage is likewise applied to the grid of V2 through resistance R3. The combination of the saw-tooth voltage and audio-frequency signal causes the saw tooth to vary with respect to the quiescent bias conditions of V2 and results in a variable-width pulse of current applied to the inductance and diode combination L1–D3. The resulting voltage wave form set up across this circuit combination is a sharp pulse corresponding to the leading edge only, a translation into time modulation. V1 represents a coupling audio-frequency amplifier, and diodes D1 and D2 limit the audio-frequency output level to a fixed value to restrict the peak time modulation to the required value and avoid break-through on adjacent channels.

3.2.3 Channel Mixers

The individual time-modulated pulse series corresponding to the separate voice channels are

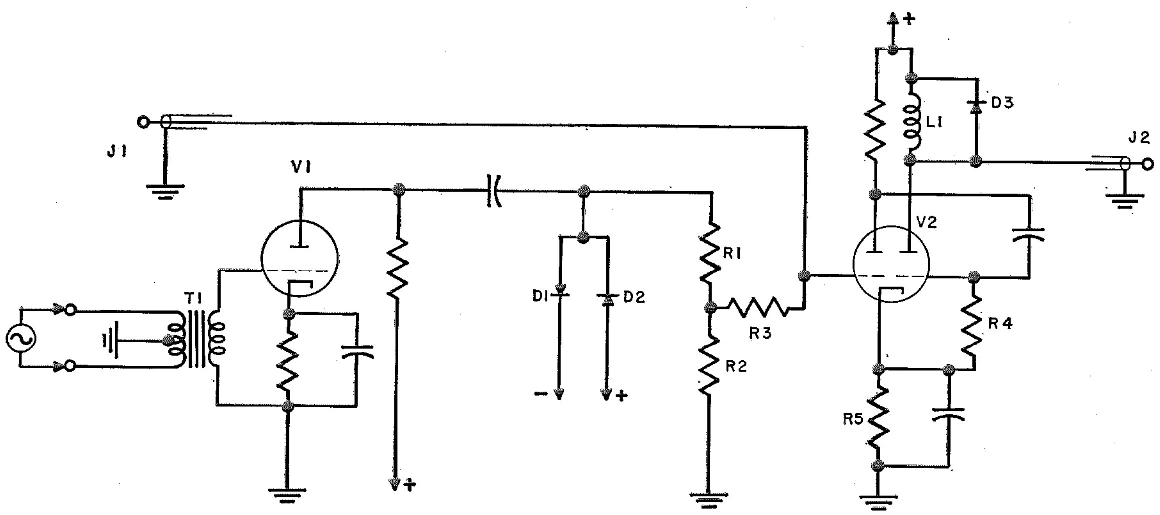

Fig. 18—Single-channel modulator schematic. The modulator includes audio amplifier, audio limiter, and pulse shaper.

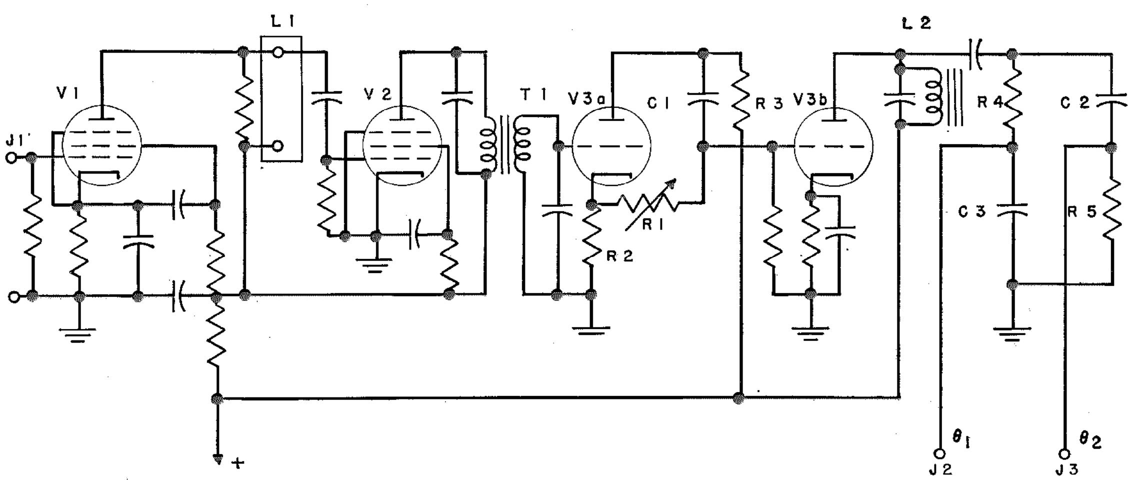

Fig. 19—Marker separator schematic. Includes limiter and phase-splitter circuits.

added together in subgroups in the channel mixers. The channel mixers contain a shaping circuit, utilizing a short-circuited delay line, which transforms the channel pulses to the ultimate shape desired for transmission.

3.2.4 Group Mixer

The 3 sets of channel groups of 8 as well as the marker pulse obtained from the base generator are added together in the group mixer. Before application of the composite pulse series to the line, amplitude inequalities among the channels are removed by a clipper stage. To present the proper low impedance to the output line so that the terminal apparatus may be located a considerable distance from the radio equipment, a cathode-follower output stage is utilized.

3.2.5 Miscellaneous

Terminal strips are provided for the 24 audio-frequency input channels to permit permanent wiring connections to be made to the incoming audio-frequency lines. Jacks are interposed between the incoming terminal and the modulator inputs. The insertion of a patch-cord plug lifts the circuit and energizes the cord to permit cross-patching.

The modulator unit is completely self-powered from the alternating-current lines. To insure maximum stability, regulated power supplies are used throughout. The design of the unit is such that variation of the input primary power source of ± 10 percent in either voltage or frequency does not affect the operating characteristics.

3.3 Multiplex Demodulator

The multiplex demodulator retranslates the time-modulated pulse series into individual audio-frequency channels. To accomplish this 3 circuit units are utilized as follows:

a. Marker separator.
b. Cyclophon demodulator.
c. Channel audio-frequency amplifiers.

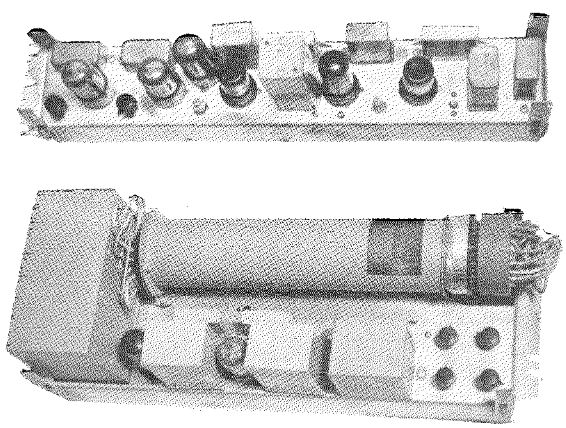

Fig. 20—Marker separator and demodulator chassis. Marker-separator chassis above and Cyclophon demodulator chassis below.

3.3.1 *Marker Separator*

The marker separator removes the marker pulse from the multiplex pulse series. This unit is designed so that "tight" synchronization is obtained at all times and is independent of voltage and tube changes. This stage also improves the signal-to-noise ratio of the received signal by the inclusion of a clipper unit.

Fig. 19 is a schematic diagram of this unit. The incoming pulse series containing the marker are applied to the open-circuited delay line L1 through coupling tube V1. The combination of the initial and reflected pulse series are applied to the clipper tube V2 which is operated as a peak rider. Since the marker represents the pulse of greatest amplitude, output of this stage contains the marker only. The marker pulse is then passed through the tuned amplifier comprising T1 and V3 which removes the fundamental pulse component and produces a sinusoid corresponding to the base repetition rate of the marker pulse. Quadratured voltages of this base sinusoid are obtained by means of the phase-shifting circuit V3a; output is taken from J2 and J3 of this stage. The separator chassis is shown in Fig. 20.

3.3.2 *Cyclophon Demodulator*

The Cyclophon demodulator shown in Fig. 20, comprises essentially the special multiplex tube previously described. This tube separates the individual channels of the pulse series and demodulates the signal.

The demodulator receives the base frequency and the time-modulated pulse series and yields the individual-channel audio-frequency outputs. Low-pass filters are provided at each channel

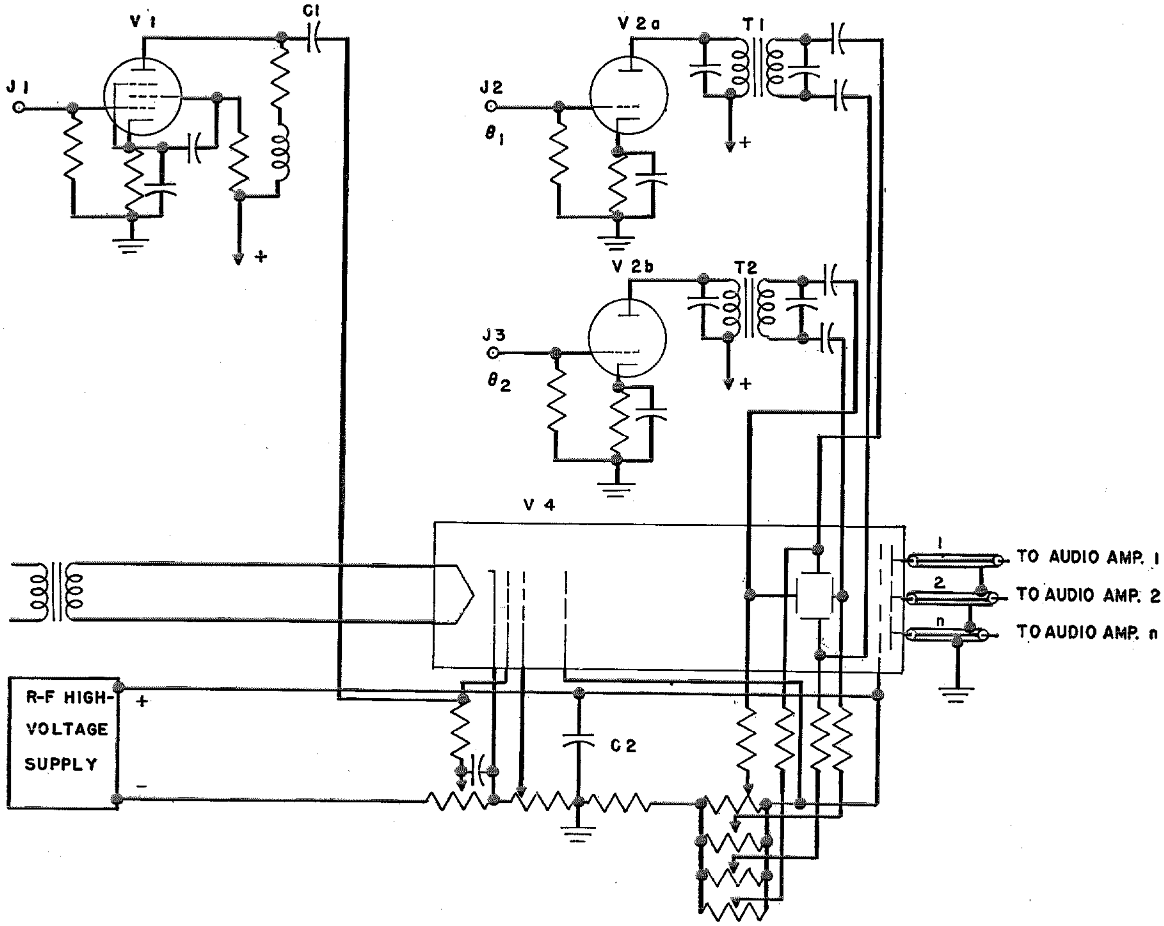

Fig. 21—Cyclophon demodulator schematic. Includes grid keying and deflection amplifiers.

output to remove high-frequency pulse components.

It can be seen from Fig. 21 that the quadrature voltages for the deflection plates and the control and focusing voltages are applied to the Cyclophon in a fashion similar to that indicated for the modulator. Pulses are applied to the grid of the Cyclophon through the coupling amplifier V1 and modulate the beam. Audio-frequency output for the different channels is obtained at the dynode elements 1, 2, 3, etc.

3.3.3 Channel Audio-Frequency Amplifiers

To provide sufficient audio-frequency output power to meet standard-level requirements, conventional audio-frequency amplifiers are utilized for each channel. Special care however is taken to avoid cross talk through common couplings.

3.3.4 Miscellaneous

The plug board and terminations in the demodulator are essentially similar to that of the modulator.

Regulated power supplies are used for all direct-voltage supply requirements. For the multiplex modulator and multiplex demodulator tubes where high direct voltage is required, a high-frequency power supply obtained from a blocking oscillator is utilized. The direct-current feeding this oscillator is obtained from a low-voltage regulated source which provides regulation for the high voltage. The use of high-frequency supply prevents hum troubles which would arise if a standard low-frequency high-voltage source were used.

3.4 Auxiliary Terminal Equipment

For normal telephone work, the multiplex equipment described provides 24 channels in each direction over a 4-wire system. If a 2-wire system is desired, a hybrid and matching line unit, wherein the transmitting and receiving voice channels are transformed into a single common line, is included.

In addition to the hybrid and terminating equipment, ringing and dialing apparatus is included. This additional apparatus comprises the direct-current amplifiers and relays necessary to transmit the direct-current dialing impulses.

With this auxiliary equipment, the channels available in the multiplex terminal behave as 24 trunk lines in conjunction with the usual line-finding and other equipment associated with an automatic exchange.

For multiplex telegraphy, the channels may be operated in the normal manner with the exception that instead of voice signals, multiplex tone frequencies corresponding to the individual telegraph transmitters are applied to the input terminals.

3.5 Controls and Operation

The control and operation of the equipment described duplicates that of the standard frequency-division-multiplex equipment. The multiplex unit is self-contained and the only external connections required are the primary power source, the input-frequency channels, the output audio-frequency channels, and the connections to and from the coaxial line or radio-frequency unit.

The goal in the design of the equipment has been to use noncritical and simple circuits to reduce service adjustments to a minimum. In addition all tubes are operated below normal ratings so the equipment will be capable of operating unattended and unserviced for long periods of time.

4 Acknowledgment

Acknowledgment is due to the early pioneers in pulse modulation, A. H. Reeves and E. M. Deloraine, who were instrumental in establishing initial principles, as well as to E. Labin who was one of the first to introduce the system in this country. Credit is also due to S. Moskowitz and other engineers and technicians of the Federal Telecommunication Laboratories who made significant contributions in the development and design of the equipment described.

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Summary

A description of the terminal equipment of a pulse-time-modulated multiplex radio relay system is given. This equipment translates the incoming voice waves into a time-modulated time-division multiplex pulse series and, at the receiving end of the circuit, accomplishes the reverse operation of translating the pulse series into individual voice signals for application to the telephone lines. Some of the advantages of this method of relay transmission include: (a) improved signal-to-noise ratio, (b) minimum cross talk between channels, (c) distortion and cross talk substantially independent of the number of repeaters, (d) constant audio-frequency output regardless of transmission vagaries, and (e) simplification of equipment.

An Ultra-High-Frequency Radio Range with Sector Identification and Simultaneous Voice*

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1 *Introduction*

THE primary purpose of a radio range for aircraft use is to provide a reliable aural or visual indication to the pilot as to his location with respect to a predetermined course. In addition, immediate and positive identification of the sector in which the airplane is at any given time; i.e., whether it is east or west of an east-west radio-range station, along with voice radiated equally in all directions from the station for communication purposes, are very desirable features.

The ultra-high-frequency radio range with sector identification and simultaneous voice represents a highly specialized recent development to fulfill the above requirements. It seems desirable, therefore, to precede its description with a brief discussion of past developments in this field.

2 *Four-Course Range and Two-Course Localizer*

2.1 Four-Course Radio Range

The conventional four-course range, whether of the low-frequency type used throughout the country, or the ultra-high-frequency type, has a radiation characteristic similar to that of Fig. 1. Two mutually perpendicular figure-eight patterns are radiated successively, one keyed with characteristic identification A(· —) and the other N(— ·), the two signals being interlocked. The course is determined by the merging of the two interlocked 1020-cycle signals. A steady 1020-cycle tone informs the pilot that he is in the "on-course" region; a definite A(· —) or N(— ·) indicates the side of the course on which the airplane is flying.

* Reprinted from *Waves and Electrons*, v. 1, pp. 9–17; January, 1946. Presented, Institute of Radio Engineers, Winter Technical Meeting, January 14, 1942, New York, New York.

† Now, Radio Research Laboratory, Harvard University, Cambridge, Massachusetts.

A limitation of this type of range is the identity of the "A" or "N" signals in opposite quadrants. As shown in Fig. 1, the same signal is received in quadrant 1 as in quadrant 3 (also quadrants 2 and 4). Information as to the airplane position with respect to the radio-range station is thus *not* conveyed to the pilot—a potentially serious cause of difficulty in case a pilot is lost and desires to fly to the nearest airport with a minimum of fuel consumption. The reader is referred to the indicated reference for further information on visual indication for orientation under instrument flight.[1]

2.2 Two-Course Localizer

With this localizer, the type installed at Indianapolis, Indiana, some five years ago and now commonly used for instrument landing, two characteristic patterns are radiated *simultaneously*

[1] P. H. Redpath and J. M. Coburn, "Air Transport Navigation" Pitman Publishing Corporation, New York, N. Y., 1943, Chapter 21, pp. 472–482.

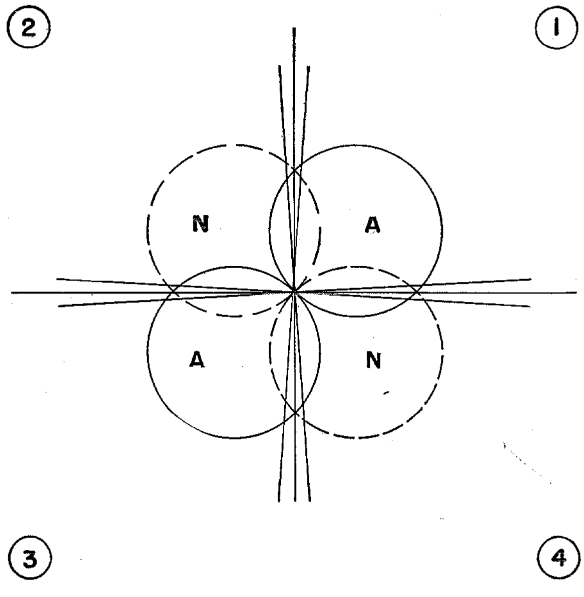


Fig. 1—Four-course radio range.

rather than successively. One pattern is modulated at 90 cycles and the other at 150 cycles. The course is determined by an indicating instrument of the zero-center type actuated by the ratio of the 90- and 150-cycle modulations. When this ratio is unity the pointer position is in the zero-center of the instrument scale, thus informing the pilot that he is "on course." Predominance of 90- or 150-cycle modulation causes the pointer to swing to the right or left, respectively, indicating "off-course" flight.

Despite the practicability of establishing a course at least three times more sharply defined than with the four-course range, the difficulty of locating position with respect to the radio-range station remains. This will be evident from Fig. 2; the same signal is received regardless of whether the airplane is in position "1" or "2" ("3" or "4"). The problem thus presented for solution was the identification of the sector at any instant so as to acquaint the pilot not only with his position with respect to the course (information which both the four-course radio range and the two-course localizer provide) but also his location with respect to the radio-range station.

3 Essential Range Requirements

Fig. 3 shows schematically the basic requirements and might represent any radio range, such as that at Indianapolis. Two indications are necessary: (1) deviation from the established

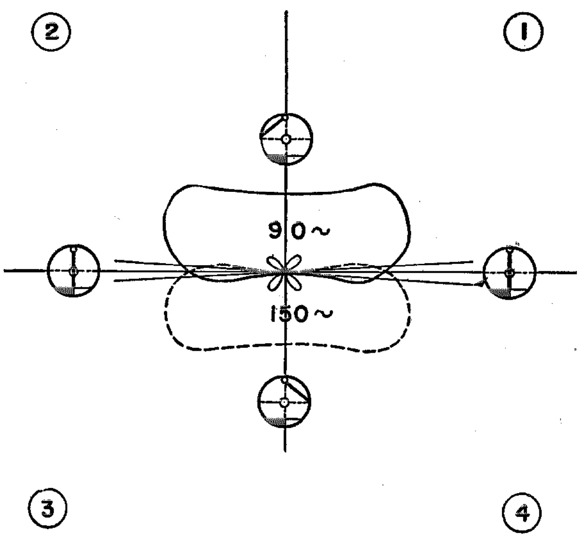


Fig. 2—Two-course localizer.

course, provided visually by a zero-center type indicator which goes off scale approximately 10 degrees each side of the course; (2) aural sector

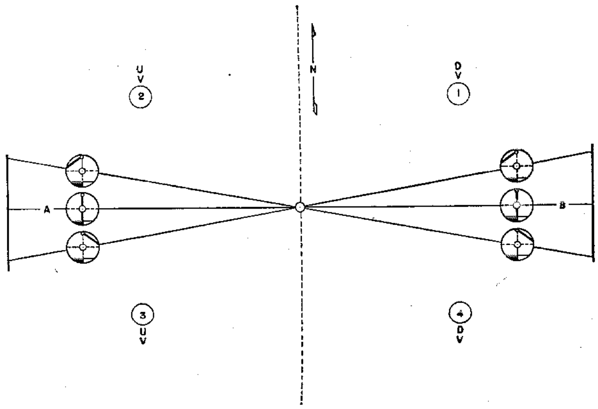


Fig. 3—Two-course radio range with sector identification and simultaneous voice.

identification; i.e., indication of the airplane position east or west of the radio-range station. In Fig. 3, the letter *V* represents voice which is radiated equally in all directions about the station.

4 Method of Solution

The solution of the signal problem of the two-course range with sector identification and simultaneous voice is indicated in Fig. 4. It is apparent from the preceding discussion that the two-course localizer provides a partial answer. Hence, two overlapping radiation patterns, modulated at 90 and 150 cycles, respectively, are transmitted simultaneously for the establishment of the east-west visual course (Fig. 4(a)). In addition, for aural sector identification, two radiation patterns are transmitted in immediate succession with interlocking D(— · ·) and U(· · —) characters; the first predominantly towards the east, and the second predominantly towards the west as in Fig. 4(b). Simultaneous voice, when applied, is radiated in a substantially circular pattern as illustrated in Fig. 4(c).

The complete radiation: aural, visual, and voice, is shown in Fig. 4(c), the relative sizes showing approximately the relative amplitudes of the aural, visual, and voice signals. The discussion concerning radiation patterns thus far refers to the sidebands only. By a process to be discussed shortly, the carrier which is common to the aural, visual, and voice signals is radiated in all directions as in Fig. 4(d). Under these conditions, Fig. 4(e) represents the total useful spectrum of the complete radio range.

5 *Antenna Problem*

The visual course radiations are produced by a group of three ultra-high-frequency loop antennas. These three antennas lie on a straight line perpendicular to the visual course with equal spacings between adjacent loops. The aural-course radiators constitute a similar array oriented 90 degrees with respect to the visual group, the center loop being common to both groups. Voice, visual, and aural sidebands and carrier are radiated circularly only by the common center loop. The loop antennas used are the type previously described.[2]

The antenna-array problem is illustrated schematically in Fig. 5. $S°$ represents the spacing of the loops in electrical degrees. With the amplitudes and spacings indicated the total radiation $F(\theta)$ in the horizontal plane is given by

$$F(\theta) = A \pm 2B \sin (S° \sin \theta). \quad (1)$$

[2] A. Alford and A. Kandoian, "Ultra-High Frequency Loop Antennae," Transactions of The American Institute of Electrical Engineers (Electrical Engineering, 1940), v. 59, pp. 843–848; 1940; and *Electrical Communication*, v. 18, pp. 255–265; April, 1940.

The choice of sign depends upon the relative phase of the outer loops with respect to the center loop and determines the particular image pattern

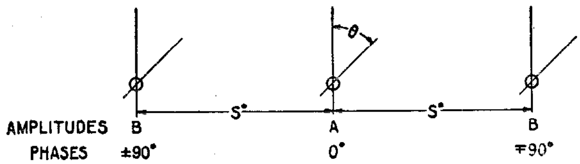


Fig. 5—Derivation of three-loop radio range.
$S°$ = spacing between loops in electrical degrees.
Radiation pattern—horizontal plane:

$$F(\theta) = A \pm 2B \sin (S° \sin \theta).$$

Visual-antenna array:

$$A = 1;\ B = 0.707;\ S = 135 \text{ degrees}.$$

Aural-antenna array: $A = 1$; $B = 0.5$; $S° = 100$ degrees.

obtained; the intersection of the two mirror-image patterns along direction $\theta = 0$ degrees and 180 degrees determines the established course. The first term A represents the radiation from the center loop; the second term, the radiation from the outer loops.

Equation (1) is generally applicable to overlapping radiation patterns. In this form, or slightly modified and expanded, it may be applied to a variety of radio-range and localizer antenna arrays.

For the case of the visual and aural arrays, the requirements impose a division of power between the center and outer loops of $A = 1$ and $B = \frac{1}{2}$ with $S = 120$ degrees. These values give an infinite clearance at angles of ± 48.6 degrees to either course, where clearance is defined as the ratio of the field strength of one mirror-image pattern to the other at any selected distance from the station.

Fig. 6 shows the visual- and aural-sideband radiation diagrams for the values of

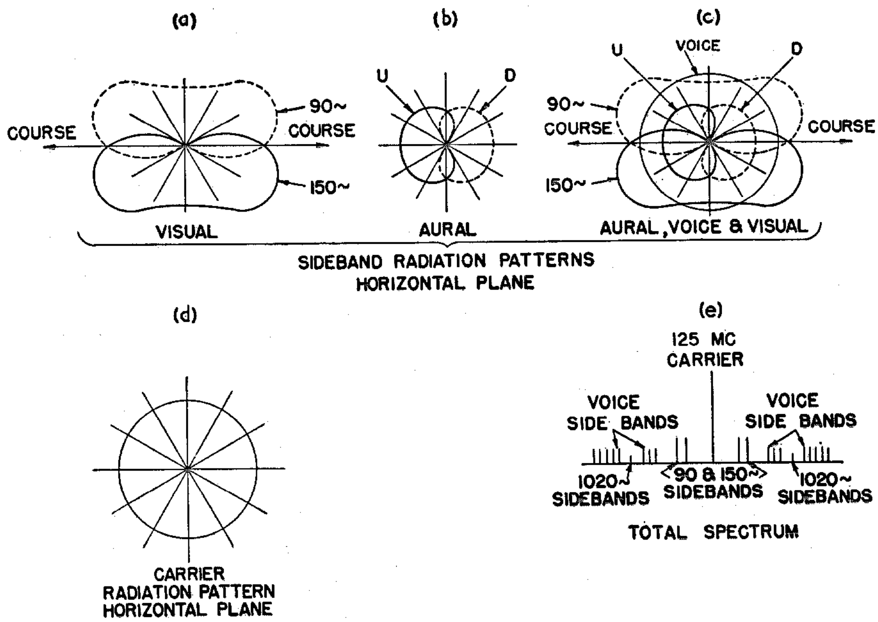


Fig. 4—Components of complete radiation.

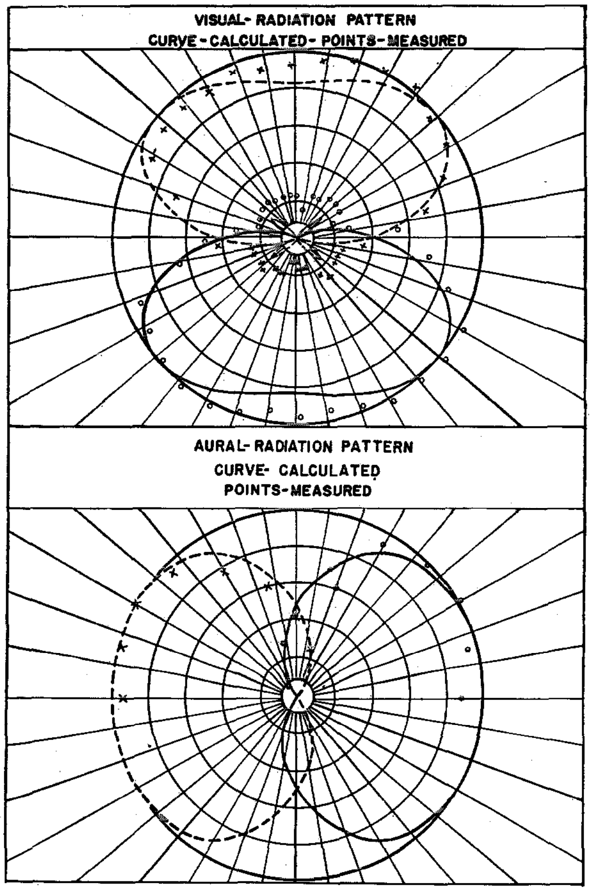


Fig. 6—Comparison of visual- and aural-radiation patterns.

A and *B* indicated in Fig. 5. This choice of current ratios and spacings is not the one used in the final range installation, but has been included to illustrate the effect of antenna spacings and current ratios on the radiation patterns.

5.1 Aural Array

The circuit of the aural antenna system is illustrated in Fig. 7. By keying at the indicated location, the phase of the two outer loops is reversed with respect to the phase of the center loop; hence, the desired mirror-image patterns are obtained alternately. In one radio-frequency keyer position, radiation occurs predominantly toward the east and the keyed identification is *D*. In the opposite position, radiation occurs predominantly toward the west and the keyed identification is *U*. Two separate antenna systems for radiating the two characteristic patterns consequently are avoided, inasmuch as the separate patterns are obtained at will by a simple phase reversal.

In this type of array, the problem of interaction between the various radiators must be considered. Since the outer loops have equal currents of opposite phase they do not induce any current in the center loop. The center loop, however, may excite the outer loops parasitically. This parasitic action can be controlled and made useful for certain applications. In the present case, however, it is undesirable and hence the relationship $EF = FG \cong \lambda/2$ is maintained (Fig. 7). This places a virtual short circuit at terminals *E* and *G* for parasitic currents, and detunes these loops insofar as parasitic action is concerned.

5.2 Visual Array

Fig. 8 depicts the visual antenna system which is similar to the aural array except that its position is oriented 90 degrees from the visual position. In this case, however, the two characteristic patterns must be transmitted simultaneously, rather than successively, so that a special network is required.

This network, a transmission-line bridge, is indicated diagrammatically in Fig. 8. The 90- and 150-cycle modulations are fed into opposite terminals of the network and arrive at the center loop in phase; but because of the phase reversal in the arm of the bridge, they reach the outer loops in opposite phase. This results in the simultaneous mirror-image patterns, one with 90-cycle and the other with 150-cycle modulation.

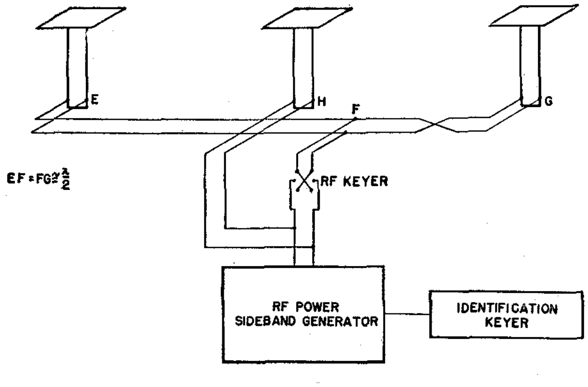


Fig. 7—Aural-antenna network.

The bridge circuit possesses another important advantage. At each of its two input terminals, in addition to the 90-cycle and 150-cycle sidebands,

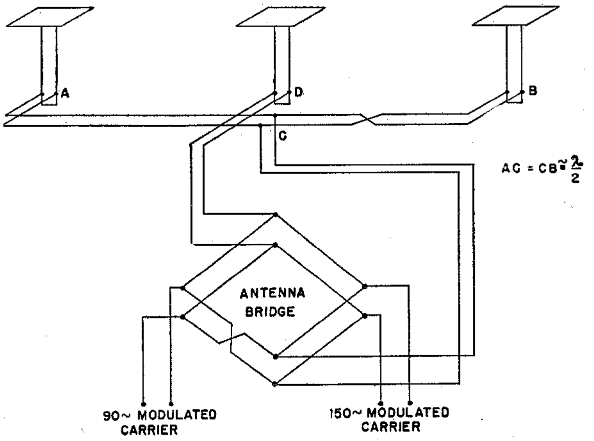


Fig. 8—Antenna network, two-course visual radio range.

there is present the 125-megacycle carrier, which arrives at the respective input terminals of the bridge in phase. At the terminals leading to the outer loops, however, the carriers cancel out because of the previously mentioned phase reversal in one arm of the bridge. Contrariwise, at the center-loop terminals, the carriers are in phase and are therefore additive. Hence, no mirror-image patterns exist insofar as the carrier is concerned; the carrier is radiated only from the center loop equally in all directions. The sideband power, however, divides equally between the center and the outer antennas and makes possible the radiation patterns already described.

The transmission-line bridge thus serves three highly important functions: (a) the realization of two different radiation patterns from a single antenna array; (b) the removal of the sidebands from the carrier of two modulated waves of the same carrier frequency without any power dissipation; and (c) the radiation of the total carrier energy solely from the center loop with uniform circular distribution.

6 Modulation Problem

6.1 Visual Modulation

The problem of obtaining two equal sources of radio-frequency power modulated at 90 and 150 cycles, respectively, requires careful consideration. Early in the development of radio ranges it became evident that two separate transmitter output stages, each with its own modulation, was not satisfactory. This was due to the fact that variation of one output stage with respect to the other resulting from a change in tube emission, or any other reason, would alter the established course correspondingly. It was necessary, therefore, to divide the transmitter carrier output into two equal parts and modulate each half separately by means not subject to difficulties arising from change of tube emission. Mechanical modulation, consequently, was adopted.

The schematic diagram of the mechanical modulator is shown in Fig. 9. It will be seen that the transmitter output is divided into two channels with a resonant quarter-wave section coupled to each. Under these conditions, the coupled sections effectively short-circuit the transmission line to the antennas.[3] These

[3] Andrew Alford, "Coupled Networks in Radio-Frequency Circuits," Proceedings of the I.R.E., v. 29, pp. 55–70; February, 1941.

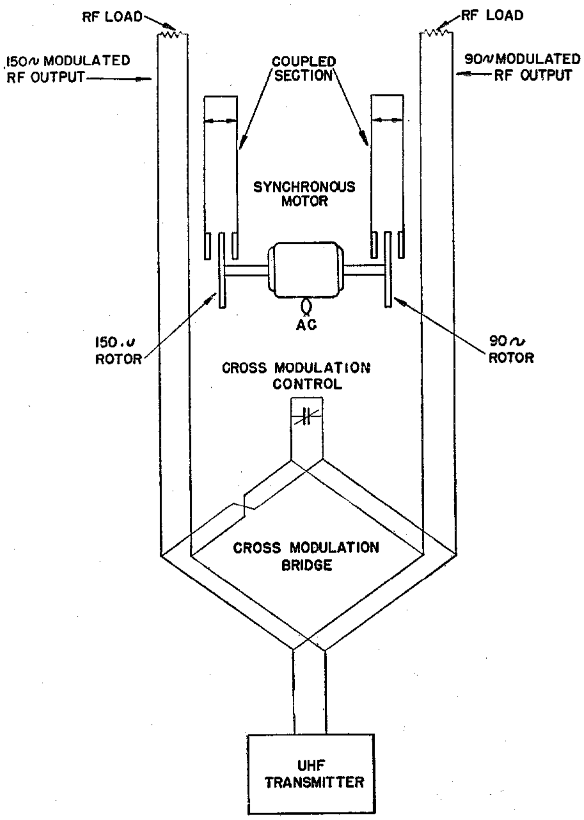


Fig. 9—Ultra-high-frequency mechanical modulator.

resonant sections are detuned periodically by 3- and 5-blade paddle wheels rotating at 1800 revolutions per minute. Thus the resulting output of each channel is modulated 100 per cent. By tuning the sections so that resonance is approached but not reached, any lesser degree of modulation may be obtained.

In arbitrarily dividing the output of a transmitter into two channels, special precautions are required to prevent cross modulation when the impedance of a channel varies during the modulation cycle. For this purpose the transmission-line bridge again proves to be a versatile tool. By varying the impedance at the terminal opposite the transmitting end, it is possible to make each branch entirely independent of the other, and hence obtain substantially zero cross modulation. It is, moreover, not difficult to show experimentally that no power need be lost in the bridge-terminating network to obtain negligible, less than 1 percent, cross modulation between channels.

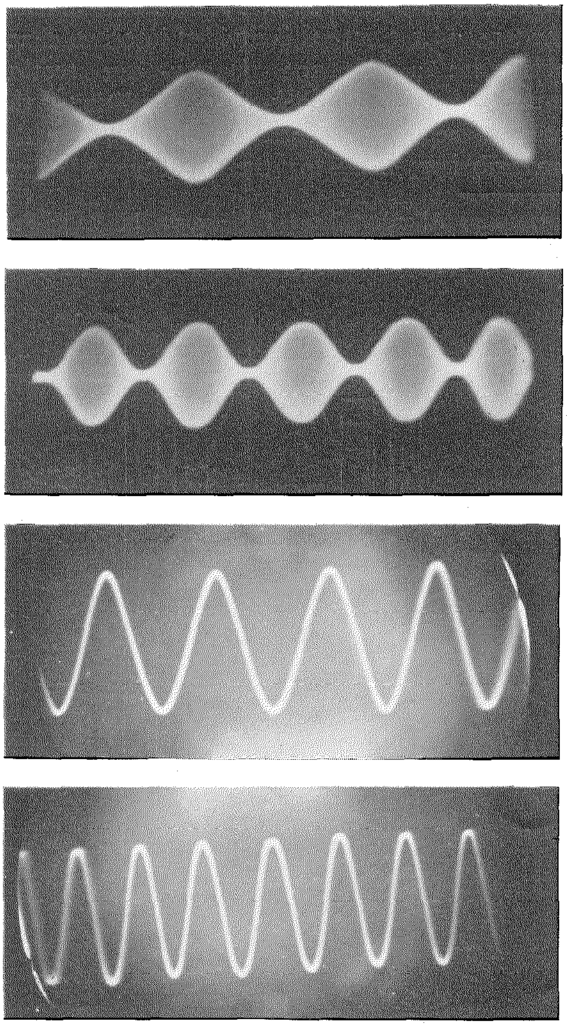


Fig. 10—Waveform from mechanical modulator.

a. 90-cycle modulation radio-frequency envelope.
b. 150-cycle modulation radio-frequency envelope.
c. Detected 90 cycles.
d. Detected 150 cycles.

The tendency prevails to associate mechanical modulation with jagged, distorted, or at least square-wave modulation rich in harmonic content. In the present case, however, this type of wave configuration is decidedly not obtained, as will be evident from Fig. 10, showing representative results. It is, in fact, not difficult to limit the total distortion of each channel to less than 10 percent and, with somewhat more care, to less than 5 percent.

6.2 Aural and Voice Modulation

The present method for application of aural and voice modulation is a result of several years development and experimentation. Throughout these years of growth leading to the present radio range, several methods were employed to achieve this addition. It seems logical, therefore, to describe the three major methods in the order in which they occurred.

Initially, only aural modulation without voice was used to obtain sector identification. In the adaptations to be described later, voice is added to the total radiated spectrum.

It is evident if a separate carrier were used for the aural portion of the radio range, and the radiation directed by means of the radio-frequency relay first to the east, then to the west, the total carrier available at the receiver would fluctuate, and hence the automatic volume control of the receiver would be affected. This would cause "kicking" on the visual course-indicating instrument each time the aural signal was keyed. It follows, therefore, that some means must be provided to transmit only 1020-cycle sidebands for the aural signal and to make use of the already existing circularly radiated carrier from the visual-instrument course.

To accomplish these results, the aural-channel facilities employ a sideband generator giving an output predominance of sideband to carrier of

30 to 40 decibels depending on the care exercised in adjustment. At the output of the sideband generator, a phaser is provided to obtain the correct phase relationship between the sidebands thus produced and the carrier from the main transmitter.

Since a carrier common to both the aural and visual modulation is utilized, it is not desirable to modulate the carrier in the mechanical modulator 100 percent.

This modulation, therefore, is reduced to approximately 70 percent and the aural signal then modulates the remaining 30 percent.

6.3 Interaction Problem

6.3.1 *Method I*

The block schematic diagram of Method I of the two-course radio range with sector identification is shown in Fig. 11. The visual and aural loops shown in this illustration are positioned

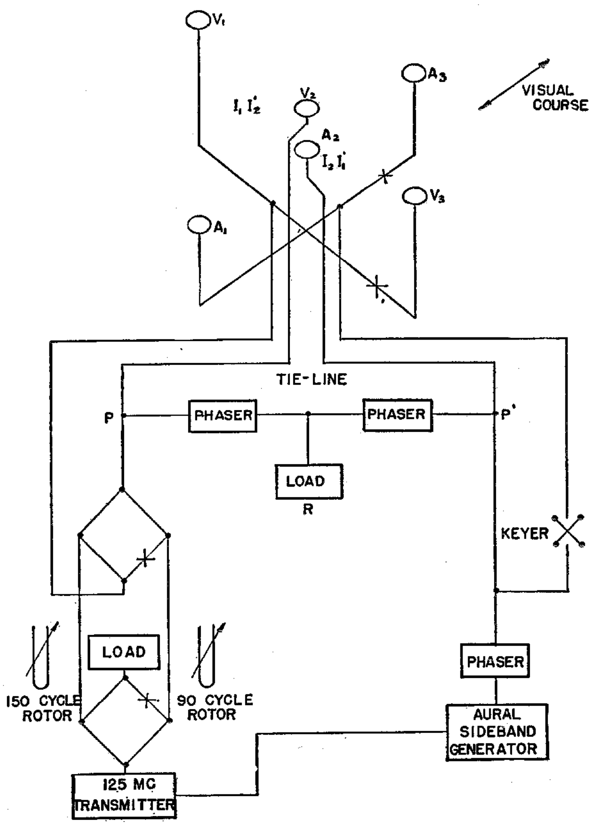


Fig. 11—Method I, schematic visual and aural system.
A_1, A_2, A_3 = aural loops.
V_1, V_2, V_3 = visual loops.

above a metallic counterpoise. The visual loops are placed a half wave above the counterpoise and the aural loops slightly more than one

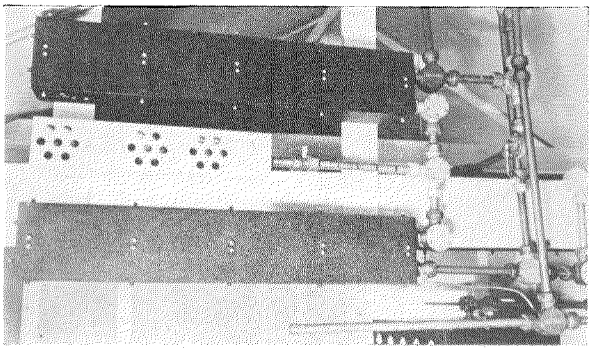


Fig. 12—Tie line used in Method I to prevent interaction between aural and visual antenna systems.

quarter. From previous discussion it is clear that the four outer loops induce no currents in the center loops. The center two loops, on the other hand, do not induce currents in the outer loops because these loops are detuned for parasitic current, since in Figs. 7 and 8

$$AC = CB = EF = FG \cong 180 \text{ degrees.}$$

Thus care is taken of all interaction, except that between the two center loops, one mounted above the other. The coupling between these two loops is serious because the visual signal will get into the radio-frequency relay in the aural circuit; furthermore, the aural sidebands would feed back into the mechanical modulator. Thus, a great deal of undesirable interaction between the aural and visual systems would result.

These difficulties are overcome by means of a properly designed tie line such as the one shown in Fig. 11. The installed tie line is shown in Fig. 12. The general function of the line is to borrow power from the source and control it in phase and amplitude so as to neutralize the unwanted voltage at a specific point.

The design considerations will be clear from the following: assume the directly fed current in the visual center loop V_2 (Fig. 11) is represented by I_1 and the induced current in the center aural loop A_2 is I_1'. If, now, a short circuit is applied along the feeder to the lower loop, it is evident that I_1' can be controlled in amplitude and to a certain extent in phase. In fact I_1' can be made negligibly small by placing the short circuit at the correct location P'. In practice, instead of an actual short circuit, a virtual short circuit is produced by means of the tie line. As a result, the top center loop is made substantially independent of the lower center loop. Conversely, point P can be located on the visual center-loop feeder in a manner such as to neutralize all the current induced in the top loop by the lower loop. The tie line, to be effective, requires a minimum of two controls: one for change of phase and another for amplitude. For phase control, some resistance is necessary in the circuit. Optimum design dictates very low power dissipation; but, with negligible power loss, tuning of the line becomes critical. A power dissipation of approximately 10 percent in the resistance load T (Fig. 11) results in adjustments that are readily made and stay put indefinitely.

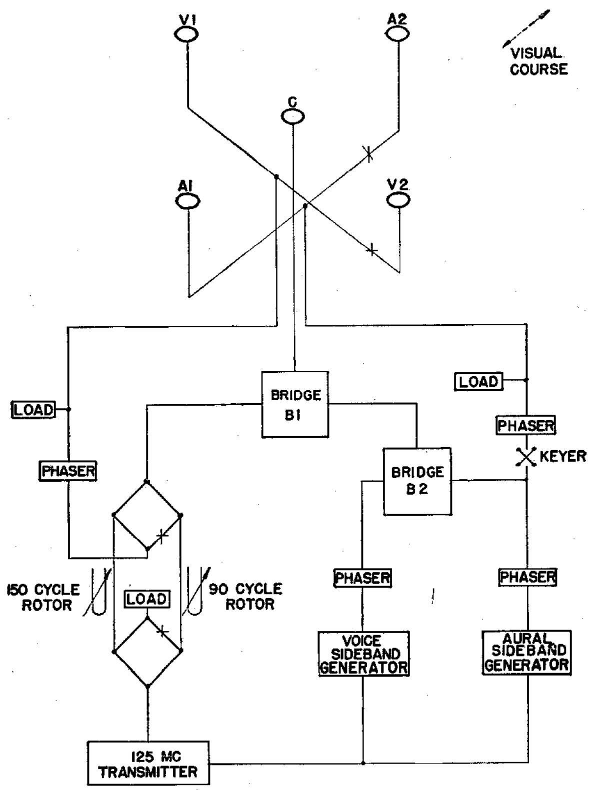


Fig. 13—Method II, schematic visual, voice, and aural system.

A_1, A_2, C = aural loops.
V_1, V_2, C = visual loops.
C = voice loop.

Method I had the following disadvantages which resulted in its replacement by Method II: (1) the tie line employed for the prevention of interaction between the center loops did not lend itself to adjustment by a maintenance man; and (2) the lower height of the outside aural loops above the metallic counterpoise gave rise to a radiated vertical component along the visual course. This vertical component occurred due to reradiation from a high current concentration induced in the metallic counterpoise below the center aural loop by the outside aural loops. In such an ultra-high-frequency radio range utilizing horizontal polarization, freedom from any vertical polarization is highly essential if the course is to be independent of the attitude of the airplane. If the course is dependent on the attitude of the airplane, a flight phenomenon known as "pushing" occurs, and the plane will zig-zag about the course in attempting to follow it.

6.3.2 Method II

A block schematic of the second method appears in Fig. 13. This differs from the previous method by the addition of voice to the system and the elimination of one center loop antenna and associated tie line.

The use of a bridge permits one antenna to be energized by two different sources without interaction between them. This ability of the bridge is utilized to excite a single center loop by both the visual and the combined aural and voice channels,[4] as illustrated in Fig. 13. The bridge B_1 also prevents either channel from feeding into the other.

Another bridge B_2 is used to apply voice. The voice facilities consist of an additional sideband generator and modulator. A phaser is provided at the output of each sideband generator to place the sidebands in the proper phase relation with the carrier at the output of bridge B_1 feeding the center antenna.

The voice sidebands do not feed into the aural outside antennas, due to the action of the bridge B_2. Likewise, the aural sidebands cannot reach the output of the voice generator.

Initially, the voice sideband generator was modulated by a 20-kilocycle subcarrier. This 20-

[4] The use of the transmission-line bridge in this manner was first suggested by Mr. W. E. Jackson, chief of the Radio Development Section of the Civil Aeronautics Administration.

kilocycle subcarrier was modulated with voice. The voice facilities were later provided with a switching arrangement to permit an instantaneous change from voice on the subcarrier to voice directly on the main carrier. This permitted a close comparison during actual flight tests. With voice directly on the main carrier, a 1020-cycle rejection and a high-pass filter were provided in the voice channel to prevent any disturbance in the visual and aural courses with voice modulation. Flight checks showed equivalent results between the two methods of voice modulation.

The loads on the outside antenna feed lines shown in Fig. 13 are used to dissipate an amount of sideband energy necessary to give the proper power ratio in the outside loops to the center loop.

Method II had one inherent disadvantage. Half of the total carrier power was dissipated in the load terminating the bridge B_1. As a consequence, Method II was replaced by Method III.

6.3.3 *Method III*

The final system used utilizes an adaptation of the mechanical-modulator bridge arrangement to the aural and voice channels. The sideband generators used in the previous method have been replaced by two 35-watt radio-frequency amplifiers (No. 1 and No. 2), shown in Fig. 14. Amplifier No. 1 is modulated with voice plus 1020 cycles, while amplifier No. 2 is modulated with voice only. The percentage of voice modulation on the equal carrier outputs of each radio-frequency amplifier is the same. As a result, the voice sidebands and carriers cancel out at the terminals of bridge B_2 feeding the outside aural antennas. The 1020-cycle sidebands of amplifier No. 1 divide equally between the center- and aural-antenna feed lines.

Since no crossover exists in the arms terminating in the upper junction of bridge B_2, the carriers and voice sidebands of both amplifiers add. The carrier power dissipation at bridge B_1 is now a small fraction of that dissipated in Method II. The sideband generators, which require careful adjustment, have been replaced by straightforward radio-frequency amplifiers.

The percentage modulation of each channel on the carrier is approximately 50 percent for the visual, 35 percent for the voice, and 15 percent for the aural sidebands. These values were found optimum by actual flight tests.

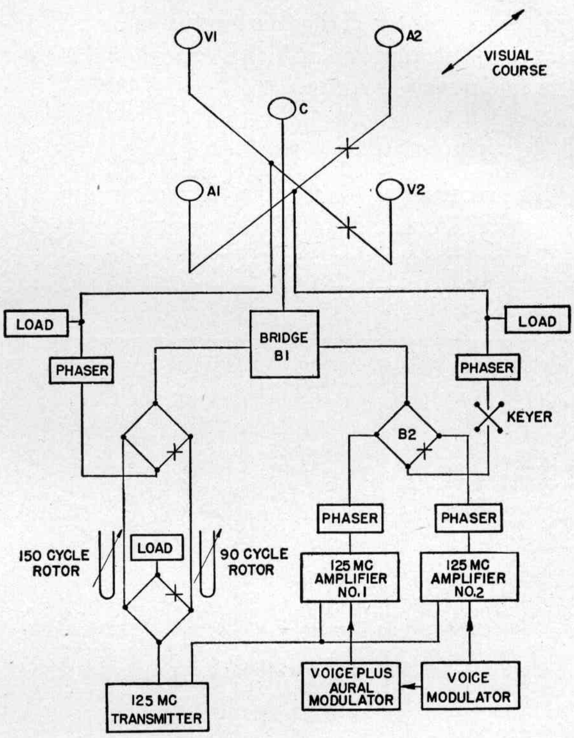


Fig. 14—Method III, schematic visual, aural, and voice system.

V1, V2, C **= visual loops.**
A1, A2, C **= aural loops.**
C **= voice loop.**

7 *Marker (125.020-Megacycle)*

A problem which presented itself, when flight checks were begun on this radio range, was irregularity of pointer indication when the plane flew at high vertical angles with respect to the transmitting equipment. This was due to lack of directly radiated signals, since the loop antennas have substantially zero radiation vertically. The receiver in the plane, because of its automatic-volume-control characteristic, became very sensitive and picked up whatever stray signal existed and hence gave irregular pointer indication.

Several possible solutions were discussed with the Civil Aeronautics Administration personnel, and, as a result, a special marker was used to overcome this difficulty. Fig. 15 shows the marker array which is fed from an auxiliary 30-watt transmitter removed in frequency from the main transmitter by approximately 20 kilocycles. This signal has no modulation and serves merely to radiate carrier straight up in order to steady the cross-pointer indicator and silence the receiver in the airplane at high vertical angles over the radio-range station.

8 *Equipment*

The receiver, designed for this radio range, is a Western Electric type RUM crystal-controlled 125-megacycle superheterodyne with an intermediate frequency of 10 megacycles. A high-pass

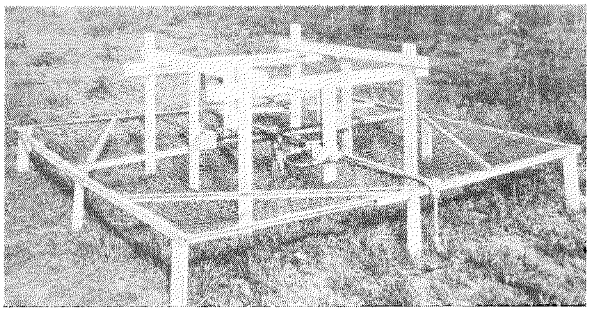


Fig. 15—125.020-megacycle marker antenna array.

filter, above 150 cycles with 1020-cycle rejection, in conjunction with a 90- and 150-cycle pass filter and a 1020-cycle pass filter, were inserted in the audio channel to separate the aural and voice signals from the 90- and 150-cycle visual signals. A more recent receiver, the Western Electric type 32A, has also been used in flight checks with very satisfactory results. The course indication is provided by a Weston cross-pointer

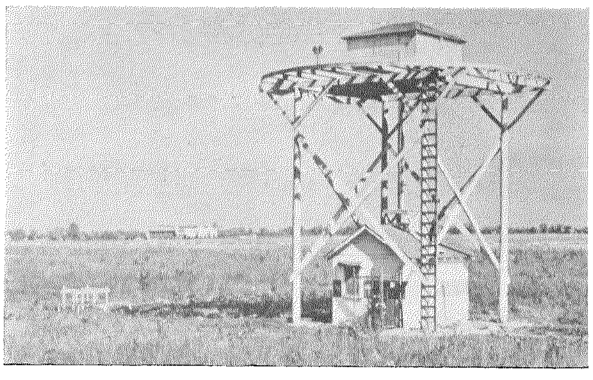


Fig. 16—Two-course radio range with sector identification and simultaneous voice, showing transmitter house, counterpoise structure, antenna house, and 125.020-megacycle marker.

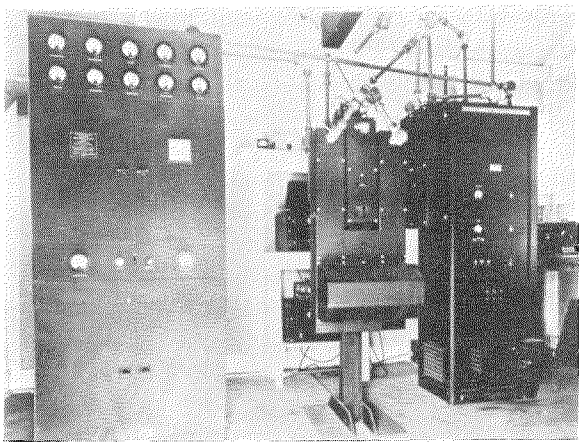


Fig. 17—Transmitting equipment, showing left to right, 125-megacycle, 300-watt transmitter, mechanical modulator, and sideband generator. Auxiliary marker transmitter is in the background.

instrument, the vertical pointer of which is utilized as illustrated in Fig. 2. The cross-pointer instrument is used in conjunction with 90- and 150-cycle pass filters in parallel. The outputs of the filters are rectified to actuate the meter. With a predominance of 90-cycle modulation, the vertical pointer deflects to the right of its "on

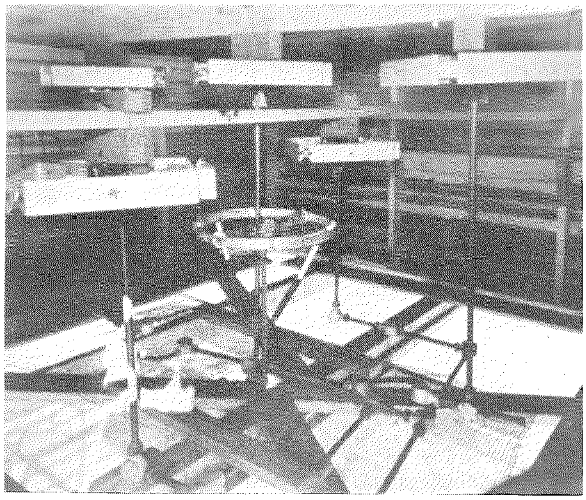


Fig. 18—Visual and aural loop antennas mounted above metal counterpoise.

course" or center position, while a predominance of 150-cycle modulation swings the pointer to the left. The receiving loop antenna on the airplane is similar to the type used for instrument landing.[5]

[5] P. C. Sandretto, "Principles of Aeronautical Radio Engineering," McGraw-Hill Book Company, Inc., New York, N. Y., 1942, Chapter III, pp. 100–105.

Figs. 16, 17, 18, 19, and 20 show views of the complete radio range, the transmitting equipment, antennas, and the airplane equipment comprised in the radio range.

Fig. 19—Civil Aeronautics Administration Boeing used in flight checks, showing receiving loop antenna.

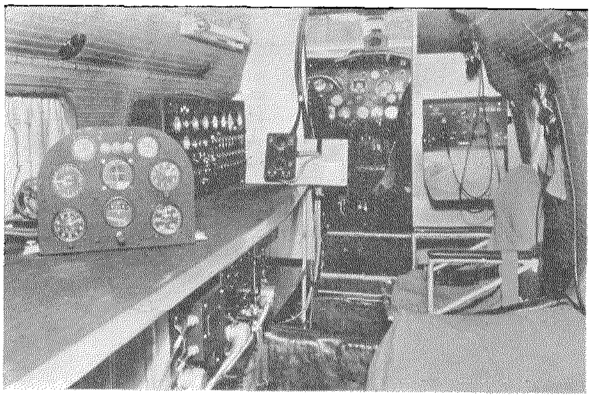


Fig. 20—Cabin view of Civil Aeronautics Administration Boeing ready for demonstration flights.

9 *Acknowledgment*

The help and co-operation of the Radio Development Section of the Civil Aeronautics Administration and particularly the personnel of the Civil Aeronautics Administration Experimental Station of Indianapolis, Indiana, is gratefully acknowledged.

Summary

The primary purpose of a radio range for aircraft use is to provide a reliable indication to the pilot of an airplane as to his location with respect to a predetermined course. In addition, it is very desirable to identify quickly and positively the sector in which the airplane is at any given time; i.e., whether it is east or west of an east-west radio-range station. Voice radiated omnidirectionally is also desirable for ground-to-plane communication.

The basis of the radio-range design described herein is the two-course localizer used in instrument landing. A group of three loop radiators provides two overlapping mirror-image patterns modulated at 90 and 150 cycles, respectively. A cross-pointer instrument, the vertical pointer of which is actuated differentially by the 90- and 150-cycle modulation, provides the pilot with the necessary information for orienting his plane.

A second pair of outside radiators, similar but at right angles to the first group, in conjunction with the center radiator, which is common to both the aural and visual systems, provides a keyed signal for aural sector identification. Except for the carrier radiation which is common to both the aural and visual signals, the two systems are entirely independent. Voice is radiated only by the center antenna.

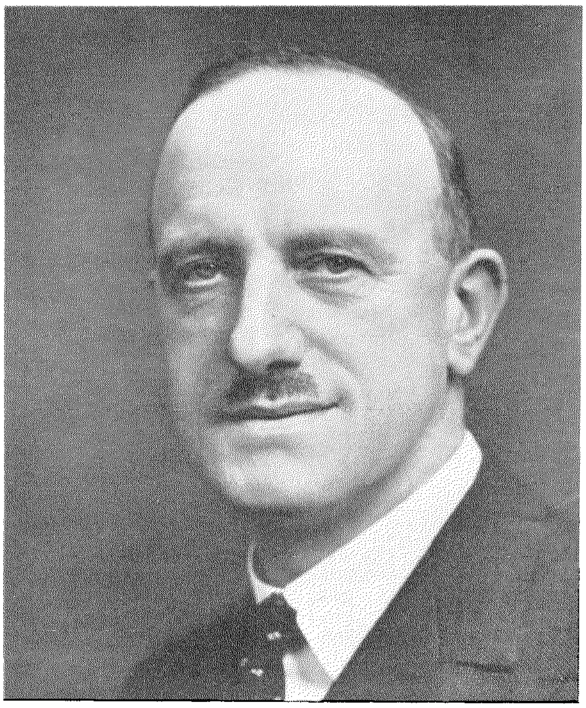
The theory of the antenna system is discussed in this paper, paying particular attention to the problem of interaction between the aural, visual and voice radiating systems. The various stages of development leading up to the final range installation at the Civil Aeronautics Administration Experimental Station in Indianapolis are given.

Sir Thomas G. Spencer, Sir Francis J. E. Brake, and Sir Norman V. Kipping

AT Buckingham Palace, London, on March 12th, 1946, the accolade of Knighthood was conferred by His Majesty King George VI on three distinguished members of I.T.&T. associate companies in Great Britain: Sir Thomas G. Spencer, Sir Francis J. E. Brake, and Sir Norman V. Kipping. The awards were made for exceptionally valuable service to their country in World War II.

Sir Thomas G. Spencer

T. G. Spencer, M.I.E.E., M.I.P.E., M.A.I.-E.E., Managing Director of Standard Telephones & Cables, Ltd., London, and Vice President of International Standard Electric Corporation, was created a Knight Bachelor in the British New Year Honours List in recognition of his contribution to the prosecution of the war.



Joining the London Company 38 years ago, he was prominently associated with much of the early development of manufactures in the communication field, particularly on the cable side as Chief Cable Engineer and Manager of the North Woolwich Cable Works.

As Assistant European General Superintendent and subsequently as European Engineer of Manufacture he travelled widely on the Continent, and during this period was actively concerned with the organisation and supervision of many factories, all of which had to be equipped and brought to manufacturing activity.

Sir Thomas is associated with many industrial organisations and committees. He has served as Chairman of the Telephone Equipment Manufacturers' Association, is a member of the Board of Management of the Engineering and Allied Employers' Federation, a member of the London Chamber of Commerce, and a member of the Council of the Cable Makers' Association, of which he is a former chairman.

His long standing interest in technical education is reflected in his governorship of the Technical College, Woolwich. Athletic sports also claim a share of his interest, and he is President of the Polytechnic Union, an organisation which embraces a nationwide chain devoted to all branches of athletics.

Sir Francis J. E. Brake

Managing Director of Creed and Company, Ltd., Croydon, and Vice President of International Standard Electric Corporation, Sir Francis received the honor of Knight Bachelor for services rendered in connection with the building up and maintenance of supplies of equipment for the Royal Air Force during the war.

Invited in May 1940 by Lord Beaverbrook to join the Ministry of Aircraft Production, Sir Francis was appointed to a small committee for organising adequate supplies of aircraft equipment to the Royal Air Force. His duty was to safeguard production by arranging for dispersal of major aircraft and equipment factories, also to organise alternative sources of supply.

His appointment as Deputy Controller and later as Controller of Construction and Regional

Services led to still heavier responsibilities. As a member of the Air Supply Board he shared with the other members of the Board responsibility for the capital expenditure incurred by the Aircraft Industry, as well as establishment for the R.A.F. of equipment preservation and packaging

methods in the tropics. As Chairman of an Inter-Service Committee, Sir Francis has assisted in co-ordinating this latter activity among all three fighting services.

Despite the duties which he undertook for the M.A.P., Sir Francis retained in the fullest degree his active personal direction of Creed & Co., Ltd. during the whole of the war period.

Sir Francis' career includes over 30 years experience in the field of telecommunications, as well as $4\frac{1}{2}$ years' military service during the 1914–1918 world war. He is a Director of Standard Telephones & Cables, Ltd., and of the International Marine Radio Company. He also is a member of the Institution of Electrical Engineers, a Freeman of the City of London, and a Member of the Worshipful Company of Gold and Silver Wire Drawers, one of the centuries-old Trades Guilds associated with the City of London.

Sir Norman V. Kipping

For his services in the war Norman V. Kipping, formerly Works Manager at the New Southgate plant of Standard Telephones and Cables, Ltd., London, was created a Knight Bachelor.

Associated with the Standard organisation since 1922, first in the European Engineering Department and later in the Manufacturing Department, he became Technical Superintendent early in 1928. By 1929 he was appointed Engineer of Manufacture and played an important part in the large-scale overall planning for the design of new factories. In 1933 he assumed control of the New Southgate factory of S.T. & C., then being reorganised and expanded to accommodate manufacturing activities formerly carried out at the Hendon factory. From that time onwards he figured prominently in the expansion of the New Southgate plant which for size and up-to-date layout is a model of its kind.

Seconded to a post in the Ministry of Supply in January 1942, he contributed materially to the successful prosecution of the war, at the end of which he was Head of the Regional Division of the Ministry of Production. Recently he was appointed to the important post of Director-General of the Federation of British Industries.

Rotary Traffic Machine

By Dr. Ir. J. KRUITHOF

Bell Telephone Manufacturing Company, Antwerp, Belgium

1 Introduction

ENGINEERS engaged in building automatic telephone exchanges face the limitation that only a part of the chance problems have been solved by the application of the calculus of probabilities.

This condition gave rise to a quest for practical methods of verifying the various existing probability formulas and possibly of obtaining solutions to problems hitherto unsolved.

A rather simple and obvious method is to prepare a haphazard traffic distribution of the required density by means of a logarithmic table or telephone guide and then place the imaginary calls one by one on the group of imaginary circuits or lines.

Some authors describe special methods for observing actual telephone traffic. The main difficulty is that such traffic varies around an average value which, however, never equals the desired value. This renders a systematic test extremely difficult, for which reason closely controlled artificial traffic is to be preferred.

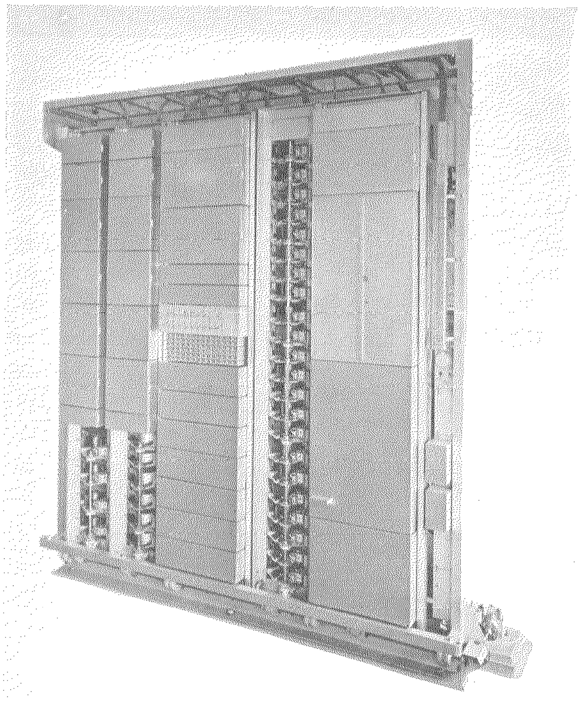


Fig. 1—Rotary traffic machine.

Elliman and Fraser[1] were the first to build an automatic machine which independently creates a flow of artificial traffic and places it on a group of artificial lines. The calls are formed by small steel balls and the element of chance is obtained by letting the balls drop on a larger ball, whereafter they are conducted to or deviated from 1 or 2 channels leading to the "lines." The holding time is the same for all calls and is realized by means of a fluid slowly flowing through a small aperture. With this machine, the authors have submitted to test some simple groups of lines.

The traffic machine of Kosten[2] employs as the element of chance the Geiger counter, which reacts on the chance passing of electrically charged particles. The calls have no physical form as in the first-mentioned machine but operate a line relay of a circuit or traffic path. Kosten has found an elegant solution for the exponential variation of the holding time by indicating in a haphazard manner whether the closure of the contact controlled by the Geiger counter is to serve for the engagement or for the release of a traffic path.

The description given by Kosten being rather brief, we are not in a position to express an opinion on the possibilities of a machine based on these principles. Its capacity of 24 traffic paths seems to be rather limited and the traffic imposed can only be varied in rather large steps because of the relation between the traffic density and the number of contacts on an auxiliary switch.

The artificial traffic machine to be described was designed by the author and built by the Bell Telephone Manufacturing Company of Antwerp

[1] E. A. Elliman and R. W. Fraser, "An Artificial Traffic Machine for Automatic Telephone Studies," *Electrical Communication*, v. 7, pp. 126–133; October, 1928.

[2] L. Kosten, "Over blokkeerings en wachtproblemen," Proefschrift Technische Hoogeschool Delft; 1942.

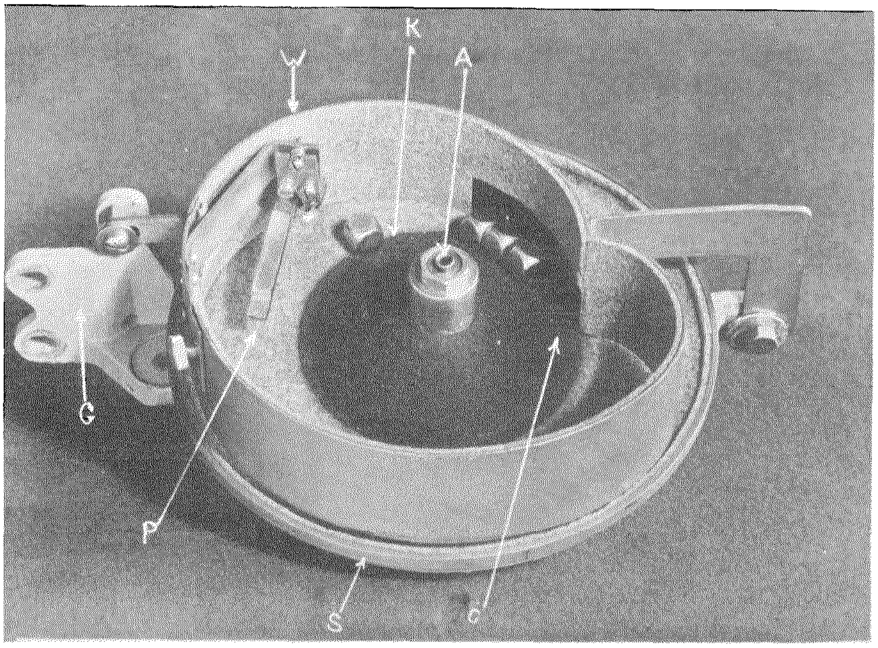


Fig. 2—Haphazard contact.

during 1939. It was ready for test by the beginning of 1940. Because of prevailing circumstances, the tests were considerably delayed.

The machine uses a specially designed haphazard contact. The calls have no physical character and only cause a time meter to leave its home position. The holding time can be varied between wide limits and can, at will, be made constant or variable in accordance with an approximately exponential law.

The results obtained with the rotary traffic machine pertain to the choice of the optimum grading (a subject hitherto not yet investigated), the traffic-carrying capacity of gradings, and the verification of various loss and delay formulas by Erlang and Molina.

From this summary it appears that the machine covers the complete field of problems dealing with traffic congestion as encountered in automatic telephony.

2 *Apparatus*

Most of the pieces of apparatus used in the traffic machine are of standard Bell Telephone Manufacturing Company design and will not be described. The 2 following devices have been specially designed by the author for incorporation in this machine.

2.1 Haphazard Contact

The horizontal disc S in Fig. 2 rotates around a vertical shaft A fixed to the base of a rotary switch. It is rotated from a vertical driving shaft by means of a gear which is not visible in the figure. The disc is flat except for the central part K which is cone-shaped. The upper side of the disc is covered by a thin layer of cork.

The vertical side W is curved as shown in the figure. The inner part is provided with a set of springs P mounted horizontally. The inner face also is covered with a thin layer of cork.

A certain number of dice, generally a dozen, are placed at random on the revolving disc.

As the disc is rotated, the dice are continuously driven towards the center of the disc where they ascend the cone. When they reach point G, they escape, roll during a few moments and stop on the flat part of the rotating disc. According to their position, they will or will not lift the spring operating the contact.

The function of this contact in the traffic machine and its operation in conjunction with the other apparatus, are explained later. It will be sufficient to state that this simple piece of apparatus fulfills all of its requirements in the machine.

2.2 Timing Device

This apparatus does not directly measure time as its name might seem to imply but controls the revolution of a driving shaft. When this device is in its normal position, it connects a terminal of the selectors to earth via contact springs. When the electromagnet operates, this earth is removed. After rotation of a shaft over a certain angle, the contact is again closed.

In Fig. 3, the armature A of a flat-type relay is provided with a lever D. The pivots of lever H are located on the core of the relay; one end of lever H rests on lever D and the other on the springs through an ebonite stud.

A washer E, having a circular hole in its center revolves freely on a square shaft, and is held between 2 washers F of smaller diameter by the light pressure of a spiral spring.

The washers F have square center holes and rotate with the shaft. Washers F will drive washer E by friction unless the latter is prevented by some obstacle. Washer E has 5 small holes on its outer edge in which small pins B can be inserted.

In Fig. 3a, the apparatus is in its normal position, i.e., free and ready to be engaged by a selector. The washers F rotate with the shaft and tend to drive washer E which is held stationary by one of the pins B pressing against the lever D which in turn forces lever H against the spring I thus maintaining the contact closed.

A selector, which stops on a free timing device, operates the relay as shown in Fig. 3b and the contact is opened. Shortly after, the armature o the relay falls back and the timing device is i the condition represented by Fig. 3c.

Of the 5 holes in washer E, 4 are separated b angular distances of 90 degrees. When pins ar inserted in these holes, constant holding time i obtained. The fifth hole has been added to permi tests with variable holding times. By displacin one of these pins, the 4 consecutive holding time will be in proportion of 0.3:0.7:1.0:2.0. Thes values have been chosen to approximate th exponential law.

3 *Operation of the Haphazard Contact*

It was necessary to devise a method of check ing the haphazard contact to find if it actuall fulfilled the requirement of operating in a purel haphazard manner. For this purpose an elec trical circuit was developed to measure the inter vals between subsequent closures of the contact This circuit was composed of relays, step-by step switches, an interrupter, and a number o counters.

By simple calculation it can be demonstrate that, if the contact operates in a haphazar

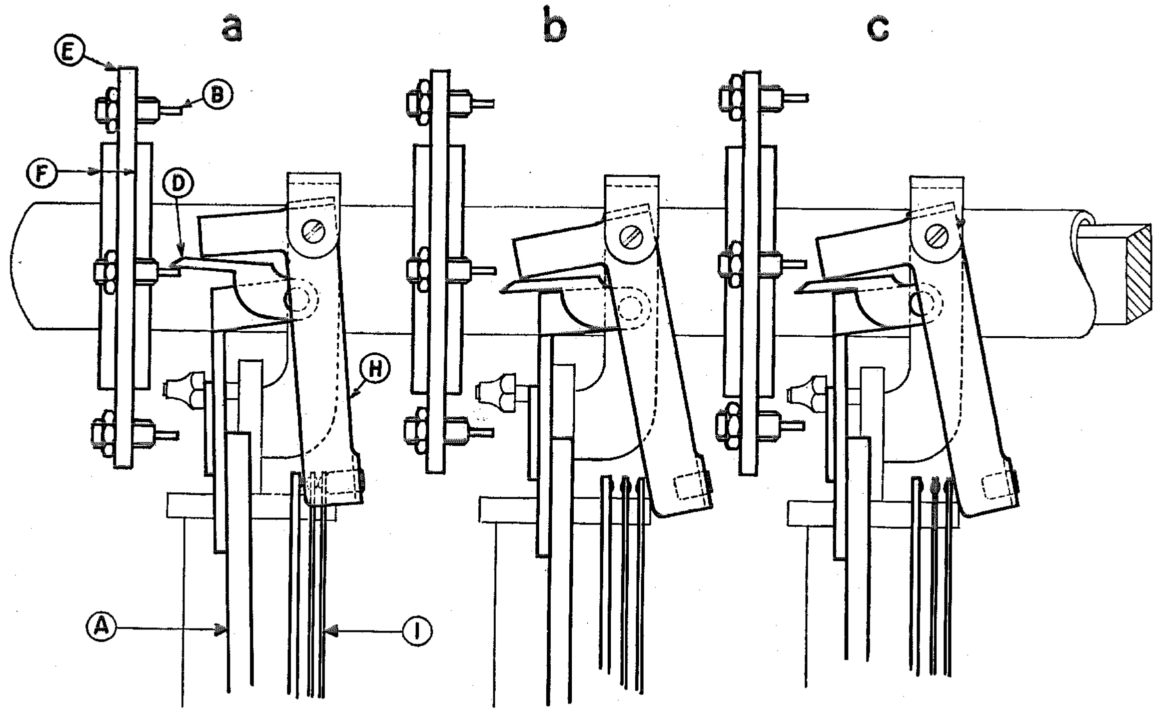


Fig. 3—Operation of the timing device.

manner,

$$p(>t)=e^{-t/T}, \quad (1)$$

where $p(>t)$ represents the probability that the interval exceeds the value t and where T is the average value of the interval. Fig. 4 shows a typical exponential curve and in addition a number of values relating to 3600 measured intervals. With the exception of some slight deviations, the points practically coincide with the curve. It may therefore be concluded that the haphazard contact entirely fulfills the imposed requirement.

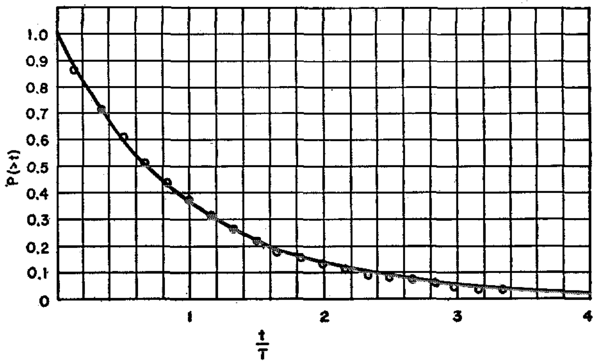


Fig. 4—Verification of haphazard contact. The curve represents the function $P(>t)=e^{-t/T}$. The measured points indicated are for 3600 intervals between successive closures of the haphazard contact.

4 Operation of the Machine

The 2 main functions of the traffic machine are to create its own traffic and subsequently to place the calls on a group of junctions.

4.1 Basic Assumptions

It will be evident that some basic assumptions underly the operation of the traffic machine, in which respect it shows similarity with the theoretical treatment of telephone traffic problems.

When imposing a certain traffic density, the machine will create exactly 6 times this amount within a period corresponding to 6 hours.

In an automatic telephone exchange the calls are routed via a number of subsequent groups and the size of a group can be of influence on the required size of the next group.

As with the majority of theories, the machine does not take into consideration the size of the preceding group and functions as if this group were infinitely large.

The hour is subdivided in 51×102, minimum intervals and if more than one call happens to fall within an interval, the machine treats these as if their moments of starting coincide. From this, it can be reasoned that the calls are in a minor respect interdependent. In reality the probability of having simultaneous calls is infinitely small. However, the error this limited subdivision introduces is extremely small and may, therefore, be disregarded.

4.2 Variety of Problems Possible

The variety of problems, the solutions of which may be demanded from the traffic machine, depends mainly on the following factors:

a. Type of group. Both perfect and imperfect groups can be tested by the machine. In case of the latter, the traffic per split varies in accordance with Poisson's law. The total traffic offered to the splits may or may not correspond exactly to the traffic density imposed on the machine.
b. Holding time. The holding time can be chosen to be equal for all calls or to be variable.
c. Loss or delay. The machine can produce tests to measure the number of 1st calls or to observe delays.

4.3 Limitations

The rotary traffic machine offers the following possibilities:

a. Maximum of 6 splits is provided.
b. Machine can create and handle a top average of 500 calls per split.
c. Duration of the calls may be taken to be equal for all calls and fixed at 1, 2, 3, or 4 minutes.
d. Duration of the calls may be variable and fixed at:
   1. 0.3, 0.7, 1.0, and 2.0 minutes
   2. 0.6, 1.4, 2.0, and 4.0 minutes
   3. 0.9, 2.1, 3.0, and 6.0 minutes
   4. 1.2, 2.8, 4.0, and 8.0 minutes
e. Cross-connecting field allows the investigation of perfect or imperfect groups.
f. Number of contacts of a level may not exceed 50.
g. Number of time meters (junctions) is limited to 120.
h. Number of waiting calls is limited to a maximum of 6 per split.
i. One test includes 6 or 60 artificial hours.

j. Duration of an artificial hour varies between 15 and 30 minutes depending on the traffic density and the number of splits used.
k. Variation of the speed of the motor driving the switches has no influence on the accuracy of the test.
l. Power supply may vary between 44 and 52 direct volts.
m. Machine contains no clockwork. Every time of occupation is measured as a fixed proportion between the speed of 2 shafts driven by the same motor.

4.4 Distribution of Calls

The machine will place an exact number of calls during a certain period permitting control of traffic within close limits. At the same time the traffic must provide:

a. Independence between calls.
b. Liberty for every call to choose any moment of the period considered. As the holding time is incorporated as a timing element in the junction circuits, the haphazard distribution of traffic is reduced to a prearranged haphazard distribution of the moments at which the calls arrive during the period considered.

   The hour is subdivided into a number of small parts, and the total number of calls is distributed over these parts in a haphazard manner, and in 2 successive steps.

4.5 First Phase of Period

The operation of the machine consists of a repetition of a plurality of similar *periods*, each comprising 6 artificial hours.

Fig. 5 shows in diagrammatic form the location of the various elements of the machine and facilitates an understanding of its operation.

During the first distribution, double the number of calls imposed are placed on 102 marker switches having 22 positions and which can store 0 to 21 calls. Each marker represents 1/51 part of an hour. The reason why double the amount of traffic is placed on double the number of markers is to vary the traffic of 6 consecutive hours by choosing the markers at random, as will be explained later in more detail.

This first distribution takes place once for every 6 artificial hours and is called the *first operational phase*. Before this phase commences, all apparatus is restored to normal. The distributor then starts to rotate and each time an associated haphazard contact closes, the switch is stopped and the marker associated with the position on which the distributor happens to be temporarily stationed is advanced by one step. The call is counted and the switch is allowed to continue its course. A counting circuit ends the first phase when all calls have been placed. At this moment, therefore, the 102 markers carry twice the imposed number of calls n_0 markers still occupy their home position, n_1 markers stand in position 1, etc. The sum $n_1+2n_2+3n_3\cdots$ will be equal to double the number of calls imposed on the machine.

n_0, n_1, n_2, etc. are counted by the CP counters and serve as a check on the operation of the machine.

4.6 Second Operational Phase, Repeated 306 Times for One Period

Every second phase is repeated 51 times for every artificial hour, in total therefore 306 times per period of 6 hours and comprises 3 distinct parts:

a. Number of calls stored on 6 markers are transferred to 6 indicator circuits.
b. Brush carriages of the 21 indicators are rotated over an arbitrary angle.
c. 1/51 part of an hour elapses.

The calls are placed on the junctions or delayed call circuits, which process may be interrupted occasionally by delayed calls, returning when a junction is liberated.

4.7 First Part of Second Operational Phase

Calls stored on a marker are transferred to an indicator circuit through a reader switch. There are 3 such switches, each with a capacity of 102 sets of 6 contacts (levels).

The 102 markers are arbitrarily connected 6 times to the arc contacts of the readers in such a manner that every marker appears 3 times in the top levels of the readers. These 3 levels supply the traffic, which is directed to the first multiple split, so that after one complete revolution of the 3 readers, 6 times the traffic imposed on the machine is placed on the junctions of this split.

The multiple of the 5 remaining levels of the 3 readers is arranged so that every marker is connected to 15 contacts in an arbitrary manner. The second level serves the second split; the third level, the third split; etc. It is, therefore, only the first split which receives exactly 6 times the imposed traffic during one period of 6 hours. No other split receives exactly 6 times the traffic, but the 5 splits together receive exactly 5 times the traffic.

The reason for making this exception, is to allow the machine to create exactly the traffic density imposed when operating with 1 or with 5 splits.

If desired, gradings having 2 or 3 multiple splits can be investigated by proper arrangements on the cross-connecting board.

Each indicator circuit comprises 21 relays, and the control circuit insures that the number of relays operated for each split corresponds to the number of calls stored on the 6 markers on which the readers are stationed.

4.8 Second Part of Second Operational Phase

During this interval the second distribution of calls takes place. For the first split, operation of a specific number of relays of the indicator circuit engage a corresponding number of indicators. For every call stored on a marker, one relay is energized; the maximum possible number of calls stored being 21, these relays and indicators necessarily also number 21.

The top levels (102 contacts) of the indicators are connected in multiple with the corresponding level of the controller. When the latter makes a complete revolution, it passes over 21 contacts on which 21 indicators are located. The controller will stop only on a terminal having an indicator whose associated relay has been operated during the first part of the second phase. The possibility and the consequences of any 2 indicators standing on any one terminal have been foreseen and suitable action taken. The machine foresees the possibility of finding in one split a maximum of 4 calls on one terminal.

The distribution of the calls is performed by a simple mixing of the brush carriages of the indicators.

With reference to the 5 remaining multiple splits, the theoretically correct solution would be to use 5 additional sets of 21 indicators. To avoid such a large quantity of apparatus, it was

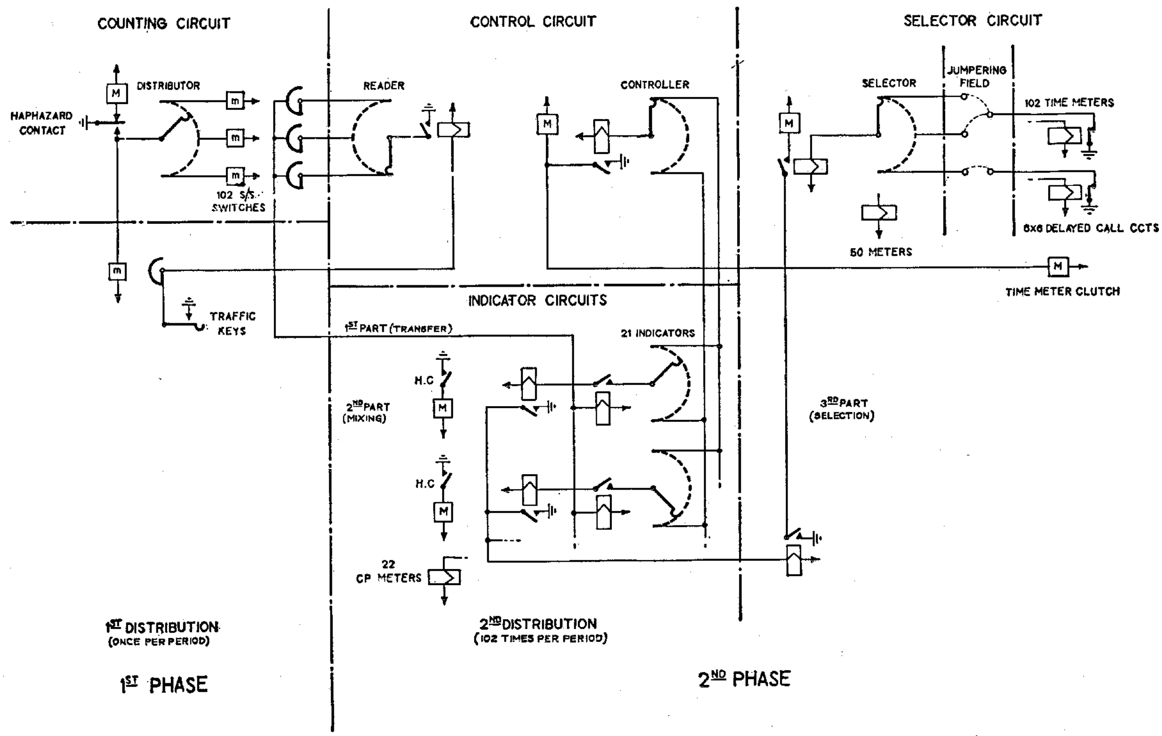


Fig. 5—Diagram of traffic machine.

decided to employ 21 switches only for all splits and to provide 6 levels of 102 sets of contacts on each of the indicators and the controller.

Measures have been taken to reduce the interdependence between the 6 splits to a minimum.

From the foregoing it can be concluded that the hour is subdivided by the first and second distribution into 51×102 minimum parts, each of which, therefore, has a theoretical duration of 0.7 second.

4.9 Third Part of Second Operational Phase

After the calls have been transferred to the indicator circuits and the mixing of the indicators has taken place, the third part of the second phase commences. During this time the controller completes one revolution, which is interrupted each time a contact is met on which an engaged indicator is stationed.

When such a contact is met, the control circuit energises one or more relays of the indication circuit via the contact, the multiple wires, and the indicator contacts and brushes.

The operation of these relays causes the selector circuit to place a number of calls, corresponding to the number of relays energized, on junctions which are not engaged. This placing of the calls happens during only one revolution of a selector.

The selector starts to rotate and beginning from the home position tests the junctions of those splits in which calls have to be placed in the order imposed by the jumpering on the cross-connecting board. When testing on a free junction, the selector is stopped and the relay of the associated time meter is operated, whereupon it continues its rotation until all calls have been placed.

Should all junctions in the desired split be engaged, the call is placed on a "delayed-call circuit," a number of which are jumpered to contacts located at the end of the selector arcs.

After the controller has made one revolution, a second phase is completed. The relays of the indicator circuits are released and a new second phase commences. The number of calls to be placed is now indicated by the markers connected to contacts of the second reader.

During the rotation of the controller, "time" advances and the shaft of the time meters is rotated. The clutches controlling the movement of the controller and the time-meter shaft always operate in unison.

When the second phase has taken place 3 times, the control circuit advances the 3 readers by one contact.

With the CPI key thrown, 22 counters register for every second phase the number of calls transferred to the first multiple split.

The selector circuit contains 3 selectors which are used alternately to accelerate the functioning of the machine.

To eliminate the possibility of double test on a free common junction by 2 calls directed to different splits, preference is given to one of the splits. The preference is changed in a cyclic manner from split to split each time a selector has completed a revolution.

4.10 Registering of Results

To one level of each of the 3 selectors, 50 counters are connected in multiple. These register the number of calls placed by the selectors on junctions connected to the corresponding sets of terminals of the 6 splits. These counters, therefore, register the result of a test.

During the first 2 "second phases," i.e., during the time the machine builds up the traffic, no metering takes place. It is for this reason that these phases are repeated at the end of the period of 6 hours.

This method of procedure may cause a slight error in the total time of occupation of the junctions.

4.11 Delayed Calls

Calls which do not find a free junction are temporarily stored on delayed-call circuits.

The moment a junction connected in the corresponding split becomes free, an occupied delayed-call circuit stops the controller and the shafts of the time meters and a selector rotates and transfers the call from the delayed-call circuit to the junction.

The number of delayed calls are counted and also the total waiting time per split.

5 *Grading of Imperfect Groups*

5.1 General Principles

In general all gradings demand that the electrical test of the junctions be performed in a definite order, the brush carriage of the selector starting from a home position. When applying this kind of hunting to a perfect group, the traffic offered to the consecutive contacts gradually diminishes and, consequently, so does the traffic carried by and the efficiency of the circuits connected to the contacts of high rank. This phenomenon is used when composing gradings for imperfect junction groups by connecting junctions to more than one split, thereby increasing the traffic offered to the junction and consequently its efficiency.

The minimum number of splits required for an imperfect group evidently equals the number of junctions divided by the number of contacts of which a level is composed. In practice, generally, double this number is used.

Further, the splits and the manner in which they are arranged must be chosen so that each split carries approximately the same average amount of traffic. Deviation from this reduces the traffic-carrying capacity of the group. Nevertheless, cases may occur in practice where deviation from this rule is required.

All gradings considered are of the regular type, i.e., those which are composed in a manner symmetrical to all splits.

The above-mentioned arrangement, which is used to advantage with graded groups, whereby contacts of higher rank carry less traffic than those which are nearer to the home position, has serious disadvantages. First, the exchange apparatus will wear out in an unequal manner, which increases the normal amount of maintenance required as it leads to occasional rejumpering of the circuits. Further, as is known from general experience, a circuit which is regularly occupied gives less trouble than a circuit with a minor but irregular load. Third, the circuits of an imperfect group demand certain precautions when distributing over the splits of the subsequent selecting stage.

If in practice insufficient attention is paid to this matter, it may easily happen that one split of the last-mentioned selecting stage receives "smooth" traffic and another split the "peak" traffic. Such poor traffic distribution adversely affects the efficiency of the groups of junctions connected to the latter selecting stage.

As a general rule, the multiple cabling of switches placed on one bay is performed in a straight manner. Between the bays of one split, a "slip" is often introduced to prevent a particular junction, which is not in proper working order, from blocking completely all traffic during periods of extremely light traffic, for example, during the night. By slipping, 2 junctions simply exchange places. Generally speaking, slipping if properly done has no reaction on the efficiency of a graded group.

5.2 Graded Imperfect Group

Fig. 6 shows diagrammatically an example of a graded group comprising 27 junctions or traffic paths connected to switches with 10 point levels and arranged in 6 multiple splits.

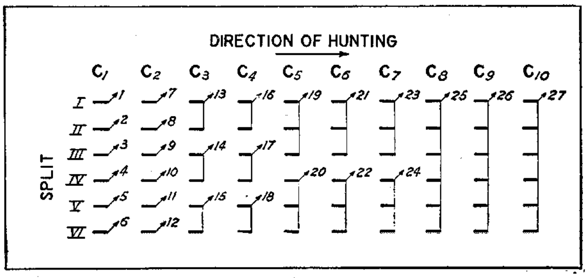


Fig. 6—Grading having 27 junctions connected to 6 splits and 10 point levels.

The symbols employed are those commonly used; the numbered arrows indicate the junctions. Junctions 1 to 12 only appear in one split, 13 to 18 in 2, 19 to 24 in 3, and 25 to 27 in 6 splits.

5.3 Fundamental Gradings

For an imperfect group consisting of n junctions, connected to levels having L sets of contacts located in the arcs of selectors spread over m multiple splits, a large number of gradings are possible.

To obtain a regular fundamental grading, the following numbers must be divisible by the number m.

a. Number of junctions appearing in one split only.

b. Number of junctions appearing in 2 splits, multiplied by 2.
c. Number of junctions appearing in 3 splits, multiplied by 3.

We, therefore, call:

$$m\frac{L_1}{1} = \text{number of "individuals,"}$$

i.e., the junctions connected to one split only,

$$m\frac{L_2}{2} = \text{the number of "2's"},$$

i.e., the junctions connected to 2 splits only, and

$$m\frac{L_3}{3} = \text{the number of "3's"},$$

i.e., the junctions connected to 3 splits only, etc.

L_1 is the number of vertical rows of contacts to which the "individuals" are connected, L_2 those for the "2's," etc. Any of the above terms must be a whole number.

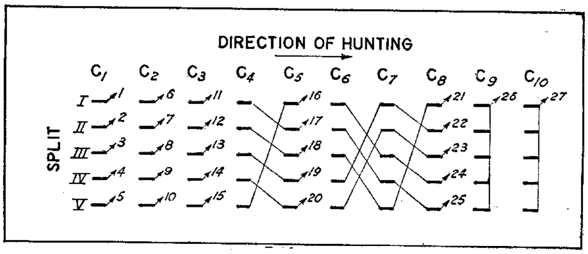


Fig. 7—Grading having 27 junctions connected to 5 splits and 10 point levels.

We now have the following equations:

$$m\left(L_1+\frac{L_2}{2}+\frac{L_3}{3}+\cdots\frac{L_m}{m}\right)=n, \qquad (2)$$

$$L_1+L_2+L_3+\cdots L_m=L. \qquad (3)$$

In the literature on grading that has come to our notice no attention is paid to the possibility of certain groups of junctions being connected to a number of contacts which is not a factor of L. For instance, with gradings over splits, the possibility of using junctions connected to 4 or to 5 splits seems to have escaped attention. Groups have been limited to those whose numbers (2's, 3's, etc.) appear as a factor in the number of splits. As a consequence gradings consisting of 2, 3, 4, 6, 8, and 12 splits only are preferred and recommended, whereas when assuming a more broad basis, gradings with 5, 7, 9, and 11 splits are perfectly possible and feasible.

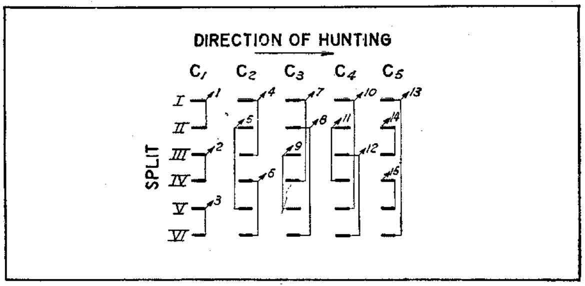


Fig. 8—Cyclic combinations of 2 contacts.

Fig. 7 shows, as an example of such a type of grading, an arrangement for a multiple having 5 splits with individuals, 2's, 3's, and 5's.

Recognition of this broader basis renders the introduction of grading more easy.

5.4 Regular Gradings

When applying equations (2) and (3) to an imperfect group of 27 junctions connected to switches having levels comprising 10 sets of contacts, we find that the minimum possible number of splits equals 3, where we have only 1 solution:

$$L_1=8, \qquad L_2=2, \qquad L_3=0.$$

When increasing the number of splits to 4, we have the 3 gradings given in Table I.

TABLE I

Gradings for 4 Splits

	Symbol Number		
	1	2	3
L_1	5	5	4
L_2	2	1	5
L_3	0	3	0
L_4	3	1	1

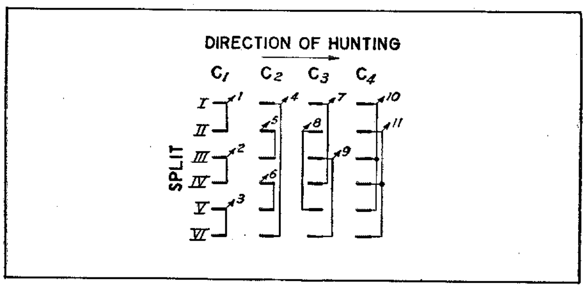


Fig. 9—Cyclic combinations of 2 and 3 contacts.

With 5 splits there are only 3 regular gradings as shown in Table II.

TABLE II

GRADINGS FOR 5 SPLITS

	Symbol Number		
	1	2	3
L_1	4	3	2
L_2	0	2	6
L_3	0	3	0
L_4	4	0	0
L_5	2	2	2

The second solution is shown in Fig. 7.

With 6 splits, the 28 fundamental gradings possible are given in Table III.

The 10th solution is shown in Fig. 6.

Summarizing, it will be noted that a great number of regular gradings exist, as the number of splits can be increased at will. In practice, the maximum possible number of splits is limited by the number of bays composing the multiple.

5.5 Dependent Gradings

From every fundamental grading found by the above method, a large number of dependent gradings can be derived by applying one of the 3 following methods:

a. Transposition of columns. By applying permutation to the vertical rows of contacts of the grading shown in Fig. 6 (avoiding repetitions) an extensive series of new gradings is obtained, each of which will have its own and perhaps a different traffic-carrying capacity.

It is generally assumed that by transposing the columns, no improvement in the group efficiency can be obtained as compared with the fundamental grading.

Lubberger, however, seems to be of the opinion that by exchanging the individuals and the 2's an advantage is obtained.

b. Cyclic combination of contacts (skipping). When carrying through the fundamental idea of grading, i.e., mutual assistance among the various multiple splits, cyclic combination of the contacts is attained. For example, gradings with 6 splits can form 15 combinations of 2 contacts requiring (see Fig. 8) 5 columns of contacts. The 3's and 4's give 20 and 15 combinations each, requiring 10 columns.

If the number of 2's is insufficient to form all combinations, the 3's may be included, etc. This idea for the composure of gradings, originated by Lubberger, leads to the general rule that a traffic peak in one split should deprive the other splits of junctions in an equal number. Fig. 9 shows an example of this kind of grading.

Cyclic combination of contacts, if properly done, increases the efficiency of a group of graded junctions.

c. Slipping. Figs. 10, 11, and 12 demonstrate the application of slipping to 2's, 3's, and 4's in gradings comprising 6 splits.

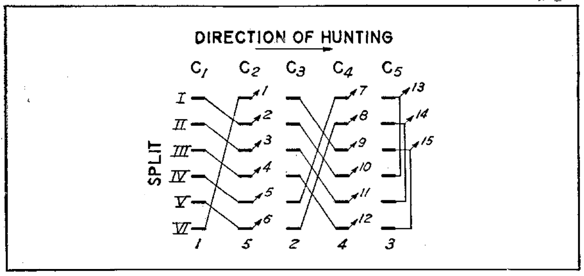


Fig. 10—Grading with slipping applied to 2's.

TABLE III

GRADINGS FOR 6 SPLITS

	Symbol Number																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
L_1	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0
L_2	1	0	0	0	0	0	3	3	3	2	2	2	2	1	1	1	0	0	6	5	5	5	4	4	3	8	8	7
L_3	0	2	1	1	0	0	1	0	0	3	2	1	0	5	4	3	7	6	0	2	1	0	4	3	6	1	0	3
L_4	0	0	2	0	4	2	0	2	0	0	2	4	6	0	2	4	0	2	0	0	2	4	0	2	0	0	2	0
L_5	0	0	0	5	0	5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L_6	6	5	4	1	3	0	4	3	0	3	2	1	0	2	1	0	1	0	3	2	1	0	1	0	0	1	0	0

The purpose of slipping is to obtain a more equal traffic distribution over the junctions. In addition, the contact columns may be transposed as indicated in the figures by the numbering shown below them. Some further advantages of slipping are:

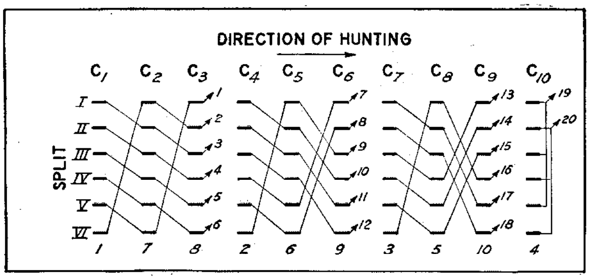


Fig. 11—Grading with slipping applied to 3's.

a. Reduced average hunting time.
b. More even wear of apparatus.
c. Reduced probability of double test.

The even distribution of the load over the junctions can only be obtained within the subgroups. Mixing individuals with 2's, 2's with 3's, etc. will always reduce the efficiency of a grading. For this reason the junctions of a grading which comprises more than one subgroup cannot be made to carry the same average load.

5.6 Family of Gradings

To facilitate systematic comparison of efficiency of gradings belonging to one "family," the gradings may be arranged in a methodical order.

By comparing the 28 different gradings mentioned in Section 5.4 it will be noted that several pairs appear to have the same difference in arrangement. The gradings numbered 3 and 4 (301204 and 301051) and 5 and 6 (300403 and 300250) show the same mutual relation or "difference," namely:

$$0.0.0.2.-5.3$$

This difference we call "transformation" and observation of this phenomenon gave rise to a general theoretical investigation.

In general, a transformation must satisfy the following 2 equations:

$$T_1+T_2+T_3+\cdots T_m=0, \tag{4}$$

$$\frac{T_1}{1}+\frac{T_2}{2}+\frac{T_3}{3}+\cdots\frac{T_m}{m}=0. \tag{5}$$

T_1, T_2, T_3, etc. represent the number of contact columns having individuals, 2's, 3's, etc. connected to them.

These 2 equations contain m unknown quantities, so to obtain one transformation $m-2$ of these may be assumed.

Because of its nature, a transformation must at least comprise 3 numbers which differ from 0; therefore, $m-2$ independent transformations must exist.

When choosing those which contain 3 subsequent terms, i.e., T_s, T_{s+1}, and $T_{s+2}\neq 0$, the above equations are reduced to:

$$T_n+T_{n+1}+T_{n+2}=0, \tag{4a}$$

$$\frac{T_n}{n}+\frac{T_{n+1}}{n+1}+\frac{T_{n+2}}{n+2}=0. \tag{5a}$$

As we are at liberty to choose one of these 3 unknown quantities, we assume

$$T_n=n$$

and find:

$$T_{n+1}=-2(n+1),$$

$$T_{n+2}=n+2.$$

When varying n, we find the following block of independent basic transformations which holds good for any arbitrary number of splits.

a.	1	−4	3	0	0	0	0	—	—
b.	0	2	−6	4	0	0	0	—	—
c.	0	0	3	−8	5	0	0	—	—
d.	0	0	0	4	−10	6	0	—	—
e.	0	0	0	0	5	−12	7	—	—
	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—

Transformations b, d, f, etc. may be divided by 2 in case of an even number.

In some instances such as 6 splits, the above transformations are not very suitable as they

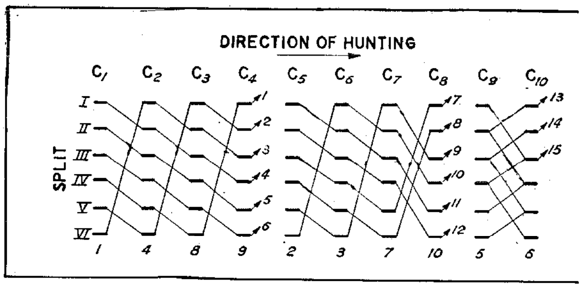


Fig. 12—Grading with slipping applied to 4's.

contain an unnecessarily high number of imaginary gradings, i.e., gradings with negative numbers. In practice, therefore, the following transformations are recommended for 6-split gradings.

a.	1	−3	1	0	0	1
b.	0	1	−2	0	0	1
c.	0	0	1	−2	0	1
d.	0	0	0	2	−5	3

Applying these transformations to the family of 28 gradings mentioned in Section 5.4 a complete and clear picture can be obtained of their relationship. As there are 4 independent transformations, this picture becomes 4 dimensional, for which reason transformation *d* is temporarily neglected, especially as it appears but rarely.

A wire model is shown illustrating a family of gradings in Fig. 13. The transformations *b*, *c*, and *a*, respectively, are parallel to the *X*, *Y*, and *Z* axes and point from left to right, front to rear, and top to bottom.

Further, there are 2 groups of gradings comprising 25 and 3 gradings, respectively, located in different spaces and interconnected by transformation *d*.

The latter group of 3 gradings is located in a single vertical plane, i.e., the gradings are interconnected by the transformations *c* and *a* only, with the exception of *b*.

The group of 25 gradings is spread over 4 horizontal planes, located at a vertical distance corresponding to transformation *a*. By applying this transformation, one passes from grading 28 to 23, from 22 to 12, or 8 to 3, etc.

The gradings located in the same horizontal plane are interconnected by transformations *b* and *c*.

With the help of this figure, the mutual relationships among the 28 gradings are readily found; the same relation exists between gradings 5 and 15, and 8 and 23, etc.

6 Results Obtained

6.1 Verification of Operation of Machine

By simple means the traffic machine exercises continuous control of its operation.

The first accurate check is on the correctness of the first distribution of calls. This check is effected by the CP counters and is threefold. These counters indicate the relative positions of the 102 markers on which the calls are placed, after the first distribution. Each marker may occupy 22 positions, and there are 22 CP counters. The CP_0 counter indicates the number of markers which have not left their normal position, the CP_1 counter the number of markers which stand in position 1, etc.

During every artificial hour the positions of 51 markers are recorded, and the first check is that the sum of all the CP readings, divided by the number of test hours be exactly 51.

Further, the reading of CP_0 multiplied by 0, plus CP_1 by 1, plus CP_2 by 2, etc. must exactly equal 60 times the number of calls imposed on the machine, in case these counters were connected to the first split. This is the second check. Should either of these checks be incorrect, the test is considered null and void.

The third check is of a theoretical nature and permits discovery of any abnormal happening during the first distribution. For this distribution, the law of Poisson holds good and the reading

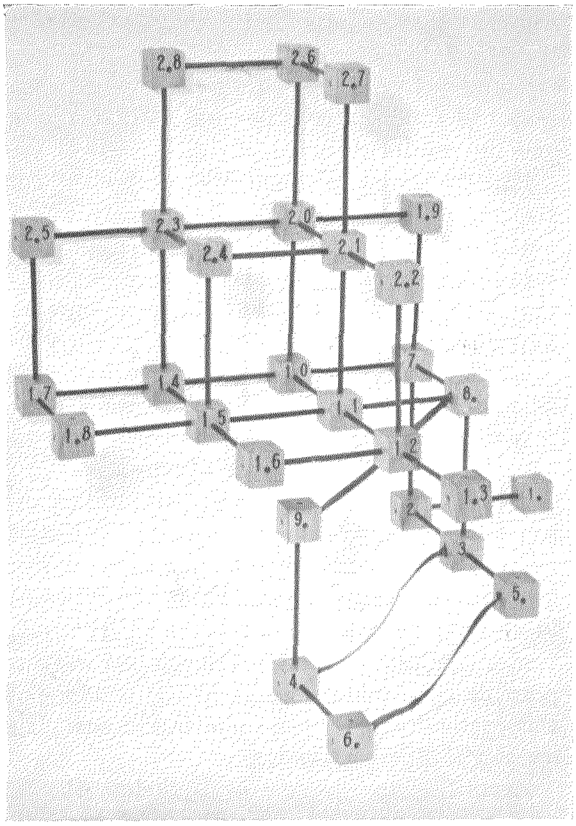


Fig. 13—Wire model of a family of gradings.

of the nth CP counter must indicate a number which approximately equals:

$$60 \cdot 51 \cdot e^{-N/51} \frac{\left(\frac{N}{51}\right)^n}{n!}. \qquad (6)$$

In general it can be stated, that during the years the machine has been carrying out tests, its operation appeared to be completely reliable. Occasional irregularities are soon discovered and the disturbance removed.

6.2 Investigation of a Family of Gradings

It is of great importance to engineers who occupy themselves with cabling and cross-connecting of automatic telephone exchanges to have a rule of thumb which permits them to select readily the best grading for a specific case.

With the aim of finding if such a rule existed, it was decided to submit a complete family of gradings to an extensive test. For this purpose the example of Sections 5.4 and 5.6 was chosen, namely 27 lines divided over 6 multiple splits comprising switches with 10 point levels. Fig. 13 shows a 3-dimensional picture of the 25+3 regular gradings possible. This picture is extremely useful in following the method of investigation and the results obtained.

Fig. 14 shows in detail the method of composition of every grading. Special care was devoted to the interconnections to approach a cyclic arrangement, as experience gained during the tests has shown that this is a matter of importance.

At the start of the tests, it was believed, that when submitting each of the 28 gradings to a test with the machine, the number of lost calls would indicate their relative quality.

As it appears that the overflow traffic, even for tests of 20 hours, shows important variations, a long series of tests would be necessary for every grading, the length increasing as the differences in quality decrease. To avoid such protracted testing, another method was developed and made possible by a minor change in the machine. By this method exactly the same traffic was placed on *several* different gradings.

According to the rule of Berkeley, the best gradings are to be found in the third horizontal plane so the investigation was started there. For all 12 tests, the results of which are given in Table IV, the traffic was fixed at an average of 80 2-minute calls per split.

TABLE IV

Test No.	Total Hours	Grading Number	Symbol	Total Number Lost Calls	Quality Tests	Number According to Berkeley
1	42	17	207001	366	1	4
		14	215002	375	2	3
		10	223003	386	3	1
		7	231004	411	4	2
2	40	18	206200	370	1	—
		15	214201	387	2	—
		11	222202	382	2	—
		8	230203	435	4	—
3	32	13	220600	336	4	—
		12	221401	311	1	—
		11	222202	317	2	—
		10	223003	318	2	—
4	20	13	220600	191	4	—
		16	213400	183	2	—
		15	214201	172	1	—
		14	215002	182	2	—
5	52	12	221401	536	3	—
		15	214201	542	4	—
		17	207001	521	2	—
		18	206200	513	1	—
6	28	5	300403	322	1	—
		3	301204	341	3	—
		2	302005	334	2	—
		1	310006	356	4	—
7	16	9	230050	209	1	—
		7	231004	207	1	—
		7	231004 (reversed)	464	4	—
		5	300403	269	3	—
8	22	9	230050	161	1	—
		4	301051	197	2	—
		6	300250	202	4	—
		5	300403	194	2	—
9	60	25	136000	491	3	3
		23	144001	442	1	1
		20	152002	467	2	2
		19	160003	506	4	4
10	44	22	150400	381	4	—
		21	151201	337	1	—
		24	143200	347	3	—
		23	144001	339	1	—
11	34	26	081001	227	3	—
		27	080200	212	1	—
		28	073000	212	1	—
		12	221401	278	4	—
12	60	27	080200	352	1	—
		20	152002	366	2	—
		21	151201	364	2	—
		11	222202	463	4	—

Reference is made to Fig. 13, which illustrates the procedure of the various comparative tests.

Where in any of the above tests 2 numbers of lost calls show too small a difference to draw a definite conclusion, the corresponding gradings are placed on the same level.

The following general conclusions can be drawn from these tests:

By comparing the quality numbers established in accordance with Berkeley's rule (without paying consideration to the 4's and 5's) with the quality numbers obtained by the tests, it appears that the "smooth-progression" theory of O'Dell is incorrect.

The introduction of the same transformation sometimes does and sometimes does not improve the quality of grading.

From the first 5 tests it can be stated that grading 18 is the best of the third plane.

From tests 6 and 7 it appears that all gradings of the fourth plane are inferior in quality to those of plane 3.

Comparing the results of tests 7 and 8, it can be concluded that the group of gradings comprising 5's is of little importance.

Tests 9 and 10 show that gradings 21 and 23 are the best of the second plane and tests 11 and 12, that the gradings of the top plane have a higher degree of efficiency than those of the third and the second plane.

As a final conclusion it can be stated that gradings 27 and 28 are the most efficient of the family of 28 gradings.

6.3 Investigation of Families of Gradings Having 20 to 36 Lines, Connected to 6 Splits and 10 Point Levels

The general result of the tests described is that the optimum grading of a family must be sought in one of the superior planes of the 3-dimensional model.

Investigation of the series of families having a number of junctions ranging from 20 to 36 shows that the family of 27 junctions happens to constitute a limit case. Families with more than 27 junctions show only 1 or 2 gradings in the top plane, whereas those with fewer than 27 lines show 3 or more gradings.

For this reason, an investigation was made to see if the conclusions reached so far also hold for 6 splits, 10 point gradings, with the number of junctions ranging from 28 to 36 lines.

From the tests, the following general conclusions may be drawn.

a. Limit the number of rows with "individuals" to the minimum or to the minimum plus 1.
b. 2's and 3's must preferably be utilized.
c. 4's and 5's etc. should not be used, with the exception that the symbol may terminate with 1.
d. Aim to arrange the connections in a cyclic manner.

When applying these rules, gradings of a much better quality are obtained than those recommended and used to date.

When adding to the above recommendations considerations of secondary importance such as minimum cross talk, the gradings in heavy print in Table V can be recommended. They indicate, if not the very best, gradings of good quality.

TABLE V

No. of Lines	Grading Symbol			
27	**073000**	136000	—	—
28	**082000**	145000	208000	—
29	091000	**154000**	217000	—
30	0.10.0000	**163000**	226000	—
31	—	**172000**	235000	—
32	—	181000	**244000**	307000
33	—	190000	**253000**	316000
34	—	—	**262000**	325000
35	—	—	271000	**334000**
36	—	—	280000	**343000**

For the families of gradings with less than 27 junctions, a number of tests were made to determine whether any important deviations from the above rules would show up. This was not the case and the gradings in Table VI can be recommended.

TABLE VI

No. of Lines	Grading Symbol					
20	0	0	10	0	0	0
21	0	1	9	0	0	0
22	0	2	8	0	0	0
23	0	3	7	0	0	0
24	0	4	6	0	0	0
25	0	5	5	0	0	0
26	0	6	4	0	0	0
27	0	7	3	0	0	0

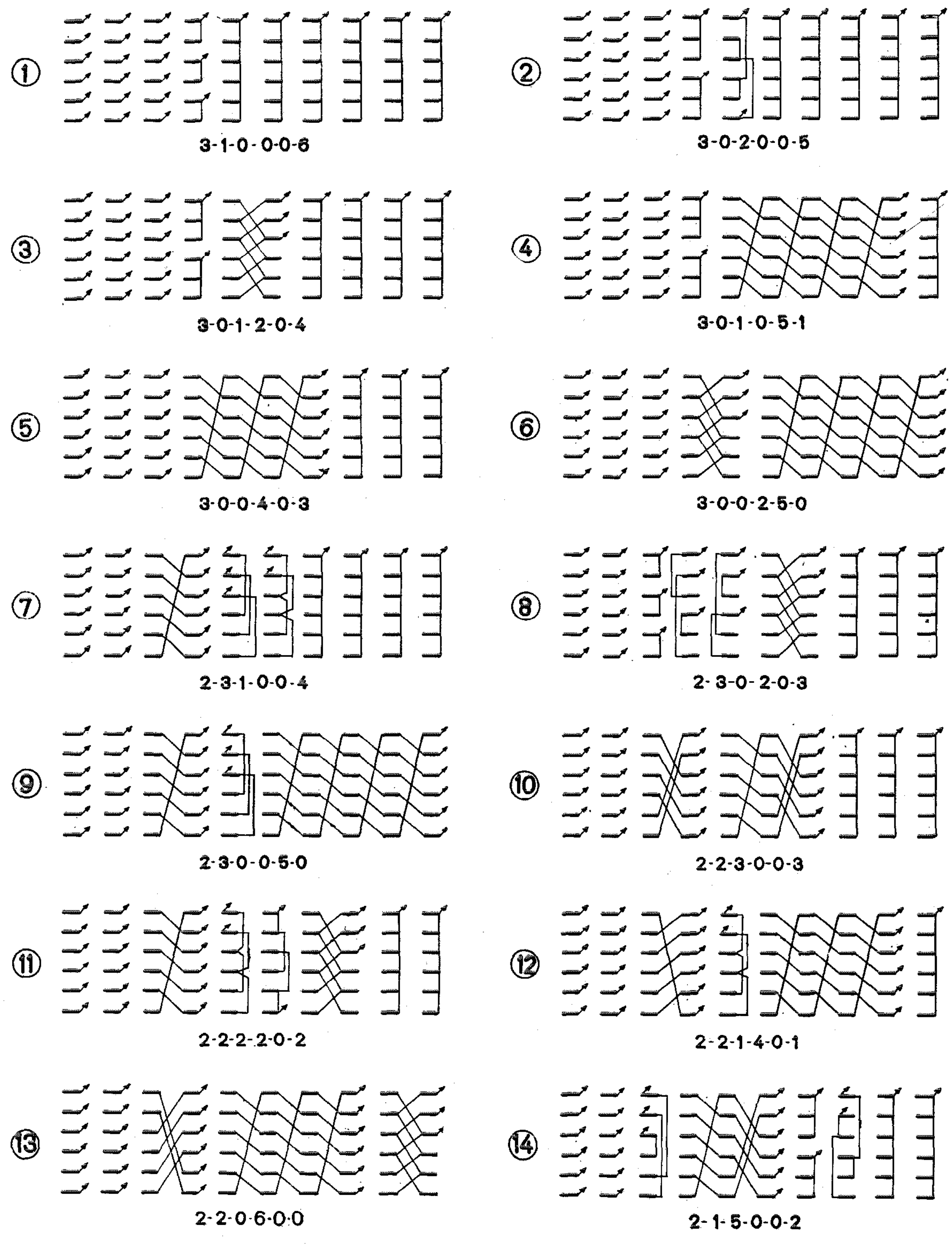


Fig. 14—Method of composition of gradings of one family of 27 junctions.

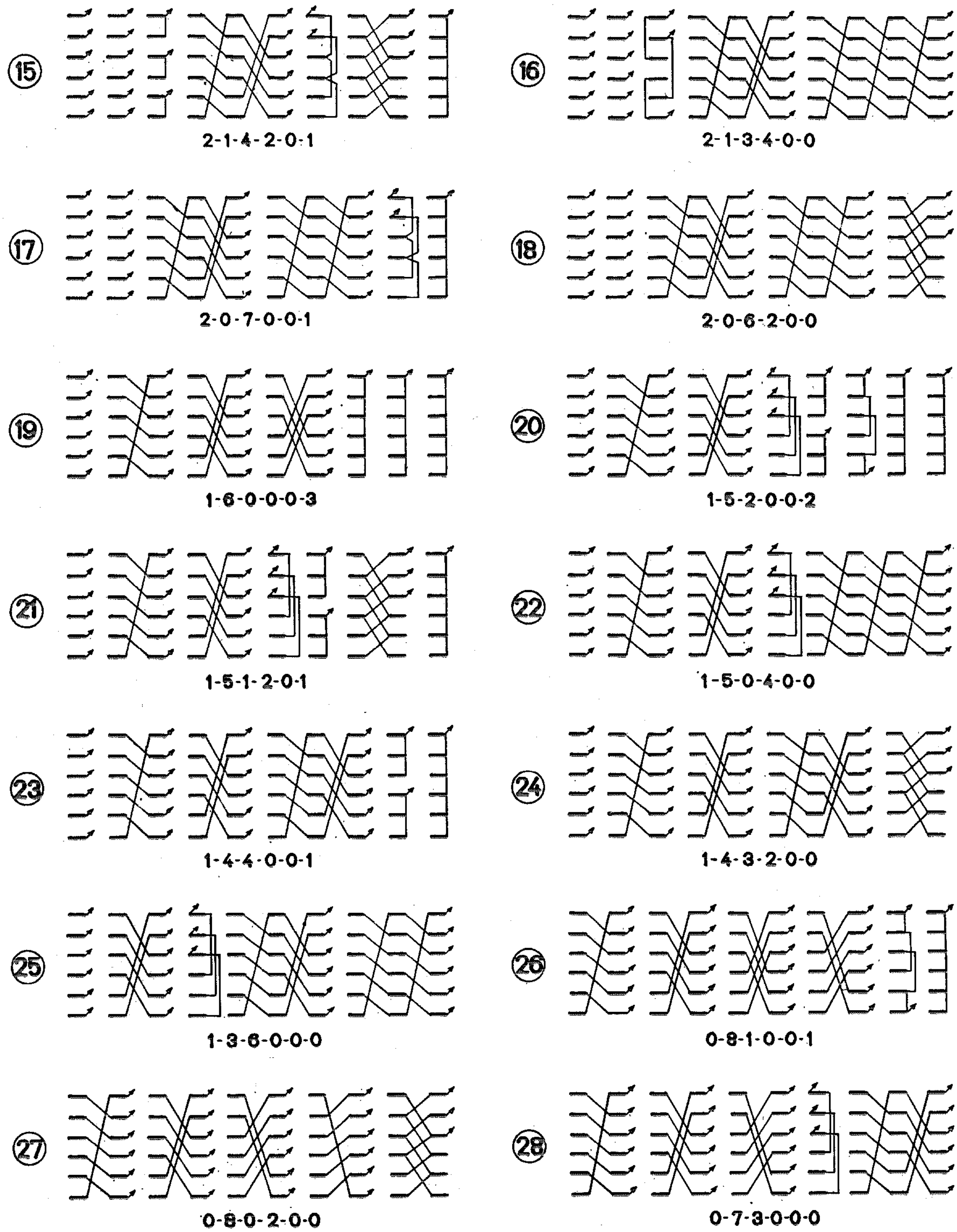


Fig. 14—Method of composition of gradings of one family of 27 junctions (continued).

6.4 Investigation of Families of Gradings Having 10 to 30 Lines, Connected to 3 Splits and 10 Point Levels

Table VII contains in a systematic form, the symbols of all possible gradings having 3 splits with 10 point levels and an ascending number of junctions.

As the result of an extensive number of tests, the optimum gradings were determined. These are indicated by heavy printed symbols.

With 2 exceptions (15 and 18 lines), it is always the grading which has the lowest number of commons ("3's") which is the best. Again it appears that the smooth-progression theory does not hold good as is clearly shown by the following results.

6.5 Investigation of Families of Grading Having 12 to 22 Lines, Connected to 4 Splits and 10 Point Levels

With gradings connected to 4 splits, 2 transformations are possible, so that the picture of a family is bidimensional.

As it is not possible to compose a single table containing all possible gradings, the following 3 separate tables (VIII, IX, and X) indicate the gradings of the first, second, and third horizontal lines.

TABLE IX
Second Horizontal Line

No. of Lines	Grading Symbol						
18	1360	**1432**	1504				
19			**1531**	**1603**			
20				**1630**	1702		
21						1801	
22							1900

TABLE X
Third Horizontal Line

No. of Lines	Grading Symbol				
20	2260	2332	2404		
21			**2431**	2503	
22				**2530**	2602

For each number of lines, the best grading is printed in heavy type. If 2 or more gradings have the same or nearly the same efficiency they are treated equally.

6.6 Grading Efficiency

In the preceding paragraph some general rules are given which when applied lead to the best grading of a family. This section deals with the manner in which the efficiency of a grading can be determined, for which purpose a method similar to the one used up till now, was applied.

TABLE VII

No. of Lines	Grading Symbol									
10	**00.10.**									
11	**028**									
12	**046**	109								
13	**064**	127								
14	**082**	145	208							
15	0.10.00	**163**	226							
16		**181**	244	307						
17			**262**	325						
18			280	**343**	406					
19				**361**	424					
20					**442**	505				
21					**460**	523				
22						**541**	604			
23							**622**			
24							**640**	703		
25								**721**		
26									**802**	
27									**820**	
28										**901**
29										—no grading—
30										**10.00**

In the arc of the selector, 2 separate groups are connected; one is composed of the grading to be tested and the second consists of a perfect group having a number of junctions common to all splits and appearing in the same order.

Exactly the same traffic is directed to the junctions of the 2 groups. The traffic density is adjusted to produce an average loss of approximately 1 percent.

For this method of testing, it is not strictly necessary that the resulting loss figure be exactly 1 percent, a result only possible by repeated tests with varying traffic densities. The purpose of the test is to determine for a particular grading, the size of an equivalent perfect group, and this size is to a minor extent dependent only on the loss figure, provided this does not differ too much from the desired loss figure.

The grading of 40 lines, represented by the symbol 442000, showed a loss of 203 calls in a total of 25,440 calls (40-hour test). By means of graphic interpolation, the grading is found to be equivalent to a perfect group of 31.2 junctions at a loss figure $P=0.8$ percent, which result is exclusively obtained by comparative tests carried out by the machine.

To convert this equivalent into the traffic-carrying capacity of the junction group, the Erlang curves can be used. A perfect group of 31.2 junctions may carry with a loss of 1 percent 641 equated busy-hour calls.

In an article[3] on "graded multiples," Wilkinson shows a number of grading gain curves. By grading gain is understood the percentage difference in efficiency between junctions of 2 groups; one group is the grading in question and the second an imaginary perfect group having a number of junctions equaling the accessibility, i.e., the number of contacts of a split.

For this case, we find a grading gain of

$$\frac{\frac{641}{40}-13.38}{13.38}100=19.9 \text{ percent,}$$

where 13.38 represents the junction efficiency of a 10-line group at $P=0.01$.

Table XI contains the measurements for gradings having a regularly growing number of junctions, 6 multiple splits, 10 point levels, and for 40 artificial hours.

TABLE XI

Symbol	No. of Graded Junctions	Equivalent Number	Grading Gain in Percent
000.10.00	15	14.2	12.1
00.10.000	20	18.4	20.8
055000	25	22.3	24.7
163000	30	25.7	24.8
334000	35	28.7	23.2
442000	40	31.2	19.9

For comparison with the theoretical results of Wilkinson, Fig. 15 shows an enlargement of his Fig. 8 into which the above 6 values were introduced and connected by a curve. Our experimental curve shows values which are slightly below those of Wilkinson's curve marked $g=6$ (g = number of splits), but the actual differences are of no great importance, especially in that part of the curve which interests us most, i.e., in the middle portion.

With Wilkinson's curve the maximum lies at 33 junctions and 27 percent and with the experimental curve at 27 junctions and 25 percent.

[3] R. I. Wilkinson, "The Interconnection of Telephone Systems—Graded Multiples," *Bell System Technical Journal,* v. 10; 1931.

TABLE VIII

FIRST HORIZONTAL LINE

No. of Lines	Grading Symbol										
12	**0064**	0136	0208								
13	**0091**	0163	0235	0307							
14		**0190**	**0262**	0334	0406						
15				**0361**	**0433**	**0505**					
16					0460	**0532**	**0604**				
17							**0631**	0703			
18								**0730**	**0802**		
19										**0901**	
20											0.10.00

Notwithstanding the admitted fact that Molina's theory, which underlies Wilkinson's grading gain curves, is incorrect as it assumes a simplification of the problem which cannot be allowed (no holes in the multiple), it seems to be corroborated by the results obtained with the traffic machine. This may be attributed to the fact that Molina's calculations pertain to gradings exclusively composed of "individuals" and in this instance of "6's," i.e., to less efficient gradings. The assumption of "no holes in the multiple" on the contrary, causes a plus error. The 2 errors apparently balance, with the result that the final result is quite near to the truth.

A point of difference is that the left part of the Wilkinson curves leans to the dotted line pertaining to perfect groups whereas the experimental curve does not show this characteristic. The experimental curve closely resembles a parabola with a slightly inclined axis.

6.7 Verification of the Erlang Loss Formula

Tests were carried out to verify the Erlang loss formula pertaining to perfect groups.

Traffic densities of 30, 90, 150, 210, 270, 300, and 450 equated busy-hour calls were used in 7 extensive tests. Each test comprised a series of 10 20-hour operations.

In each case the traffic was placed on a perfect group of lines, observing at the same time a definite order of testing. The holding time of 2 minutes was equal for all calls.

It appears that a slight but persistent difference exists between the measured and calculated values. The traffic actually placed on the lines located in the beginning of the groups is always slightly higher than the theoretical value and the other lines evidently carry less; the turning point is located approximately at the junction whose number corresponds to the average traffic density expressed in hours.

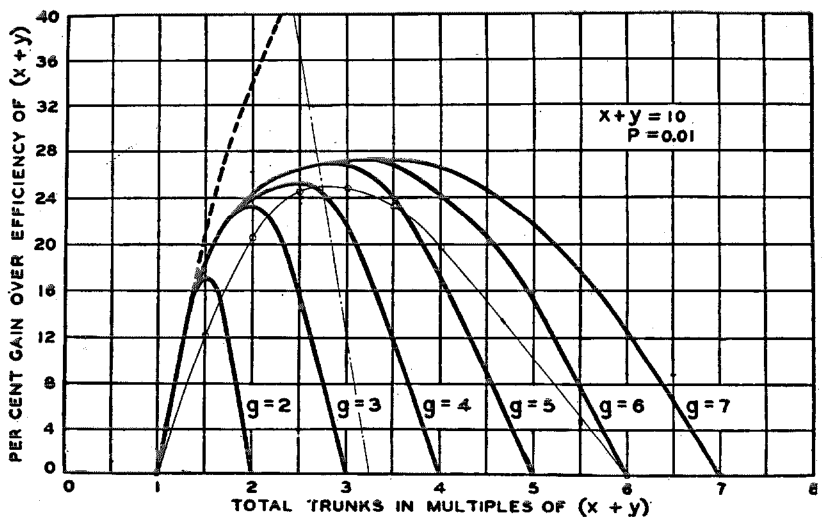


Fig. 15—Graded multiple efficiency. (Reprinted from R. I. Wilkinson, "Interconnection of Telephone Systems—Graded Multiples," Bell System Technical Journal, v. 10, pp 531–564; October, 1931.)

There were 2 types of deviation. In the first type, the measured values of both the beginning and the end exceed the theoretical values. For the second type, the values for the first number of junctions exceed those found by theory whereas those for the last junctions are below the theoretical values. In case we had to do with only the latter type of deviation, the phenomenon could be explained by assuming an error of less than 1 percent in the operation of the time meters. Notwithstanding all our precautions, we believe such an error possible because the closure of electrical contacts always requires a slight follow of the contact springs. Trials intended to measure such possible error have not led to any conclusion.

The deviation of the first type may perhaps be explained by the fact that the number of tests was too small, especially as the error shows up with the tests having the smallest number of calls.

As a conclusion it can be stated that the results obtained with the traffic machine definitely confirm the correctness of Erlang's loss formula for perfect groups, or; conversely, these results confirm the correct operation of the machine.

6.8 Verification of Delay Formulas

As a last example of the results obtained with the traffic machine, we are appending below the results of a test with continuous hunting. A perfect group of 13 junctions was chosen, charged with an average traffic density of 260 calls each of 2 minutes duration.

Introducing these values for x and y into Pollaczek's delay formula[4] for $P(>0)$, we find that this probability amounts to 11.35 percent.

The total number of test calls amounted to 46,800. The delays measured are given in Table XII.

TABLE XII

Test Number	Number of Hours	CTA Counters	Number of Delayed Calls		Delay per Delayed Call Seconds
			Total	Percent	
1	60	333	1663	10.7	19.8
2	40	224	1133	10.9	19.3
3	20	99	508	9.8	18.9
4	20	95	529	10.2	16.3
5	40	230	1197	11.5	18.5
	180	981	5030	10.75	18.9

The figures in the last column were calculated from the 2 preceding columns. A single step of a CTA meter equals 169.4 seconds. However, the result obtained in this manner is to be reduced by 14.1 seconds owing to the design of the machine.

Beside the above test, 2 more tests were made, each extending over 180 artificial hours with the results given in Table XIII.

As a conclusion, it can be stated that Erlang's theory, further developed by Pollaczek, closely corresponds to what was found by the machine. Further it appears that there is a considerable and persistent difference between the observed values and those calculated by Molina's formulas[5] and that, therefore, they are insufficiently correct.

TABLE XIII

No. of Junctions	Traffic Offered in EBHC	Percent Delayed Calls			Delay per Call Expressed in Seconds		
		Observed	Calculated		Observed	Calculated	
			Pol.	Molina		Pol.	Molina
8	120	5.15	5.43	5.90	1.09	1.12	1.57
13	260	10.75	11.35	12.56	2.06	2.02	3.24
20	420	7.83	8.44	9.35	1.22	1.14	1.78

Summary

This traffic machine was developed by engineers of the Bell Telephone Manufacturing Company for making individual studies of the problems of telephone traffic. The results, for all practical purposes, confirm those of such an eminent mathematician as Erlang. Studies of different methods of grading have been pushed further and some new applications and arrangements devised.

[4] F. Pollaczek, "Thorie des Wartens vor 'Schaltern,'" Telegraphen und Fernsprech Technik; 1930.

[5] E. C. Molina, "Application of the Theory of Probability to Telephone Trunking Problems," *Bell System Technical Journal*, v. 6; July, 1927.

Le Matériel Téléphonique Receives "A" Award

IN recognition of its important contributions to the war effort, the United States Army presented the coveted "A" award, comparable to the Army-Navy "E" award in the U.S.A., to Le Matériel Téléphonique, Paris, France, on February 12, 1946.

The presentation was made by Colonel Gallager, U.S.A., Chief Signal Officer, Western Base, representing General Lewis, who was unable to be present. The citation follows:

Colonel Gallager delivering the presentation speech. From right to left are: Colonel Gallager; General Hellot; Colonel Gilson, French Chief Signal Officer; Mr. Joly, Director of Telecommunications representing the P.T.T. Minister; General Merlin, General Inspector of French Army Transmission; and Colonel Cazenave of the French Air Forces.

CITATION

"Le Matériel Téléphonique, of Boulogne-Billancourt, France for meritorious service in connection with military operations is awarded the Achievement 'A" award. This award is given in recognition of efficiency and outstanding achievement in production in the war effort against the common enemy.

"The manufacture of vitally needed mine detectors, radio sets, and telephone equipment by Le Matériel Téléphonique for the United States Army made possible the great successes of the Allied Armies. The speed with which the material was delivered to the United States Army reflects great credit both upon the management and the workers of Le Matériel Téléphonique."

An inspection of the plant was made after the presentation of the Award. Seen above are, left to right; Mr. Queffelean, Sales Manager; Cdt. de Maille, French Liaison; Mr. Roussel, Managing Director; and Colonel Gallager, who presented the Award.

The pennant and certificate were received by General Hellot, President of the Board of Directors of Le Matériel Téléphonique, who extended the thanks of the entire staff for this recognition of its contributions toward the defeat of the enemy. He expressed the hope that a durable peace has at last been attained.

The United States Army similarly recognized the contributions of Laboratoire Central de Télécommunications, formerly Les Laboratoires, Le Matériel Téléphonique, Paris, by presenting an "A" award to it on October 29, 1945.

In Memoriam

GEORGES MARCEL EDME PERROUX

1897–1944

Georges Marcel Edme Perroux was born on December 20, 1897 at Chambery, France. He became actively interested in radio in 1910 when he built his first receiver.

Serving as a volunteer, he was wounded during World War I, and held the rank of lieutenant at its close. He then resumed his studies at l'Ecole Superieure d'Electricite and on graduation entered the radio field. In 1922, he won top honors in Europe for the reception of trans-atlantic high-frequency signals.

When Les Laboratoires Le Matériel Téléphonique were established, he joined its engineering staff and later became a department head. In Paris, London, and Antwerp, he directed a program on ship-to-shore radiotelegraphy which included transmission, reception, and traffic problems. During these experiments, the first radiotelephone link was set up between the continent and the S. S. Berengaria. After serving in Bucharest and Belgrade, he returned to Paris where he made important contributions in the fields of aircraft instrument landing and air navigation.

In 1939, he again volunteered for military service and in 1940 resumed his work at the laboratories. Among his developments for the French Administrations during the next few years were a panoramic receiver, frequency-modulated transmitter-receiver, and various transmitters and receivers for high and medium frequencies.

He became active in the French Forces of the Interior where his excellent command of English made him particularly valuable in dealing with the Allied forces. An enemy detachment, informed of the location of his group, surprised the command post and immediately shot its occupants.

The highest tribute which can be paid to his memory is found in the Divisional Citation bestowed on him on April 20, 1945 by General Delmas, Commanding the 5th Military Region. This citation included the Croix de Guerre with Silver Star.

> "Perroux, Georges, Captain in the Reserve, Group of Sancerrois, volunteer in the Sancerrois, has taken part in the defense of Saint Thibault starting August 15, 1944. Fallen in the hands of the enemy on August 26, 1944, he was savagely slaughtered by them."

Electrical Communication: 1940-1945

War Years' Review—Part II

Editor's Note: This second installment of I. T. & T. associate companies' war activities presents contributions of Federal Telecommunication Laboratories, Inc. and Federal Telephone and Radio Corporation. The initial installment[1] covered activities of Standard Telephones and Cables, Ltd., London, and Standard Telephones and Cables Pty., Ltd., Sydney.

FEDERAL TELECOMMUNICATION LABORATORIES, INC., NEW YORK, NEW YORK

THE laboratories, now known as the Federal Telecommunication Laboratories, were started early in 1941 in New York. When hostilities ceased, the organization included over 950 scientists, engineers, technicians, and administrative personnel. Housing facilities in New York City were progressively expanded and, in 1945, the first 50,000-square-foot unit of a modern laboratory building in Nutley, New Jersey, was opened.

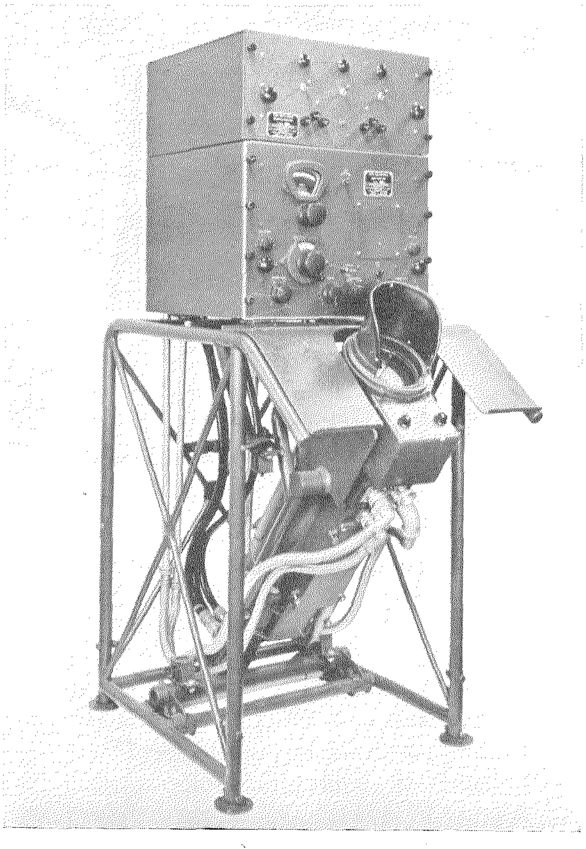


Fig. 1—High-frequency automatic direction finder. The cathode-ray tube and motor-driven goniometer are mounted in the slanted housing.

First as a division of Federal Telephone and Radio Corporation and later as Federal Telecommunication Laboratories, its functions were research and engineering. Federal Telephone and Radio Corporation supplied the mass-production facilities to make up the team that produced advanced radio and electronic equipments in huge quantities for the Armed Forces of the United Nations.

During this period of nearly 5 years, over 160 development contracts, mostly of a secret or confidential nature, were received from the U. S. Army, Navy, and National Defense Research Committee. They varied in nature and included theoretical studies of fundamentals, development of techniques, and design of specific components and systems. Their scope also was varied and encompassed vacuum tubes, radar, communications, aerial navigation, direction finding, and countermeasures. To describe in detail the work of these years is obviously impossible in this review. Moreover, security regulations still prevent publication of certain activities.

In March, 1943, the Laboratories were awarded the Army-Navy "E" for excellence in production. This award was followed in 1944 and 1945 by 3 stars to be placed on the pennant as a symbol of continued excellence in production. Following the cessation of hostilities, public releases of the Army, Navy, and National Defense Research Committee paid glowing tributes to the part played by the Laboratories in the war effort.

[1] "Electrical Communication: 1940–1945," *Electrical Communication*, v. 23, pp. 3–18; March, 1946.

Although the Laboratories were actively engaged in a wide range of engineering and research problems, the predominant program was in the fields of direction finding and aerial navigation.

1 Direction Finding

Fundamental direction-finding research was carried on under the auspices of the National Research Council. It included long-term studies of propagation and ground conditions and their effects on direction-finding performance in all frequency ranges as well as studies of conventional loop direction finders and aircraft direction finders for countermeasure purposes.

Many types of direction-finding equipment employing cathode-ray-tube indication were developed. Particular attention was given to the elimination of polarization errors, which reduced the effectiveness of earlier equipment. A monopole-antenna and counterpoise system and improved transmission lines were developed.[2] Goniometers were designed to give improved performance on several frequency bands.

These developments led to the construction of a large number of fixed shore-type direction finders for the Navy. The use of 4 arrays, spaced several hundred feet from each other and from the central control room, eliminated interaction between antennas and permitted control apparatus to be grouped in a central building for operating convenience. Figs. 1 and 2 show 2 types of these terminal equipments.

For use by the Air Forces, a high-frequency direction finder, SCR-291, suitable for transportation by air and erection in a few hours, was developed. For the collector, telescoping plywood masts, flexible ground mats, and quickly detachable coupling amplifier units were employed. A flexible solid-dielectric high-frequency cable,[3] which had been under development by the I.T.&T. System for several years, gave excellent service. These radio-frequency transmission lines could be run some 250 feet from the antenna system to the goniometer and receiving equipment, simplifying the camouflaging of installations.

SCR-291 direction finders were installed in ground stations all over the world. They were particularly effective in guiding "lost" airplanes back to their bases. Several hundred airplanes and their crews were thus saved.

Studies were made of direction finders operating in all communication frequency ranges for the Army, and in several ranges not previously covered for the Navy.

An equipment, designed for shipboard operation, used improved transmission lines and cathode-ray-tube indication. Securing proper sense operation over the wide frequency range required was a major difficulty. Water-proofing of the system and protection of connections

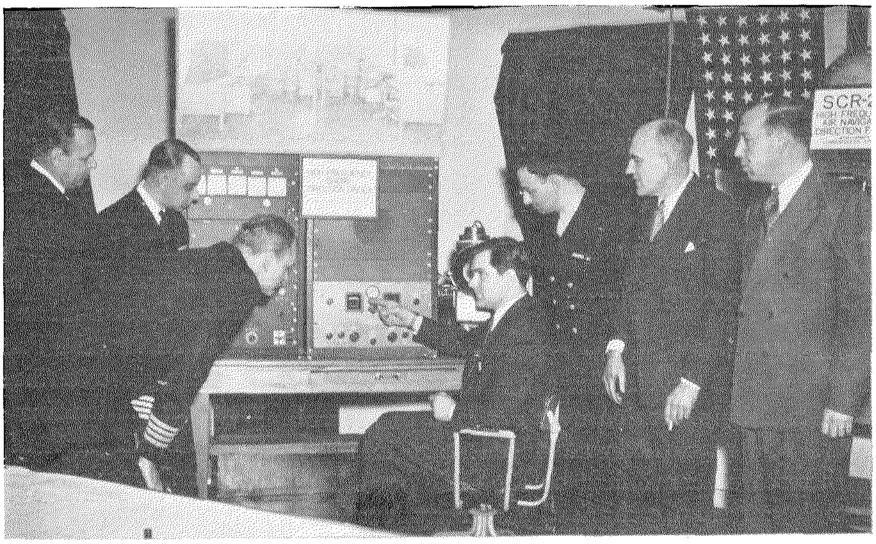


Fig. 2—High-frequency automatic direction finder of the type used on shore by the U. S. Navy and Coast Guard. From left to right: Lt. Commander C. L. Lantz; Lt. Commander A. E. Wolf; Captain J. B. Berkley; Frank Chessus, engineer; Ensign A. Checkoway; and H. H. Buttner and H. Busignies, respectively, president and director of Federal Telecommunication Laboratories.

[2] H. Busignies, "Applications of High-Frequency Solid-Dielectric Flexible Lines to Radio Equipment," *Electrical Communication*, v. 22, n. 4, pp. 295–301; 1945.

[3] N. Marchand, "Special Aspects of High Frequency Flexible Balanced Cables," *Electrical Communication*, v. 22, n. 3, pp. 193–197; 1945.

against salt spray and soot also demanded considerable attention. Numbers of these units were produced in time to contribute to the winning of the Battle of the Atlantic, and eventually most ships of the Atlantic and Pacific Fleets were equipped. A later model simplified frequency-searching operations by incorporation of electronic sweep circuits and by cathode-ray indication of received signals and of the direction of a selected station.

These high-frequency direction finders (HF-DF) were often referred to as "Huff-Duff." The U. S. Navy in commenting on their effectiveness stated, "During the latter part of the war this device was employed largely to track and locate the hordes of Axis submarines in the Atlantic and did it so successfully that sinkings of allied shipping due to submarines in the first few months of the use of "Huff-Duff" were reduced by a factor of 10 to 1 and finally by a 50 to 1 ratio."

Development of direction-finding equipment in all frequency ranges included the radio receivers for these ranges. Receivers were built which were continuously tunable over a very large frequency range.

Work was done on the correlation of radar and direction-finder bearings, primarily to identify single airplanes in a group returning to the base in connection with the ground-control-approach program. This was accomplished by superimposing optically the direction-finder indication as a red radial line on the radar plan-position indicator. Under ideal conditions, the red line passes through the reflection of the airplane which is transmitting.

2 *Aerial Navigation*

2.1 Instrument Landing

An instrument landing system which had been in process of development for the Civil Aeronautics Administration over a period of several years[4] had reached an advanced stage in 1941, with research continuing on the glide path. The complete system comprised a runway localizer, a glide-path unit, and 2 markers. The localizer defined a vertical plane through the center line of the runway, extending for several miles in both directions from the airport. The plane was produced by overlapping directive radiation patterns, each modulated with a different frequency. A marker-beacon transmitter was installed along the approach at 4.5 miles from the point of contact and another was near the boundary of the field. They indicated to the pilot his progress along the course to the landing area.

The slope of the original constant-intensity glide path was very steep at the start and very gradual as the point of contact was approached. To overcome this and other undesireable features, an equi-signal glide path was developed. The equi-signal patterns were produced by 2 antennas placed one above the other on a vertical mast. Each antenna produced lobes of radiation, the intersection of which formed a glide path which was straight to the limit of the distance at which signals could be received. The glide-path equipment was placed near the point of contact and about 400 feet on either side of the center line of the runway. Distortion of the horizontal radiation patterns was incorporated so that the offset from the center line might not produce a curved glide path near the landing area.

The Army realized that such a system would be required for the operation of large numbers of military aircraft during periods of poor visibility and, accordingly, instituted modifications of this system to adapt it for portable use. The resulting equipment is known as the SCS-51 Instrument Landing System.[5] To permit the required demountability, an Intelin cable was developed for both the localizer and glide-path units.

The SCS-51 Instrument Landing System has been installed and used by the Air Technical Service Command and the Air Forces in Europe, North Africa, the Pacific, and elsewhere. Credit has been given to this system by the Army for its usefulness in landing combat and transport airplanes in all parts of the world and under the most unfavorable weather conditions.

The localizer unit employed an array of 5 loop radiators mounted on the roof of a $2\frac{1}{2}$-ton van-

[4] H. H. Buttner and A. G. Kandoian, "Development of Aircraft Instrument Landing Systems," *Electrical Communication*, v. 22, n. 3, pp. 179–192; 1945.

[5] Sidney Pickles, "Army Air Forces' Portable Instrument Landing System," *Electrical Communication*, v. 22, n. 4, pp. 262–294; 1945.

body Army truck. The transmitter, modulator, monitoring equipment, and spare parts were carried in the truck together with an engine-operated generating plant. This unit is shown in Fig. 3.

The glide-path unit was arranged in a similar manner. The transmitter, mechanical modulator, and monitor unit were housed in a single cabinet and the power supply and control units in another. These cabinets, together with a gasoline-engine-driven generator and a supply of spare parts, were mounted on an air-transportable trailer as shown in Fig. 4.

The glide path proved to be very sharp over the last half mile, resulting in extreme up or down indications of the landing indicator. To make the path easier to fly at the lower end, an auxiliary unit was developed which radiated an unmodulated signal sharply toward the point of contact. This signal caused the automatic volume control to lower the sensitivity of the receiver and therby decrease the deflections of the indicator on the last part of the approach. The antenna of this unit was mounted on the same mast with the antennas of the glide-path unit, and the transmitter with its power supply occupied a small cabinet near the trailer housing the glide-path unit.

In planning the future development of instrument landing systems, the Provisional International Civil Aviation Organization, the Commonwealth and Empire Radio Conference on Civil Aviation, and the Army Technical Service Command Electronic Subdivision Advisory Group on Air Navigation have specified the SCS-51 as the basic system to which further attention will be directed.

Fig. 3—Localizer truck for the SCS-51 portable instrument landing system used by the Army Air Forces.

2.2 Very-High-Frequency Radio Range

A very-high-frequency radio range with aural indication was developed to provide navigational facilities on aircraft equipped only with the SCR-522 radio set. This equipment furnished an A-N course which was periodically interrupted to provide a second course at right angles to the first, characterized by an interlocked D-U signal. The supplementary course enabled the pilot to identify the quadrant in which he was located. Incorporation of simultaneous voice permitted communication by the ground station with the pilot without interference with the operation of the radio range.

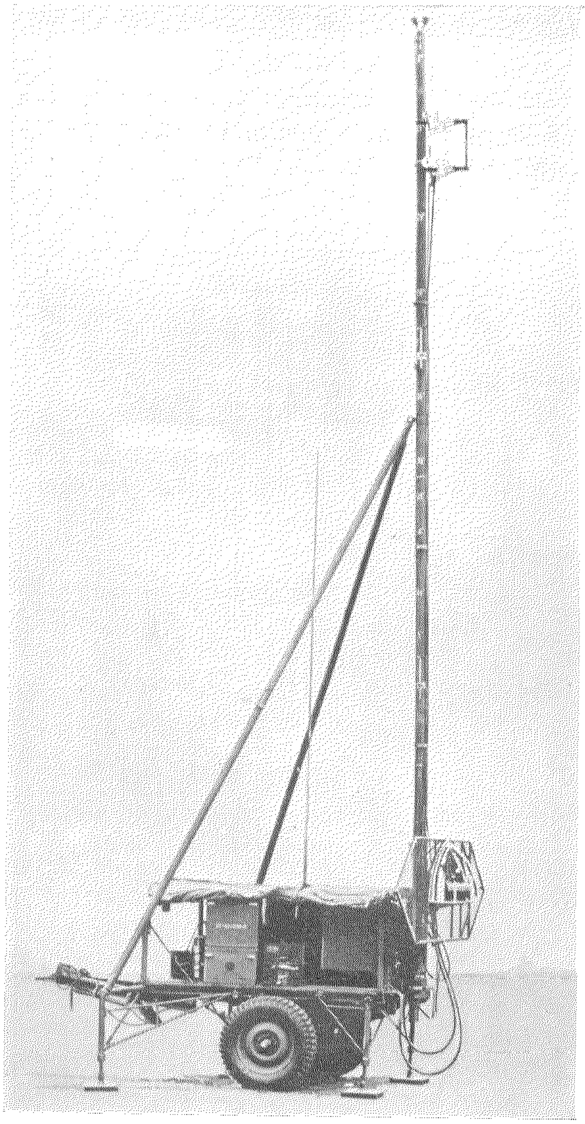


Fig. 4—SCS-51 glide-path transmitter is mounted on a small trailer. The antennas are supported by the demountable ply-wood mast.

2.3 Omnidirectional Radio Range

An omnidirectional radio range was also developed for use in aircraft equipped only with the SCR-522. The range equipment was mounted on a small Army truck. It provided the pilot with a bearing relative to the signal source and indicated the heading to be followed to reach the range station. This radio range required no additional installation in the plane, and was provided with simultaneous voice.

3 Countermeasures

Both offensive and defensive countermeasures were developed. Offensive measures included jamming of enemy communications and radar. Defensive devices included direction finders for detection of enemy radar and antijamming equipment for communications.

3.1 Jamming and Antijamming Equipment

Extensive studies of the theoretical problems involved in the field of countermeasures were conducted. This work, sponsored by the National Defense Research Committee, proved to be of material importance in the development of countermeasures by Federal and other organizations.

An airborne jammer covering the communication band was developed. This equipment, making use of unconventional circuits and features, gave a visual presentation which permitted by comparison methods rapid and accurate tuning of the jamming transmitter to the enemy's frequency. This work was continued under the sponsorship of the National Defense Research Committee.

Telegraphic signals can be jammed with reasonable amounts of power only when the jamming signal contains frequencies which coincide with the continuous-wave signal. It was found increasingly difficult to jam signals as the telegraph keying speed was reduced.

Successful limiters and clippers were constructed to protect receivers from impulse jamming, and from noise jamming of saturation intensity.

A tape printer was developed which operated successfully through jamming signals 10 decibels stronger than the telegraph signals, by virtue of slow transmission speed (about 1 character per second) and the use of selective filters.

3.2 Radar

As early as 1941, research on anti-radar methods had advanced to the stage where solutions of direction-finder problems were reported to the Armed Forces. The success of such countermeasures was demonstrated in a highly valuable manner during the invasion of Normandy when concentrations of enemy fighter airplanes, far from the actual point of attack, searched fruitlessly for nonexisting United Nations squadrons.

It is possible to detect radar signals at distances beyond the operating range of the radar equipment. Thus, automatic direction finders of adequate sensitivity permitted radar transmitters to be located while the searching airplane or ship remained beyond the range of the radar equipment.

A spot-frequency noise jamming equipment was developed for aircraft use against enemy radar. It covered a bandwidth of 4 to 6 megacycles, the midfrequency of which could be set at any frequency in the 550–600-megacycle range.

4 *Pulse-Time Modulation*

The principles of pulse-time modulation[6] indicate its inherent suitability for time-division multiplex[7] operation. The Armed Forces believed that pulse modulation offered certain advantages in wartime communication, even with single-channel systems, and 4 such equipments, designated Radio Link P1, were developed and demonstrated to the Army and Navy in 1943.

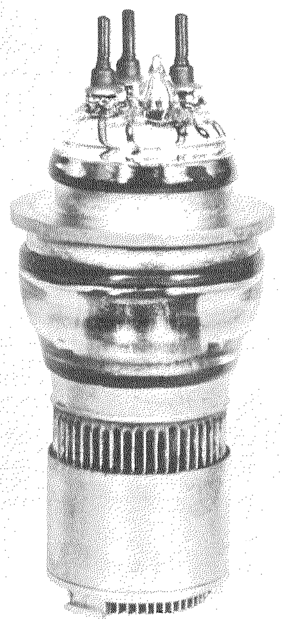


Fig. 5—L600 forced-air-cooled triode designed to produce 25 kilowatts of power at 600 megacycles in pulse radar operation.

Later, 2 new types of equipment were designed for aircraft and for shipboard installation. In 1944, it became evident that enemy countermeasures would be less serious than had been expected, and the adoption of a new system of modulation requiring replacement of existing equipment was considered unjustifiable. Attention was then directed to the development of a 24-channel micro-wave relay system[8] operating on a single carrier frequency.

5 *Vacuum Tubes*

The vacuum-tube laboratory was established in 1941, and during the war devoted its efforts mainly to the development of a line of triodes for operation over a wide range of frequency and power. A number of other vacuum tubes were also developed and, just prior to the cessation of

[6] E. M. Deloraine and E. Labin, "Pulse Time Modulation," *Electrical Communication,* v. 22, n. 2, pp. 91–98; 1944.

[7] D. D. Grieg, "Multiplex Broadcasting," *Electrical Communication,* v. 23, pp. 19–26; March, 1946.

[8] D. D. Grieg and A. M. Levine, "Pulse-Time-Modulated Multiplex Radio Relay System: Multiplex Terminal Equipment," *Electrical Communication,* v. 23, pp. 159–178; June, 1946.

hostilities, developmental contracts were accepted for multicavity magnetrons.

The first tube made, completed in November, 1941, was a facsimile of the British type S25A. Subsequently 3 improved tubes of this design were developed, one of which produced low-power oscillations up to 1300 megacycles. During the war, 580 tubes of these 3 types were delivered.

A somewhat later development was a thoriated-tungsten-filament tube capable of delivering 600 watts output at 35 percent efficiency at 600 megacycles. At present this is the most powerful triode for operation at this frequency. About 200 of these tubes were delivered to the Armed Forces, and the tube is expected to find application in future television and frequency-modulated transmitters. An air-cooled version of this tube shown in Fig. 5 was also developed.

Another triode with thoriated-tungsten filament produced 1000 kilowatts of peak power output at 200 megacycles with 2 tubes as oscillators. Although its high filament-power requirement of 1300 watts limited its application, 51 tubes were delivered to the Armed Forces.

An oxide-coated indirectly heated cathode tube was developed for pulse applications at 600 megacycles. A single tube delivered 560 kilowatts peak power, 300 watts average power, at 600 megacycles, for 1200 hours. The Armed Forces are still interested in equipment utilizing this tube, and 24 tubes have been delivered.

Special equipment has been built to aid in studies of electron optics. This research has been very helpful in solving many vacuum-tube problems.

Unconventional tubes have been produced, combining the multiplexing, modulating, and demodulating processes for pulse-time-modulated multiplex systems. They permit marked simplification of the associated equipment.

6 Guided Missiles

A system was developed to guide a robot aircraft carrying a bomb to its target by remote control from another aircraft. The robot plane may be directed up, down, right, left, or in straight-line flight.

For each change required during flight, a short pulse of very large power is transmitted. The controls are locked in position until a subsequent pulse is received. The extremely short period of transmission, and the selection of one channel out of many, would make it very difficult for the enemy to devise countermeasures which would enable him to take control of the robot airplane.

7 Antennas

For ultra-high-frequency communication between vessels, a broad-band antenna was desired to eliminate antenna tuning controls. A simple, sturdy, loop antenna was developed to provide omnidirectional radiation from 300 to 350 megacycles in a horizontal plane without adjustment.

For a frequency of 400 megacycles, a rotating antenna was designed to be used with pulse-detection systems for azimuth and elevation measurements of meteorological balloons and other mobile targets.

An antenna was designed for a new type of beacon to operate on frequencies between 250 and 285 megacycles, and to use time modulation with a visual indicator instead of amplitude modulation and an aural indicator.

8 Pulse Oscilloscopes

Pulse oscilloscopes were designed primarily for the measurement of pulse and peak power of radar transmitters. They may be used also as conventional wide-band oscilloscopes. A complete unit includes a generator which provides the special pulsing wave forms in conjunction with a calibrating voltage and a full-sweep voltage, and an oscilloscope with vertical and horizontal amplifiers. The units are mounted in cabinets about 5 feet high, with all controls and viewing instruments on the front panel.

9 Radar

In 1941 a proposal was made for a radar transmitter to deliver 200 kilowatts at 200 megacycles. It required the development of a special vacuum tube with a large filament capable of higher emission than that of conventional tubes. After development of tube and transmitter was completed, further work was done to make this suitable for meteorological uses. These developments were successful, and the power was progressively increased. Later, the Army and Navy received 2 other equipments of much greater power.

Progressively higher frequencies came into use for radar, and special types were developed for both the Army and Navy.

An air-transportable laboratory-test-model radar incorporated an antenna which provided adequate directivity over a frequency band extending ±8 percent from the midfrequency. Frequency scanning was thus made possible and provided some protection against jamming.

10 Standardization

A program of standardization was followed in co-operation with other organizations. An important development was the standard aircraft rack for communication equipment. It provides complete mechanical interchangeability for aviation equipment and is comparable to the 19-inch relay rack and standard panels in the field of wire communication.

Standardization covered all of the most commonly used electrical components, including composition resistors, fixed capacitators, primary cells, high-frequency cable, rheostats, electrical indicating instruments, and vacuum tubes.

FEDERAL TELEPHONE AND RADIO CORPORATION, NEWARK, NEW JERSEY

At the beginning of the decade prior to the war, Federal Telegraph Company was engaged primarily in the development and manufacture of radio communication equipment for Mackay Radio and Telegraph Company. The use of its products outside the I.T.&T. System began with the sale of vacuum tubes to broadcast transmitting stations; subsequently, transmitters were manufactured for export. Sales to the United States Government began during the middle of this period and became a substantial part of all production by the end of the decade.

During the war, production was multiplied to meet the needs of the United Nations. Huge quantities of entirely new wartime apparatus were produced while older peacetime designs, found to be adequate for wartime services, were manufactured in ever-expanding volume.

In addition to products which it engineered, Federal Telephone and Radio Corporation manufactured many equipments that had been designed and developed by Federal Telecommunication Laboratories. Notable examples of these are most of the automatic-direction-finder equipments and the equi-signal glide-path equipment for the instrument landing system. The Laboratories collaborated with factory engineers in the design of other equipments such as the localizer for the Army instrument landing system and the very-high-frequency radio range system.

Many years of experience in research, design, and manufacture of direction finders resulted in Federal being the only supplier of automatic direction finders to the U. S. Navy. Thousands of these equipments were installed on ships of all sizes and types.

The SCR-291 automatic direction finder was designed for the U. S. Army and was supplied in large quantities to the Signal Corps for the Air Technical Service Command and the Army Airways Communication System for installation all over the world. These equipments took much of the guesswork out of reconnaissance and air navigation and were instrumental in bringing home numerous airplanes that otherwise might not have returned.

All of the instrument landing equipment, used by the U. S. Army for guiding airplanes to safe landings during periods of poor visibility, was built by Federal. These, too, were used all over the world and in many cases were installed, adjusted, and maintained by Federal-trained civilian personnel. Long-range operations requiring several hours for the round trip to the target and bombing through overcast were much less hazardous when airplanes could be landed with precision on their return to the base regardless of changes in the weather during the mission.

Almost a hundred ground-control-approach radar equipments, AN/MPN-1C, were constructed under extremely difficult conditions of time and material procurement. A large truck and trailer are required to hold this high-precision radar, and its use in landing airplanes equipped only with radio communication apparatus served a vital need. This highly complex apparatus was designed by the National Radiation Laboratory, and Federal produced the second largest quantity of these equipments supplied by 3 manufacturers.

The early design by Mackay Radio of a "packaged" radio communication transmitter and receiver for merchant vessels permitted substantial time savings in installations which previously required the services of skilled radio technicians. These savings were of no small importance in the rapidity with which new ships could be put in service during the first years of the war when enemy submarines were insolently sinking vessels within sight of our own shores. Later, the automatic direction finder played a striking role in turning the tables and making the submarine the prey rather than the hunter.

In addition to the manufacture of radio apparatus, Federal was the largest producer of the EE-8 field telephone set which was widely used by the American and Russian armies in maintaining communication with the vast reaches of "fluid" fronts introduced by highly mechanized warfare. It was the principal supplier of portable telephone repeaters to the U. S. Army Air Forces and Signal Corps and, jointly with the latter organization, developed the EE-99 repeater. This is a very simple but highly flexible equipment which extends the range of operation of field telephones.

The RC-47 units permit complete control of a radio transmitter from a remote receiving location. Thus, advantageous transmission sites may be used while the receiving equipment and operators are placed in positions of greater accessibility and safety. This standard Signal Corps equipment was improved by Federal.

The development and manufacture of millions of feet of solid-dielectric flexible cable suitable for transmitting high radio frequencies contributed invaluably to the practical design of automatic direction finders and other equipments. Improvements in the design and in manufacturing processes for transformers, vacuum tubes, and quartz crystals were not insignificant in the quantity production of telecommunication apparatus for the Armed Forces.

1 Manufacturing Facilities

Initially, manufacturing was carried on in a building in Newark, New Jersey. The available area, less than 100,000 square feet, being inadequate for the increasing production, additional space was leased temporarily in East Newark, New Jersey.

Nearly 200 acres of land at Clifton and Nutley, New Jersey, were acquired to provide permanently for research and manufacturing activities. To date 3 units have been completed on this site for manufacturing and a fourth unit for the research laboratories. Additional units are now under construction to accommodate most of the activities presently being conducted in temporary leased quarters.

At the peak of production over 1,750,000 square feet in some 60 locations were devoted to manufacturing. Several test fields were also used for checking the performance of direction-finder, instrument landing, and radar equipment. The number of regular employees grew from fewer than 500 to more than 13,000 at the peak of the war effort.

2 Aerial Navigation Aids

2.1 Instrument Landing Systems

Because of its pioneering efforts with instrument landing systems and previous production of equipment for the airports serving the principal cities of the United States, Federal was well prepared to develop and furnish the large quantity of instrument landing equipment required for military purposes during the war and was the only producer of this essential equipment for the Army Air Forces. Essential features of this system and descriptions of its development and application have been published in this journal.[9,10,11]

2.2 Radio Range Equipment

When the Bureau of Air Commerce, predecessor of the Civil Aeronautics Administration, began modernizing and extending the civil airways in the United States, Federal was one of 4 concerns supplying the radio equipment.

The most modern type of radio range equipment, shown in Fig. 6, provides simultaneous radio range and radiotelephone signals. It serves all important airports and the principal airways not only in the U. S. A. but also throughout the world. By introducing improvements, Federal became the leading producer of this essential naviagtional aid and, by the end of the war, shipped more equipment than all other U. S. A. manufacturers combined.

Medium-power loop-type radio range equipment was supplied to the Navy for use as localizers at base and training air fields. These equipments are similar to those employed by the Civil Aeronautics Administration for secondary air fields.

A number of portable radio range equipments were designed and manufactured for the Army consisting of a radio transmitter with power rectifier unit, goniometer with automatic radio range keyer, antenna tuning unit, control box, mast, antenna system, generator which may be driven either by a gasoline engine or an alternating-current motor, and the trailer in which all of the apparatus is mounted.

A 4-course radio range equipment, with provision for simultaneous voice transmission, was developed for use at ultra-high frequencies. This design permitted identification of all 4 courses without ambiguity by D-U signals on one pair of courses and A-N signals on the other pair of courses.

2.3 Ground-Control-Approach System

As the art progressed, radar techniques were applied to many phases of warfare. One apparatus, which may have important peacetime application, is the ground-control-approach system. The principal advantage of this system is that only a radio communication transmitter and receiver are required in the airplane. The highly complicated radar equipment is on the ground. Federal and 2 other concerns manufactured this type of equipment, shown in Fig. 7, for the Armed Forces.

The main components of the system are 2 radar equipments. A search radar, having an effective range of about 30 miles and operating at 3000 megacycles (10 centimeters), is used in guiding the airplane to the landing field. The second radar, operating at 10,000 megacycles (3 centimeters), is then used to guide the airplane to within 50 feet of the center of the runway. This radar gives an indication with precision over a sector of 20 degrees in azimuth and 7 degrees in elevation and has a range of 50,000 feet.

The equipment is installed in a trailer which, in service, is

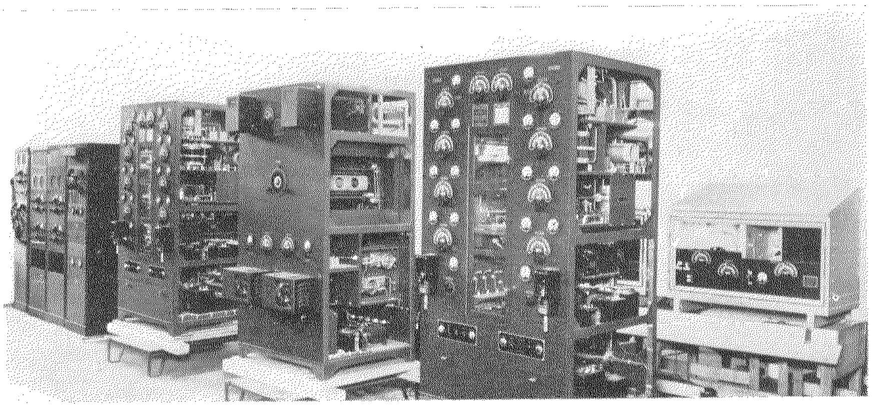


Fig. 6—Civil Aeronautics Authority type of radio range transmitters having provision for simultaneous voice communication.

[9] W. E. Jackson, A. Alford, P. F. Byrne and H. B. Fischer, "The Development of the Civil Aeronautics Authority Instrument Landing System at Indianapolis," *Electrical Communication,* v. 18, pp. 285–302; April, 1940.

[10] H. H. Buttner and A. G. Kandoian, "Development of Aircraft Instrument Landing Systems," *Electrical Communication,* v. 22, n. 3, pp. 179–192; 1945.

[11] Sidney Pickles, "Army Air Forces' Portable Instrument Landing System," *Electrical Communication,* v. 22, n. 4, pp. 262–294; 1945.

located near the end of the landing runway. The operator informs the pilot by ordinary 2-way radiotelephony of his position; the term "talk-down" has been commonly used to identify this type of landing. While the system requires only a radio transmitter and receiver in the airplane, the pilot must rely entirely on instructions from the ground and has no means for checking this information. Under normal conditions and regardless of types, airplanes can be landed at a rate of approximately 1 every 2 minutes with this AN/MPN-1C equipment.

2.4 Other Radio Aids

A considerable quantity of ultra-high-frequency fan-marker equipments, originally designed for the Civil Aeronautics Administration, was manufactured during the war for the U. S. Signal Corps.

3 Radio Communication

3.1 Telegraph Transmitters

Because of its previous experience in the design and manufacture of radiotelegraph communication equipment for Mackay Radio[12] and other I.T.&T. System companies,[13] Federal was well prepared to produce Radio Transmitter BC-339 in sufficient quantities to equip most of the important stations in the extensive network of point-to-point high-frequency circuits operated by the U. S. Signal Corps. A feature of the design is that the chassis containing the crystals and low-level radio-frequency circuits may be rolled out for inspection and maintenance. The plate-supply rectifier and other auxiliaries are contained within the cabinet.

Key radio stations in the Army network were equipped with Radio-Frequency Power Amplifier BC-340 which, together with accessories and transmitter BC-339 as an exciter, provided an output of 10 kilowatts. The complete equipment is shown in Fig. 8.

Radio Transmitter BC-447 consists of 2 transmitters within a common frame, one designed to

[12] Haraden Pratt, "Plant Facilities of the Mackay Radio and Telegraph Company in the New York Area," *Electrical Communication*, v. 20, n. 1, pp. 32–43; 1941.
[13] F. D. Webster and R. E. Downing, "A New Short Wave Radio Transmitting Equipment for South America," *Electrical Communication*, v. 20, n. 3, pp. 217–228; 1942.

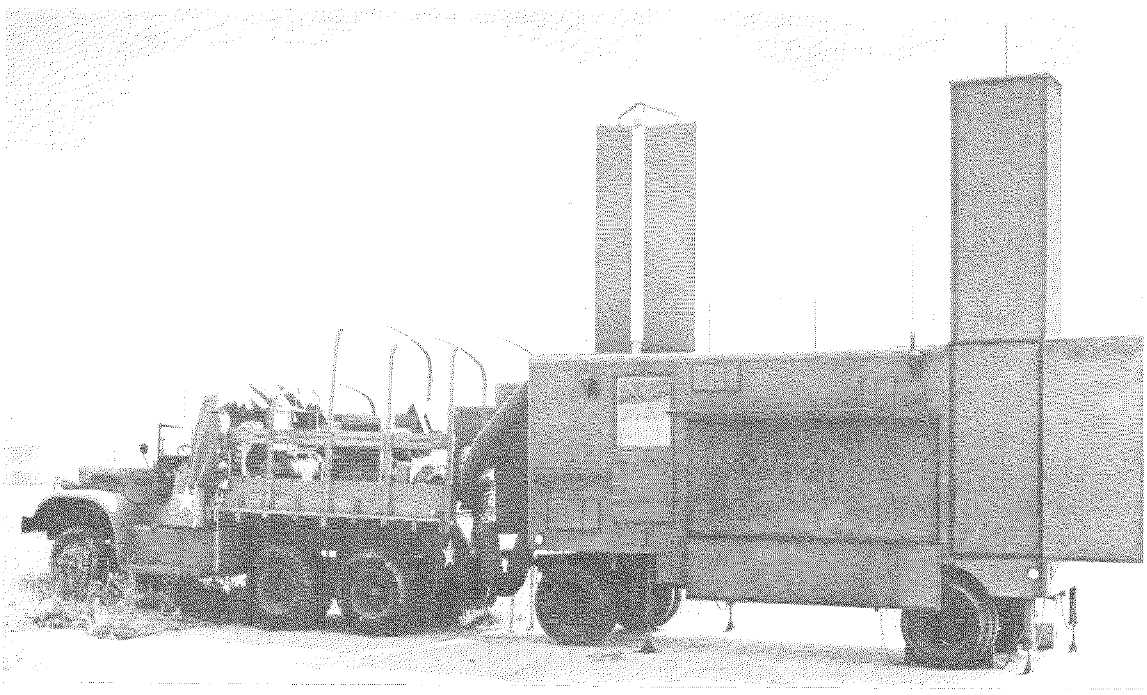


Fig. 7—Ground control approach equipment, AN/MPN-1C, for landing aircraft. High-precision radar indications permit the operator to inform the pilot constantly of the position of his airplane during landing. Only a radiotelephone transmitter and receiver for communication are needed in the aircraft.

operate at any frequency between 4 and 13.4 megacycles and the other at any frequency between 2 and 8 megacycles. The power output from each transmitter is 300 watts.

An output of 350 watts at any frequency between 150 and 350 kilocycles is obtained from Radio Transmitter BC-365. These transmitters provided very satisfactory service where high-frequency transmission was unsuitable because of skip distance or other sky-wave-transmission deficiencies.

Radio Transmitter 170A, rated for an output of 300 watts, and Power Amplifier 164A, rated for 2 kilowatts output, were designed and manufactured for use from Seattle to Alaska and within that territory. Any one of 5 preadjusted frequencies between 100 and 550 kilocycles may be selected by a front-panel switch. Normally 4 frequencies are crystal controlled and a master oscillator determines the other frequency.

Many years of experience with low-frequency radio communication greatly facilitated design to specifications of the Civil Aeronautics Administration of a transmitter, shown in Fig. 9, for high-speed point-to-point radiotelegraphy at any frequency between 80 and 200 kilocycles with an output of 10 kilowatts. These highly dependable low frequencies are essential in Alaska and Canada where high-frequency radio communication is seriously interrupted at times of high sun-spot activity. The transmitting equipment included an exciter unit, which may be operated as a 500-watt transmitter, power-amplifier, rectifier power supply, antenna tuning control, antenna loading inductors, remote-control apparatus, and certain installation material.

Type THS transmitting equipment was also designed to specifications of the Civil Aeronautics Administration to provide high-speed point-to-point radiotelegraph service in the control of overseas flights. Each radio-frequency unit is divided into 2 sections, a driver and a power amplifier. The transmitter operates at any frequency between 5.5 and 24 megacycles with a maximum rated output of 20 kilowatts. Each

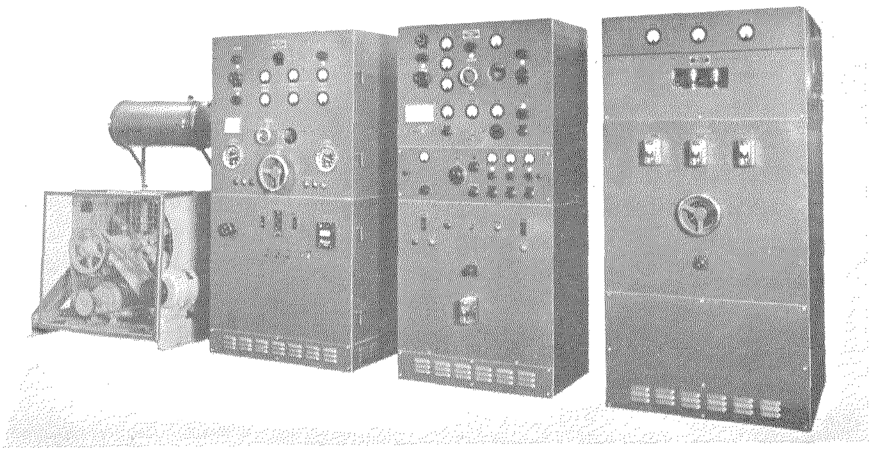


Fig. 8—10-kilowatt radiotelegraph transmitter consisting of water-cooling unit, rectifier, 1-kilowatt transmitter BC-339, and amplifier BC-340. Frequency range is from 4 to 26.5 megacycles.

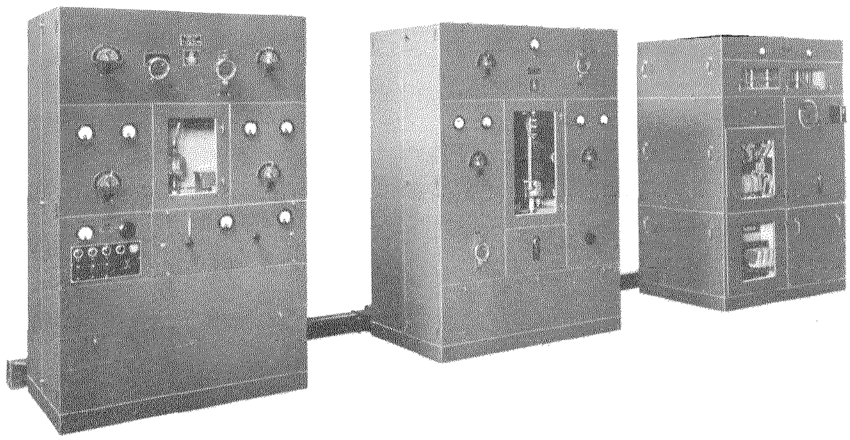


Fig. 9—These 3 units, exciter, power amplifier, and rectifier, comprise a 10-kilowatt radiotelegraph installation for operation between 80 and 200 kilocycles.

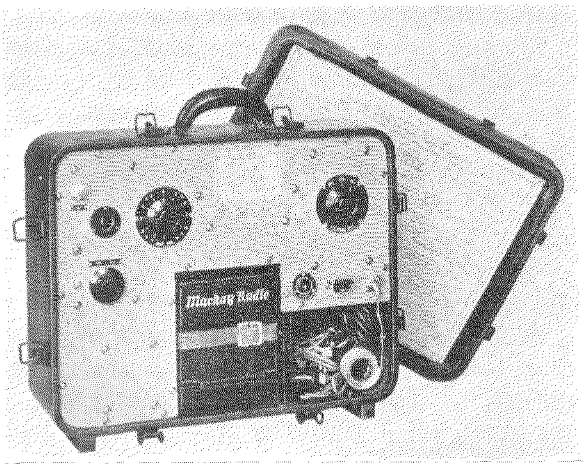


Fig. 10—Portable emergency lifeboat transmitter for use by untrained personnel. Distress signals are transmitted at 500 kilocycles from a 5-watt transmitter. The storage battery will operate the set for 1½ hours continuously or for 48 intermittent transmissions of 2 minutes each. Pressing a button initiates each transmission.

station in which a number of these transmitters are usually installed has a rectifier to deliver up to 225 kilowatts of plate current at voltages up to 12,000.

3.2 Telephone Transmitters

A number of 25-watt 200-to-410-kilocycle radiotelephone transmitters were manufactured for the U. S. Signal Corps to be installed at airports for traffic control.

Radio Transmitter 270, which now provides radio communication between many cities in South America, was also produced during the war for the U. S. Signal Corps.

Another transmitter, FTR-3, which was initially designed for general commercial service, was manufactured in considerable quantities for the U. S. Signal Corps, Civil Aeronautics Administration, U. S. Navy, and the Canadian Government. This 3-kilowatt multiunit high-frequency equipment is similar to that previously delivered to United Airlines[14] and affords the same flexibility in choice of units to provide any desired service.

[14] Devereaux Martin, "A New Unit Type Multi-frequency 5 Kilowatt Transmitting Equipment," *Electrical Communication*, v. 19, n. 4, pp. 93–98; 1941.

3.3 Marine Radio

Portable emergency radio transmitting equipment, type 168, is intended to be stored on a vessel for immediate removal to a lifeboat or similar craft in case of emergency. It is designed for operation by untrained persons and will automatically transmit the distress signal after the start button is pressed. Use of this device, shown in Fig. 10, resulted in the saving of many lives that might otherwise have been lost.

Lifeboat transmitter 101-B was manufactured for installation in a ship's lifeboat to provide emergency communication between the lifeboat and a rescue vessel.

Sea rescue equipment was developed for the use of personnel adrift at sea. It may be taken aboard a lifeboat or liferaft from a surface vessel or it may be carried by an aircraft operating over seas. It includes a hand-operated generator, radio transmitter, and accessories in a waterproof bag.

The introduction of Marine Radio Unit[15] FT-105 for maritime service at intermediate frequencies was so well received that Marine Radio Unit[16] FT-102 was designed to supplement it by providing communication at high frequencies. Marine Radio Unit FT-106 is a combination of FT-102 and FT-105 units.

[15] E. J. Girard, "A New Marine Radio Unit for Cargo Vessels," *Electrical Communication*, v. 20, n. 2, pp. 71–72; 1941.

[16] E. J. Girard, "The H. F. Marine Radio Unit," *Electrical Communication*, v. 21, n. 2, pp. 85–88; 1943.

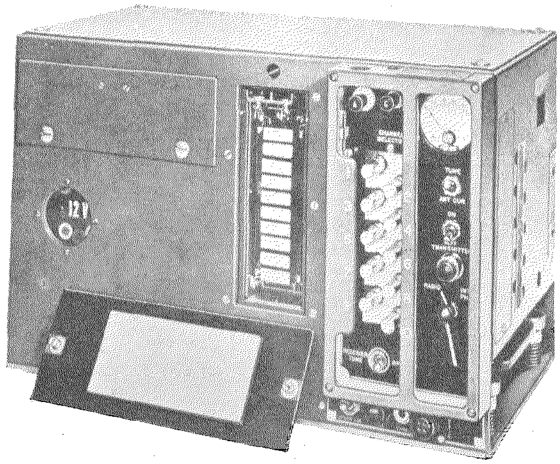


Fig. 11—BC-604 frequency-modulated radiotelephone transmitter for vehicular use. This 30-watt transmitter operates at any of 10 preadjusted frequencies from 20 to 30 megacycles.

Model T-106 transmitter was designed and built to U. S. Coast Guard specifications to provide continuous-wave radiotelegraph or radiotelephone service for ships.

Radio transmitter 149 was manufactured for shipboard installation to provide emergency transmission with a power output of 25 watts on any of 5 predetermined frequencies between 350 and 500 kilocycles.

Other transmitters for marine service manufactured during the war period included Radio Transmitters 156 and 167, each providing an output of 200 watts in the high-frequency bands.

3.4 Vehicular Radio

Federal became one of the first producers of radio transmitters for use on vehicles of the U. S. Signal Corps when it began manufacturing Radio Set SCR-197. The 400-watt radio transmitter and all auxiliaries are mounted in a motor truck which pulls a trailer carrying the receiving apparatus. A complete portable radio station for a large field organization is thus provided.

The U. S. Navy received a number of equipments mounted in trailers which included 2 FTR-3 3-kilowatt multiunit radio transmitters, control apparatus, and certain accessories.

The quantities of Radio Transmitter BC-604 delivered to the U. S. Signal Corps were so large that special assembly lines were prepared to expedite manufacture. These low-power radiotelephone transmitters were designed for use in a truck, tank, reconnaissance car, command car, or other military vehicle. The BC-604 may be seen in Fig. 11.

3.5 Receivers

High-quality radio receivers specially designed for communication purposes were manufactured. These included the R-100, with a tuning range from 90 to 1500 kilocycles for general purposes; the RBA, with a tuning range from 15 to 600 kilocycles for the U. S. Navy; type 128, with a tuning range from 15 to 650 kilocycles for maritime service; type 138, with a tuning range from 85 to 550 kilocycles and from 1.9 to 24 megacycles for maritime service; the fixed-tuned receivers for auto alarm equipments; and the receivers for direction finders, both manual and automatic-indication types.

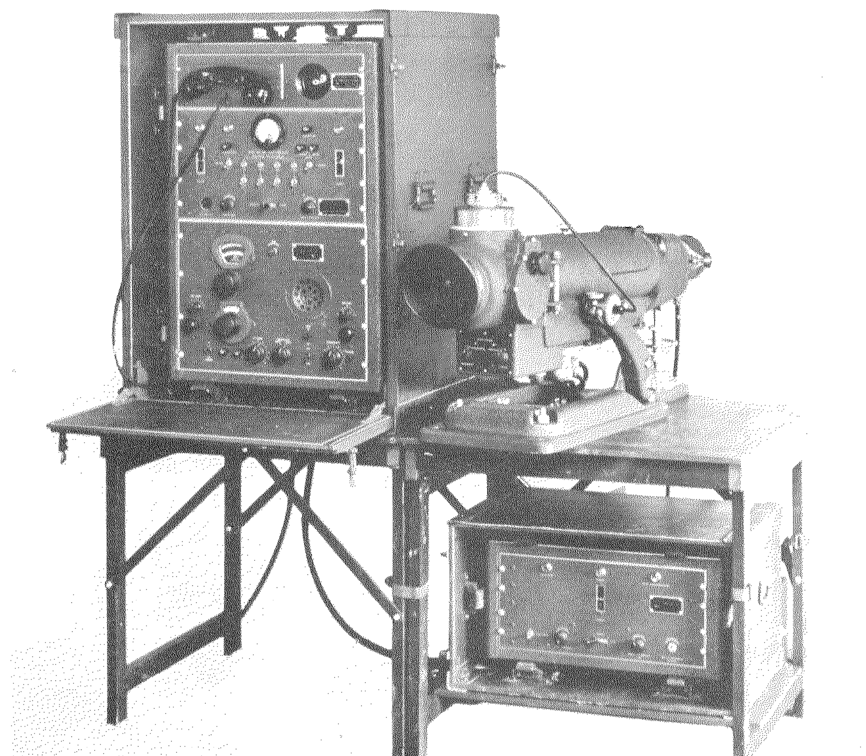


Fig. 12—SCR-502 automatic direction finder. This is a semi-portable equipment for operation between 1.5 and 30 megacycles.

3.6 Aircraft Transmitter

The type ITA-100 radio transmitter was designed and built for use on military aircraft.

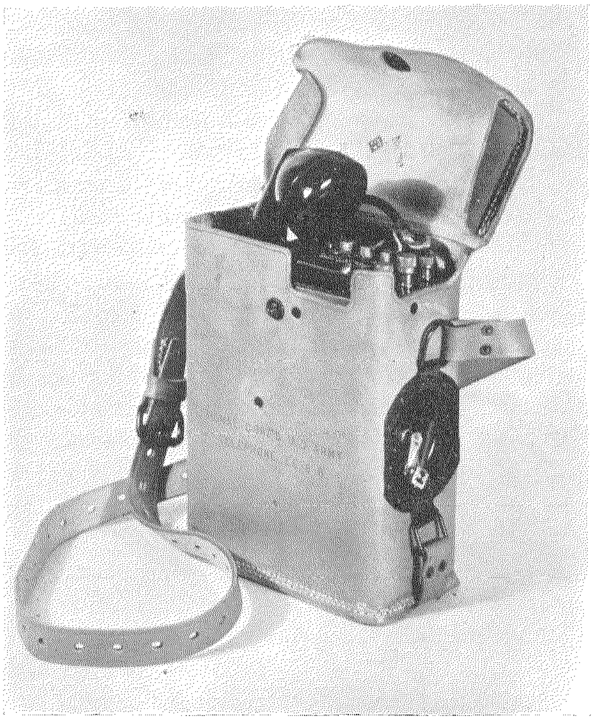


Fig. 13—EE8 field telephone set manufactured in hugh quantities.

3.7 Broadcast Transmitters

Previous experience with the manufacture of broadcast transmitting equipment including the 50-kilowatt transmitter for WABC,[17] and the 50-kilowatt high-frequency transmitters for the Columbia Broadcasting System international broadcast service[18] was of great benefit in the design, manufacture, and installation of 2 broadcast transmitters[19] rated at 200 kilowatts each for the Office of War Information. Programs directed over these facilities are credited with assisting in the early capitulation of the Japanese ruler.

3.8 Radar

Federal built the keyer portion of the first radar set manufactured for the U. S. Signal Corps and subsequently manufactured Keyer BC-985-A, Transmitter BC-982-A, Radio Modulator BC-983-A, and Rectifier RA-67-A in behalf of the General Electric Company which was prime contractor for Radio Set SCR-527.

[17] E. M. Ostlund, "WABC—Key Station of the Columbia Broadcasting System," *Electrical Communication*, v. 21, n. 1, pp. 61–72; 1942.

[18] H. Romander, "New 50-Kilowatt CBS International Broadcasters," *Electrical Communication*, v. 21, n. 2, pp. 112–123; 1943.

[19] H. Romander, "200-Kilowatt High-Frequency Broadcast Transmitters," *Electrical Communication*, v. 22, n. 4, pp. 253–261; 1945.

4 Direction Finders

Federal developed the first commercial direction finder for marine service in 1921 and has continually improved these equipments. Radio Direction Finders[20] 105 and 106 were manufactured in great quantities for the large fleet of merchant vessels constructed during the war.

Automatic direction finders, developed in Federal Laboratories, were made in various designs for land, ship, and portable services. Supplied in considerable quantities, they were urgently required to combat enemy submarine activities. The German Navy attempted to maintain security by transmitting radio signals for very brief periods of time. However, the instantaneous visual bearings provided by 2 or more direction finders afforded knowledge of a submarine's position so that offensive action could be taken. This apparatus operated in various frequency bands from 250 kilocycles to 3000 megacycles. Fig. 12 shows one of these equipments.

[20] E. H. Price and W. J. Gillule, "Marine Navigation Aids," *Electrical Communication*, v. 22, n. 1, pp. 56–69; 1944.

Fig. 14—Convertible magneto telephone. The cradle may be reversed to convert it to a wall-type instrument.

5 *Telephone Products*

A number of countries where I.T.&T. associate companies manufactured all types of telephone equipment were occupied by the Axis. To replace this lost manufacturing capacity, a Telephone Division was set up in Newark, New Jersey, in 1940. On the entry of the United States into the war, these facilities were made available to the Armed Forces for the production of military communication equipment.

Numerous telephone facilities were developed to meet the severe requirements of the Armed Forces and necessitated many new components as well as revolutionary types of small compact telephone equipments not previously available.

5.1 Telephone Sets

The Telephone Product line was largely engaged in producing portable field telephone equipment for the U. S. Signal Corps. It was one of the first and became the largest producer of the EE-8 field telephone sets shown in Fig. 13, producing over 20,000 sets per month and a total of over 450,000 sets. Major savings in critical material, effected by the use of non-critical materials, amounted to 70 tons of aluminum, 30 tons of brass, 10 tons of beryllium copper, and 20 tons of cobalt steel per 100,000 telephone field sets.

A Russian type field telephone set, employing the components of the American EE-8 and assembled in a metal case, was designed and produced in substantial quantities.

Numerous other types of telephone instruments were furnished such as the TP-6 common-battery telephone set, the T-30 throat microphone, the TS-13 hand set, and the T-17 microphone.

The first convertible magneto telephone ever made in the United States was designed and produced for the Signal Corps. A screw driver only is used to reverse the cradle and convert a table model into a wall-type instrument. This telephone set is shown in Fig. 14.

5.2 Small Components

The development of "midget" switching keys and supervisory drops contributed in a major degree towards portable field switchboards

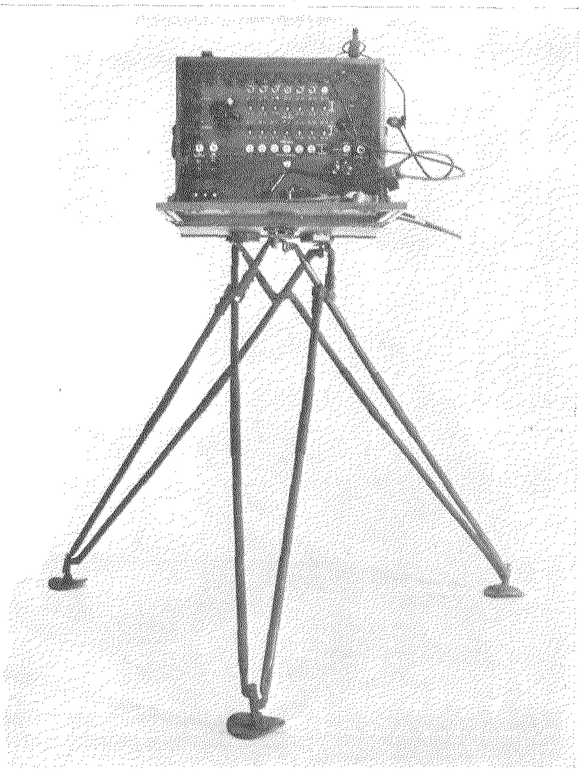


Fig. 15—Flash range-finding switchboard used in determining location of enemy guns.

which were smaller and lighter than any previously available. The FTR-810 lever key switch (midget type) employs many of the same basic parts as the standard FTR-800 Universal key switch. The new FTR-802A supervisory drop (midget type) requires only half the space needed for the former designs. These midget units may be mounted on 7/16-inch centers.

5.3 Switchboards and Remote-Control Equipment

A quantity of light-weight switchboards embodying the midget components were delivered for use in North Africa. Providing for 60 lines and having 10 cord circuits, they were particularly suited for small exchanges. Military cordless switchboards with a capacity for 10 lines and 5 trunk circuits, arranged so that each unit could be removed for inspection and maintenance, were supplied to the Netherlands Government.

Particularly noteworthy in switchboard developments was the SD-4 range-finder switchboard, Fig. 15, designed for determining by

Fig. 16—Equipment used at a radio transmitter to be controlled from a remote position. This apparatus operates with that shown in Fig. 17.

triangulation the range and location of enemy guns. It was used in measuring the time for sound to arrive at 2 to 6 different positions. The switchboard, conveniently portable in a watertight metal case, had an ingenious tripod to permit rapid setting up for operation.

Several remote-control equipments were manufactured in large quantities. The RM-29 unit was designed for use with field radiotelephone equipments. A through-position locking-type selector switch affords means for handling either through traffic, communications with the radio set, or with a distant EE-8 field telephone set. The AN/TRA-2, shown in Figs. 16 and 17, permits the remote control of a radio transmitter. On a 2- or 4-wire basis, it provides "press-to-talk" control of the radio set, volume limiting of the transmission level to the radio transmitter, listening at remote stations with either phones or loudspeaker, intercommunication among attendants, manual volume control for headphones at the remote stations, automatic radio repeater operation, and facilities for 3 attendants at the remote station.

5.4 Power Supplies

There were 29 different types of power plants designed and produced for the telephone and telegraph installations of the Soviet Union which were furnished through the U. S. Treasury Department. Over 400 complete power plants, ranging in size up to 25 kilovolt-amperes, were delivered. It is noteworthy that the telephone and telegraph power plants embody the largest selenium-rectifier battery chargers ever manufactured.

5.5 Automatic Telephone Apparatus

In addition to the strictly military types of telephone communication equipment, 30,000 lines of 7A2 Rotary Automatic central-office telephone apparatus were delivered to Puerto Rico and Brazil. Expansion of their telephone facilities was necessitated by activities in defense of the western hemisphere. Approximately 3000 lines of PABX equipment were furnished to the U. S. Signal Corps for installation in New Zealand during the South Pacific campaigns.

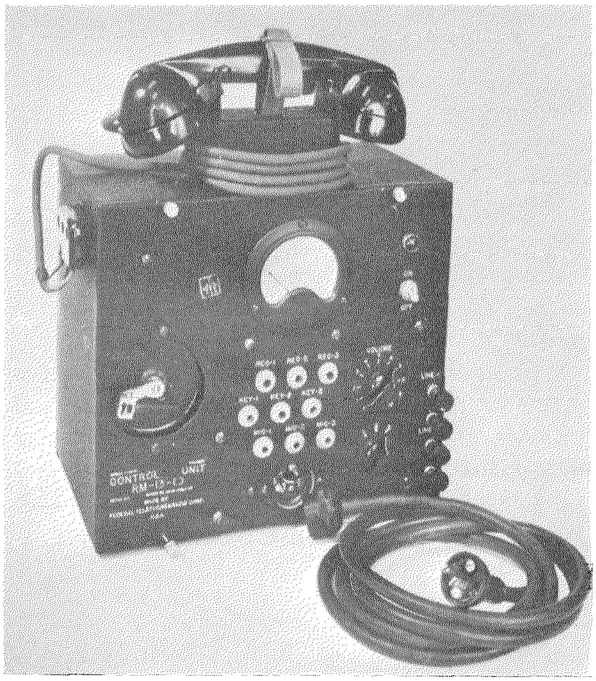


Fig. 17—Equipment used at the remote location from which a radio transmitter is to be controlled.

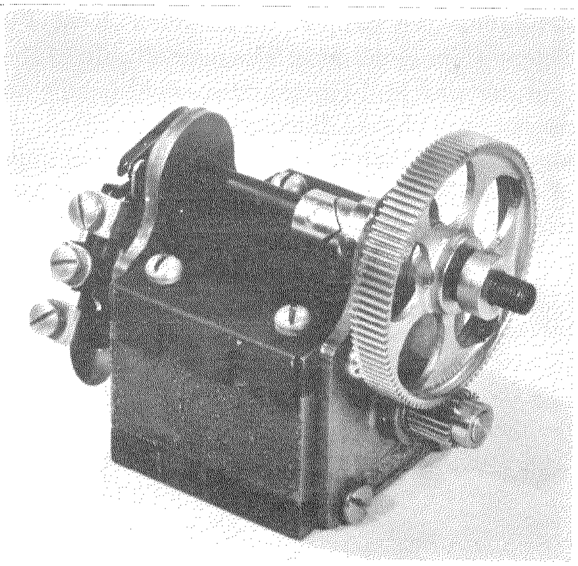


Fig. 18—The bar-type permanent magnets of this generator are assembled with the pole pieces to provide a dustproof enclosure for the armature.

Numerous Federal telephone components found application in military equipment manufactured by other concerns. The FTR-800 automatic selector, because of its high-speed operation and compactness, was incorporated in aircraft and other equipments where size and weight were important factors.

5.6 Generators

Federal was the leading manufacturer of the GN-38B generator, an essential component in the EE-8 field telephone and other types of equipment. This generator, which may be seen in Fig. 18, represented a radical departure from conventional design in that it used bar-type permanent magnets which, when assembled with the pole pieces of the generator and the end plates, formed a dustproof enclosure that completely protected the armature winding.

6 *Wire Transmission Products*

This product line came into being through the development of the American equivalent of the portable combined terminal and intermediate 4-wire telephone repeater which Standard Telephones and Cables, Ltd., London, England, designed and built for the British Armed Services. From its inauguration early in 1942, it rapidly became the principal supplier of all types of portable telephone repeaters used by both the Air and Signal Corps of the U. S. Army. In addition to furnishing the American Armed Forces, it designed and supplied special types of telephone repeaters to the British and the Russians.

The acceptance of these telephone repeaters by the signal branches of the military services led to the development and production of other portable wire-transmission equipments such as voice-frequency ringers, remote-control units, speech-plus-duplex, carrier telephone systems, single-channel carrier telephone equipment, push-to-type telegraph terminals, transmission sets, and a waterproof field telephone set incorporating terminal amplification. Here again, small components played an important role in cutting down the size and weight of communication equipment without any sacrifice in transmission performance or accessability for operational and maintenance purposes.

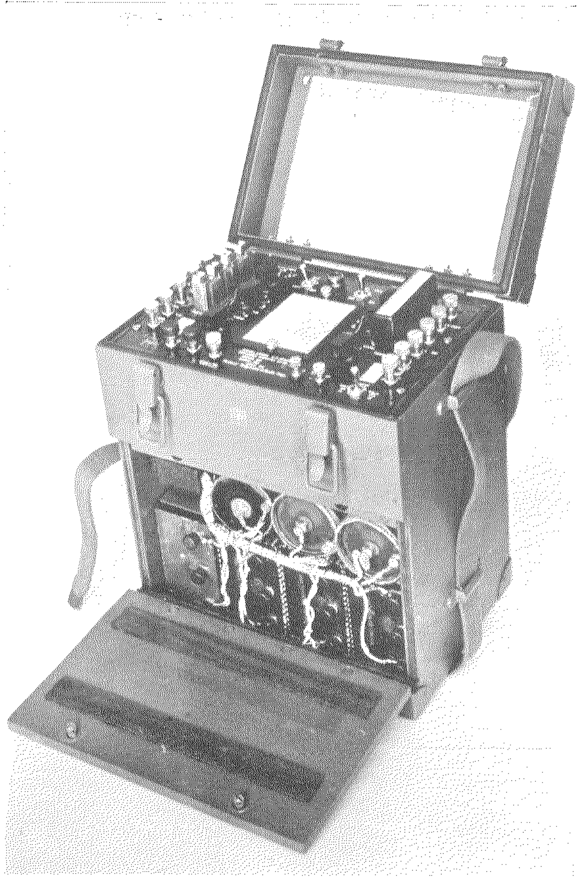


Fig. 19—Designed as the simplest form of telephone repeater, the EE-99 may be used for terminating a 4-wire line or as an intermediate repeater.

6.1 Telephone Repeaters

Commercial telephone repeaters, while more compact than those available in World War I, still were too large for portable use. A single unit should contain not only the repeater but the source of power and testing facilities to permit proper adjustment under field conditions. The development of the simplest form of telephone repeater to meet these military requirements was carried on jointly with the U. S. Signal Corps Ground Signal Laboratory and resulted in the EE-99 4-wire telephone repeater shown in Fig. 19.

The EE-99 repeater was mounted in a weatherproof case 14 by 11 by 8 inches; with either dry cells or a power supply unit, it weighed less than 40 pounds. The repeater was designed to serve primarily as a 4-wire terminating or intermediate repeater with 3 degrees of equalization to compensate for different lengths of field wire under variable weather conditions. The amplifier input and output transformers were arranged ingeniously to provide not only the 2-wire hybrid connections but also the simplex connections permitting the through-phantom circuit to be used for ordinary 20-cycle ringing current or telegraph signal pulses. It was also equipped with a simple neon-tube indicating device to determine the proper transmission level for different line conditions. The over-all gain of the repeater was 35 decibels and it could handle an output level of +15 dbm satisfactorily. Monitoring and talking arrangements for both directions of transmission were also provided and the line wire protectors were mounted right in the repeater unit.

Thousands of EE-99 repeaters were manufactured and an average production as high as 90 was reached in a single 8-hour shift.

An outgrowth of the EE-99 was a repeater designed specially for operation over the British field quad, the TP-7, a 4-wire terminating and intermediate telephone repeater. While this apparatus was furnished in portable form, its repeater and power supply units were designed for standard 19-inch relay-rack mounting and could be easily removed from the carrying cases and mounted on standard central-office relay racks. The TP-7 repeater embodied all the operating features of the EE-99 but was equalized for transmission up to 10 kilocycles and was capable of operating at a transmission level of +20 dbm. Operation was from 100 to 130 or 200 to 250 volts alternating current or from a 12-volt storage battery. The complete portable unit with spare tubes and vibrators weighed 45 pounds and could be easily carried by a man.

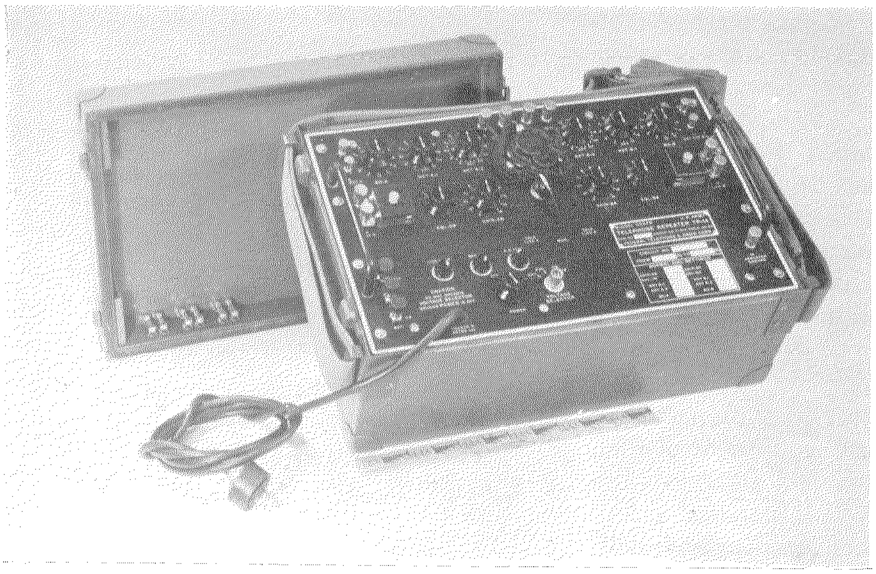


Fig. 20—This 2-wire telephone repeater, TP-14, can be removed from the carrying case and installed on a standard 19-inch rack. It contains fully adjustable networks for balancing nonloaded open wire and cable circuits.

The simplest repeater design, the EE-89A, was for use when only one or possibly 2 repeaters were required on a single 2-wire circuit and was of the so-called "21" type. It was adapted for dry-battery operation and was used where adjacent line sections were similar. A single telephone receiver for monitoring purposes and a single gain control were the only operational facilities provided. The unit in its carrying case measures 7 by 8 by 9 inches and weighs less than 8 pounds without the battery.

Possibly the most outstanding telephone repeater development was the TP-14, Fig. 20, designed for the U. S. Signal Corps. This 2-wire repeater of the conventional "22" type was a complete portable unit including amplifiers, networks, and power supply mounted in a carrying case approximately 20 by 11 by 9 inches and weighing about 48 pounds. It contained fully adjustable networks for balancing all types of nonloaded open wire and cable circuits. Power consumption was only 11 watts and operation was from either alternating-voltage of 100–130 or 200–250 volts or from a 12-volt storage battery or dry cells. The complete unit could be readily removed from the carrying case and mounted on a standard 19-inch relay rack.

A modification of the TP-14 resulted in the FTR-105A 2-wire repeater for the Russian Government. This repeater was designed for fixed locations and operation from standard central-office batteries.

6.2 Voice-Frequency Signalling and Remote Control

In the development of special voice-frequency signaling devices, it was necessary to provide for both American and European standard voice frequencies. The American standard is 1000 cycles and the European is 500 cycles, both modulated by 20 cycles. There was developed an exceedingly simple and compact voice-frequency ringer unit, FTR101-B, weighing less than 48 pounds and housed in a carrying case 20 by 10 by 8 inches. The ringer and power units are capable of being mounted on 19-inch standard relay racks. The unit not only met the American and European ringing-frequency requirements but in an emergency could be operated on either 1000- or 500-cycle unmodulated signals. It is the acme of simplicity since it is a vacuum-tube-operated device employing a common flat-type

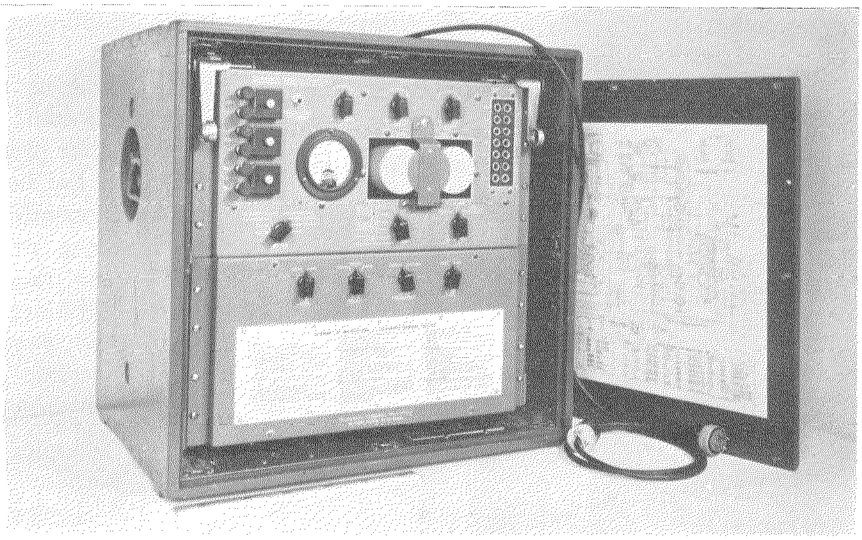


Fig. 21—Front view of "Speech Plus Duplex" telegraph terminal.

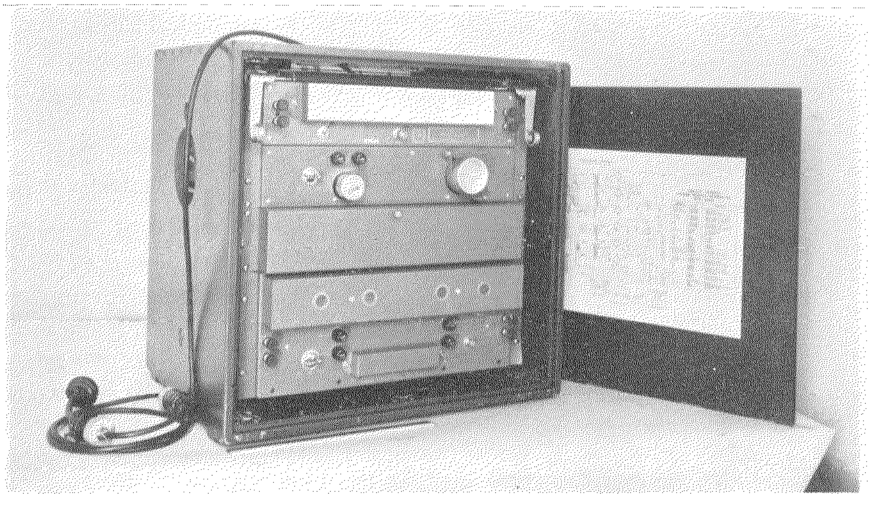


Fig. 22—Rear view of "Speech Plus Duplex" telegraph terminal.

relay for transmitting and another for receiving. Under operating conditions this unit showed remarkable freedom from false rings and was capable of long periods of operation without trouble, excess maintenance, or adjustment. Its sensitivity was better than −30 dbm and it operated with an initial adjustment on any signal strength between −30 and 0 dbm.

Close to 10,000 RC-47 remote-control units were produced. A complete redesign by Federal of the previous model was accepted by the U. S. Signal Corps as standard and reduced size and weight by 30 and 50 percent, respectively. This remote-control unit was part of the SCR-188A radio set and permitted radio transmitter BC-191 to be controlled remotely from the radio receiving location.

6.3 Speech Plus Duplex

The American signal services early recognized the potentialities of the Speech-Plus-Duplex telegraph terminal equipment designed by Standard Telephones & Cables, Ltd., London, for the British Signals. As telegraph practices and particularly leg circuits incorporated in the telegraph equipment standardized by the U. S. Signal Corps were different from the British requirements, the resulting American design embodied in the TH-1/TCC-1 provides for a much wider field of application than its British counterpart. Front and rear views are shown in Figs. 21 and 22.

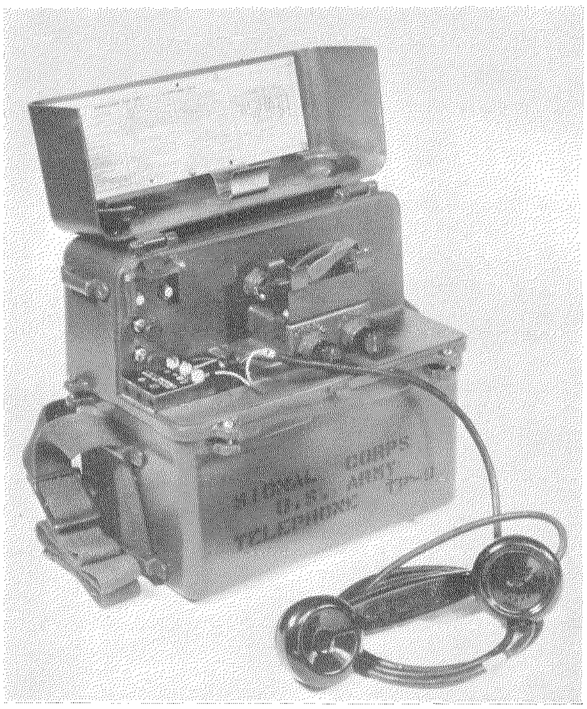


Fig. 23—With the exception of the hand set, this TP-9 telephone set is completely waterproof. It was extensively used in the latter stages of the Pacific operations.

The TH-1/TCC-1 conformed to U. S. Signal Corps standard dimensions of $17\frac{3}{4}$ by $21\frac{1}{4}$ by $22\frac{1}{4}$ inches and weighed only 200 pounds. It probably had a higher space utilization than any comparable piece of ground communication equipment used in World War II. It provided not only a high-speed duplex telegraph channel capable of 66-word-per-minute operation but incorporated a complete power supply requiring only 160 watts to energize the voice-frequency carrier telegraph, the voice-frequency ringer, and the voice-frequency terminal equipment included in the unit. Accessibility for maintenance and operational purposes was provided either from the front or rear of the cabinet and all units could be easily removed for mounting on standard 19-inch relay racks. Full monitoring and leg-circuit features were embodied and by convenient switch settings all of the following service conditions could be met.

a. Half-duplex, neutral-to-positive battery operation.
b. Full-duplex, neutral-to-positive battery operation.
c. Half-duplex, neutral-to-negative battery operation.
d. Full-duplex, neutral-to-negative battery operation.
e. Polarential half-duplex operation.
f. 2-path polar operation.
g. Half-duplex neutral operation with no battery at outlying point.

The U. S. Navy became interested in the possibilities of the TH-1/TCC-1 for application on shipboard for push-to-type omnibus-printer radio networks. Some of the first units delivered to the Signal Corps were obtained by the Navy. Development is continuing on a push-to-type unit, exemplified in the PTT/RATT, designed to meet the exacting requirements of shipboard use. Further extension of this same development for naval aircraft is under way.

Incidentally, this important wartime development is finding increased interest and demand for peacetime applications in the communication networks of railroad, pipe-line, and telegraph companies.

6.4 Applications of Small-Component and Weatherproofing Techniques

The small-component technique was readily applied to post-war commercial equipment. First of these products is the 9-A-1 single-channel carrier telephone system incorporating hermetically sealed small components and meeting the following operating conditions.

a. An additional high-grade telephone communication channel over open wire lines and cable.
b. Operation without substantial loss to existing voice-frequency circuits.
c. Permanent or temporary installation on circuits up to 300 miles in length and, with intermediate repeaters, up to at least 1000 miles in length, depending on the gauge of open wire conductors, length of intermediate cables, and number of bridged stations.

The improved features of this development will be the subject of an article to appear in this publication in the near future.

Complete control of transformer and coil design and production are of paramount importance to the successful production of small compact equipment. In the initial period of the war an attempt was made to secure transformers and coils to exacting specifications from outside suppliers. Neither the quality nor quantity requirements could be met even by the best domestic suppliers and Wire Transmission was forced to do its own manufacture. From a meager beginning in 1942, the transformer department grew to over 100 in personnel and approximately 15,000 square feet of production area with an enviable record of never failing to support the production program which required a total of over 1,000,000 precision transformers and coils.

The first hermetically sealed small-type precision transformer used in military communication equipment was designed and produced in quantity. Glass-sealed terminals in Kovar cases provided hermetical sealing for high-precision voice-frequency transformers and coils of the order of a 1.5-inch cube. This design contributed to outstanding compactness and durability under all operating conditions as demonstrated by the TP-14 telephone repeater and the TP-9 telephone set. Similar units are now incorporated in the 9-C-1 carrier telephone equipment.

Particularly suited for and extensively used in the latter stages of the Pacific operations was the TP-9 telephone set illustrated in Fig. 23. This unit, developed and produced exclusively by Wire Transmission, was completely waterproof with the exception of the handset. Each unit was placed under a few pounds pressure of nitrogen and submerged in water to insure that all seals were watertight. It provided a transmission gain of 15 decibels and a receiving gain up to 60 decibels, and extended the normal talking range over W110-B field wire facilities by 3 times that possible with the standard EE-8 field telephone set.

Many of the component, circuit, and equipment developments brought about by the war effort will find application to peacetime equipments and systems. First of these communication systems will be single and multichannel carrier telephone and telegraph systems, a new voice-frequency repeater system, improved voice-frequency ringers, speech-plus-duplex carrier telegraph terminal equipment, and facsimile.

7 *Selenium Rectifiers*

The manufacture of selenium rectifiers in the U. S. A. was introduced by I.T.&T. in 1938. This organization was included as a product line in the Telephone Division. Facilities were considerably expanded to meet the widespread demands for efficient metallic-type rectifier stacks and equipment involved in radio, telephony, and telegraphy. Selenium rectifiers with output ratings from a few milliwatts to 60 kilowatts were manufactured.

Some measure of the contribution made to the war effort by selenium rectifiers is the total of well over 30,000,000 rectifier plates supplied from 1940 to the end of the war in 1945. Production reached a peak of over 1,000,000 plates per month in June and July of 1945. While the total quantity represents a figure of large proportions,

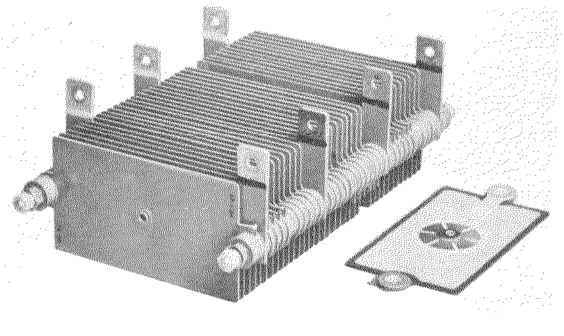


Fig. 24—Selenium rectifier stack using rectangular aluminum plates.

it must be realized that it was made up of all sizes and shapes of plates from a 1-millimeter plate with a microscopic dot of selenium to a plate of 118-millimeter dimensions.

The exacting requirements that selenium rectifiers had to meet relative to size, weight, temperature, humidity, and vibration in the myriads of military applications have contributed to the improvement of the product for post-war applications. The conversion from the use of aluminum to steel for rectifier plates was successfully accomplished when aluminum became a critically needed material, and improved finishes were developed to withstand the deleterious effects of excessive humidity and tropical fungi. Outstanding in the improvement of selenium-rectifier stack assemblies was the introduction of the center-contact type of construction which eliminated many of the problems encountered when using a metal spring washer for contact.

To enumerate all the various types of rectifier stacks with their performance ratings and fields of usage would run into catalog proportions. Accordingly, mention will be made of only a few typical types. Fig. 24 shows a selenium-rectifier stack employing rectangular aluminum plates. These light-weight highly efficient units were particularly useful in aircraft to supply direct current to motors, relays, etc. Another type shown in Fig. 25 is one section of a 3-phase rectifier furnishing heavy current at low voltage. For electroplating or other similar applications requiring high current at low voltage, 6 of these stacks deliver 600 amperes at 12 volts.

A rectifier stack for furnishing plate current to vacuum-tube amplifiers is shown in Fig. 26, and 8 of these stacks provide 0.388 ampere at 1310 volts.

Certain of the proximity fuses, an exceedingly important secret weapon of the war, were powered by wind-driven alternating-current generators. Small cartridge-type light-weight selenium rectifiers were used to convert the alternating current to direct current to provide power for the plates of the several vacuum tubes used in each of these fuses.

Millions of small selenium rectifiers of the type shown in Fig. 27 were furnished. The assembly at the top is rated at 0.005 ampere at 105 volts and a single rectifier element at the bottom has a rating of 0.001 ampere.

Some of the numerous power supplies designed and furnished are briefly listed in Table I.

8 *Intelin Products*

Following a nation-wide survey of the power utilities and power-cable manufacturers in the spring of 1941, it was decided that Federal would enter the field of plastic insulation by making available materials for high-tension joints and terminations, utilizing the experience of the London company, Standard Telephone and Cables, Ltd.[21] In the autumn of 1941, an engineer from London was sent over, a small group of engineers and technicians assembled, and plans made for the acquisition of the necessary plant. Before the

[21] T. R. Scott and J. K. Webb, "The Application of Styrene to H. T. Cable Systems," Electrical Communication: Part I, v. 16, pp. 174–179; October, 1937: Part II, v. 16, pp. 276–284; January, 1938: Part III, v. 17, pp. 88–95; July, 1938: and Part IV, v. 19, pp. 108–117; October, 1940.

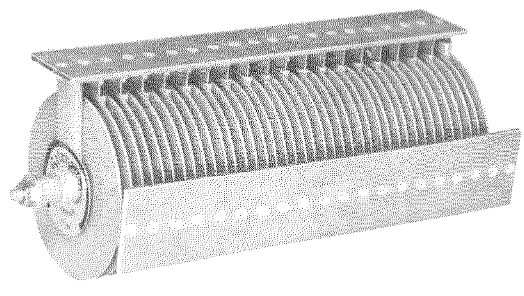


Fig. 25—One section of a 3-phase heavy-current selenium rectifier.

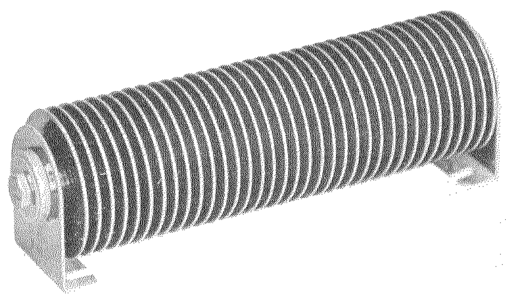


Fig. 26—Rectifier stack for plate supply for vacuum-tube amplifiers.

plant could be equipped, however, the advent of war caused a serious demand for a special insulation for ultra-high-frequency transmission lines, and the activities of the group were switched to this problem. Utilizing the basic inventions of the London laboratories, and by much fundamental research and development, such an insulation was discovered and put into production.

Of the initial staff of 7 employees at the end of 1941, only one had experience in the cable manufacturing field, but by 1943 the activities of the division had expanded to require nearly 1000 employees and 3 plants totalling over 160,000 square feet of laboratory and manufacturing space. Unlike most other industries where increased production was the only problem, Intelin was continuously creating new products under emergency conditions, bringing these products to a developed state, and putting them into mass production. The development of the special insulation, IN-45, came at a time when many raw materials were in critical demand, and not only did it meet the stringent Army and Navy specifications but also utilized a minimum of critical raw materials.

In 1943, the Navy program of polyethylene production was realized, and Intelin quickly swung over to the use of this material at the Navy's demand.

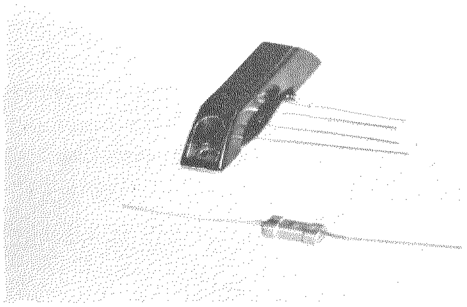


Fig. 27—Assembly and single element of a small selenium rectifier.

TABLE I

SELENIUM RECTIFIERS

Type	Output		Remarks
	Volts	Amperes	
FTR-3128-S	22–30	10	Output voltage regulated within 0.5 volt for line fluctuations of 10 percent.
RE-47	24	12	Vacuum-tube filament supply, maximum output ripple of 5 percent.
RE-54	230	0.65	Operated from 3-phase circuit to energize magnetic chuck, etc.
RE-71A	12.5	5.5	Maximum output ripple of 2 percent.
RE-82	24	12	Telephone and battery charger with filtered and regulated output.
RE-92	128	35	Output voltage continuously adjustable.
RE-115	115	1	
RE-117	115	10	
RE-109	6(12)	30(16)	Output voltage continuously adjustable.
RE-91	6	140	Electroplating, output voltage continuously adjustable.
RE-89	6	1050	Output voltage continuously adjustable.
DE-19	12	5000	Operated from 3-phase circuit. Stacks are immersed in oil and fan is used for cooling.
FTR-9159-S			Battery charger for 15 to 18 cells at 25–100 amperes (high rate) or 10–25 amperes (low rate). Automatic switch from high to low to off.
FTR-5114-S	10–40	20	Cathodic protection to reduce corroding of buried pipes.
FTR-3182-S	12(24)	200(100)	Aircraft-engine starting (Fig. 28).

Intelin's technical leadership in the high-frequency transmission-line field was fundamentally due to basic research and development carried on throughout the whole war, coupled with extensive and imaginative engineering and a manufacturing flexibility which could absorb new designs and changed specification requirements without undue loss of production. This leadership was reflected in the close co-ordination of its activities with those of the Bureau of Ships, Naval Research Laboratory, Aircraft Radio Laboratory, and National Radiation Laboratory, as well as with leading industrial organizations such as Bell Telephone Laboratories. Some of the contributions of Intelin during the war years are given below:

a. First company to produce a solid-dielectric high-frequency transmission line meeting all the stringent requirements of the Armed Services.
b. Developed attenuation-measuring equipment for transmission lines at ultra-high frequency which was designed for factory operation and which read directly in decibels per 100 feet.
c. Made the first and only commercially successful dual coaxial transmission line used for direction finders and instrument landing systems.
d. Received type approval on more types of transmission line than any other manufacturer.
e. Developed, in conjunction with the Radiation Laboratory, the first spiral delay line.
f. Instituted a system of inspection which was subsequently used as a model for other manufacturers, and was the first to inaugurate a joint Army-Navy-Company inspection system.
g. Pioneered in the development of low-capacitance transmission lines.
h. Investigated the contamination of high-frequency transmission-line dielectrics, and developed a noncontaminating jacket which was standardized for the industry.

Apart from the above contributions, Intelin pioneered in the mass production of harness assemblies for mobile equipments. These special harnesses, one of which may be seen in Fig. 29, consisted of cables cut to precise electrical length by means of an equipment developed by Intelin, and fitted with special connectors or junction boxes. For special radar applications many of the connectors, which were machined to high dimensional accuracy, were either gold or silver plated.

Apart from the ultra-high-frequency transmission lines, there were also produced a variety of plastic-insulated wires and cables used for radio assemblies, antennas, telephones, hospitals, and so forth.

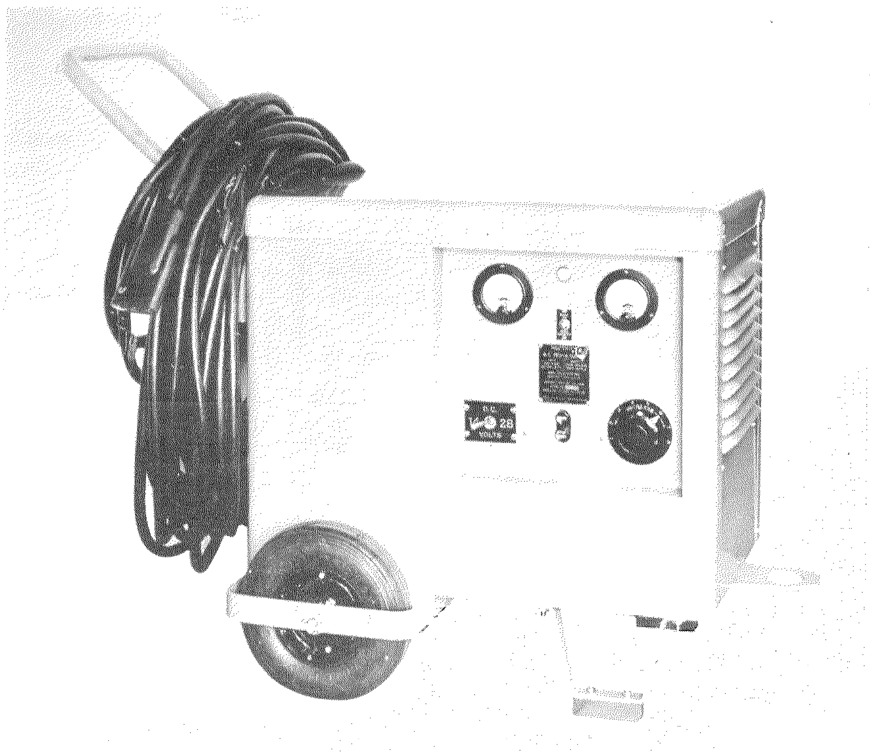


Fig. 28—Selenium rectifier for aircraft-engine starting. Output may be 200 amperes at 12 volts or 100 amperes at 24 volts.

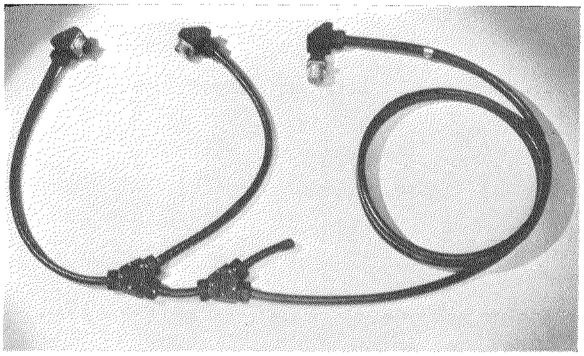


Fig. 29—Special harness assembly made by Intelin for a direction finder.

A special cable was also developed for the Manhattan Project (atomic bomb), and this cable was proving very successful at the termination of hostilities.

Late in 1943, the product line also commenced the manufacture of molded parts using thermosetting materials. Certain small items such as instrument control knobs, quartz-crystal holders, and so forth, were produced.

9 Megatherm

Development of industrial electronic equipment began soon after the U. S. A. entered World War II. By the end of the third year, over 150 units had been delivered. The principal application of this high-frequency heating apparatus is in the mass production of manufactured items. It is often used in heat-treating steel. In many applications the steel piece may be finished to its final size and then case hardened without fear of change in dimensions. Other applications are in the heating of plastic materials prior to forming in the press, sterilization and dehydration of food, and heat-treating of wood, rubber, paper, textiles, drugs, and food stuffs.

10 Transformers

Inability of other suppliers to meet our requirements made necessary great expansion of production of transformers and reactors for the manufacture of radio transmitters, telephone repeaters, rectifier apparatus, radio receivers, induction heating units, and other electronic devices.

Nearly 900 types of transformer and reactor units were produced. Some were of orthodox construction having an open frame, others were semi-enclosed having cast-iron or drawn sheet-metal covers over the open portion of the coil, and still others employed the latest techniques to provide hermetically sealed units to comply with the requirements of the Armed Forces for greatest resistance to tropical weather.

11 Vacuum Tubes

Production of vacuum tubes prior to World War II was principally of high-power water-cooled types. Starting with a small quantity required by associated companies, production increased until Federal became one of the leading producers of these types. Although not experienced in mass production at the outbreak of the war, manufacturing facilities were expanded and processes modified to permit the manufacture of several hundred thousand type 15-E triodes, Fig. 30, and type 15-R diodes for radar service.

The need for more production facilities resulted in the building of a new plant at Nutley, New Jersey, having 110,000 square feet of floor space allocated for the production of vacuum tubes. All power supplies, rotating vacuum pumps, and maintenance facilities were located in the basement, permitting efficient use of manufacturing floor space. Purifiers were designed

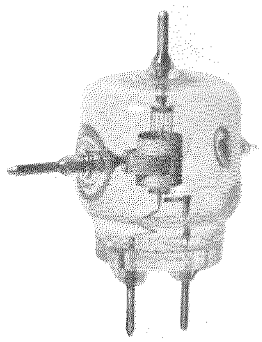


Fig. 30—Several hundred thousand of these 15E triodes were manufactured.

and built to provide nitrogen and hydrogen having greater purity than commerically available gases. These factors contributed importantly to the high quality of the vacuum tubes produced.

An engineering laboratory was installed at the Nutley plant so that experimental tubes could be made without interfering with production.

In addition to the production of many standard American types of tubes, many foreign designs were reproduced from samples. Several types of magnetron tubes were designed and built in considerable quantities.

12 Quartz Crystals

The piezoelectric properties and extremely high stability of quartz make it the heart of wartime communications apparatus. The frequencies at which transmitters and receivers operate are controlled by quartz crystals. During the war, production facilities were expanded and vast quantities of precision quartz crystals were manufactured.

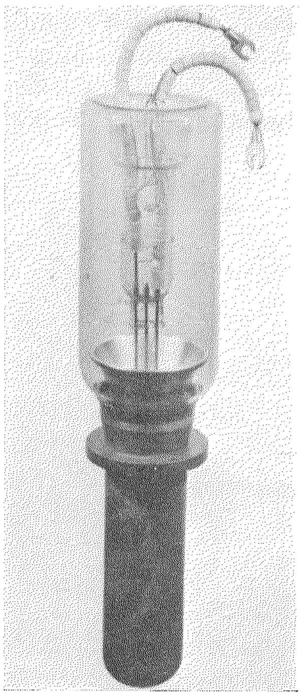


Fig. 31—Many thousands of F-660 high-vacuum diodes were delivered to the Manhattan Project which produced the atomic bomb.

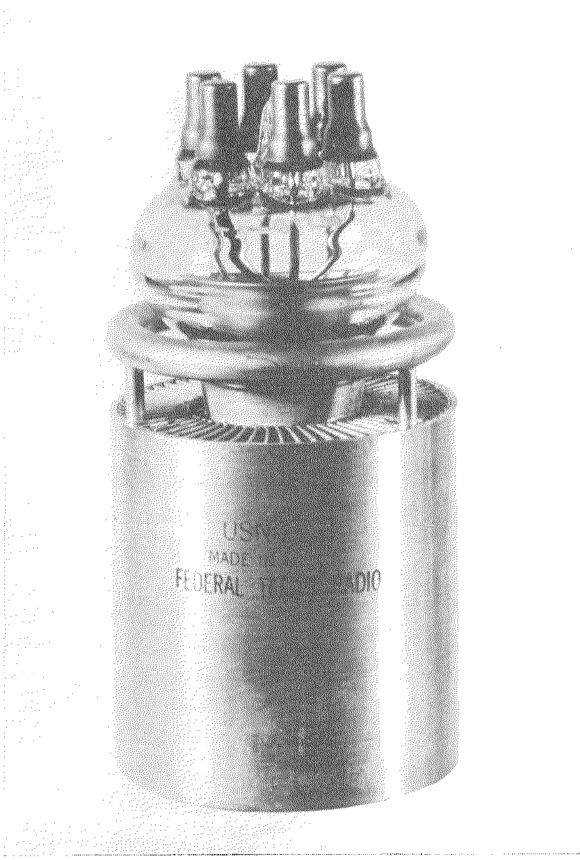


Fig. 32—7C23 forced-air-cooled triode used in radar service.

Because of the urgent demand for large quantities, earlier methods involving grinding by skilled workers were inadequate so that it was necessary to break down the procedure into a number of successive steps. Special equipment was installed for finishing considerable numbers of crystal blanks at the same time. By the adoption of mechanized procedures, unskilled workers could be employed for most of the operations.

Modern techniques were employed to facilitate mass production, including the use of X-rays to determine the axes of the crystal, carefully controlled etching for slight reduction of thickness, silver plating crystal surfaces to form the electrodes, and soldering the lead wires to the silver-plated electrodes.

A crystal holder having a metal enclosure with hermetically sealed leads was developed and in production at the end of the war.

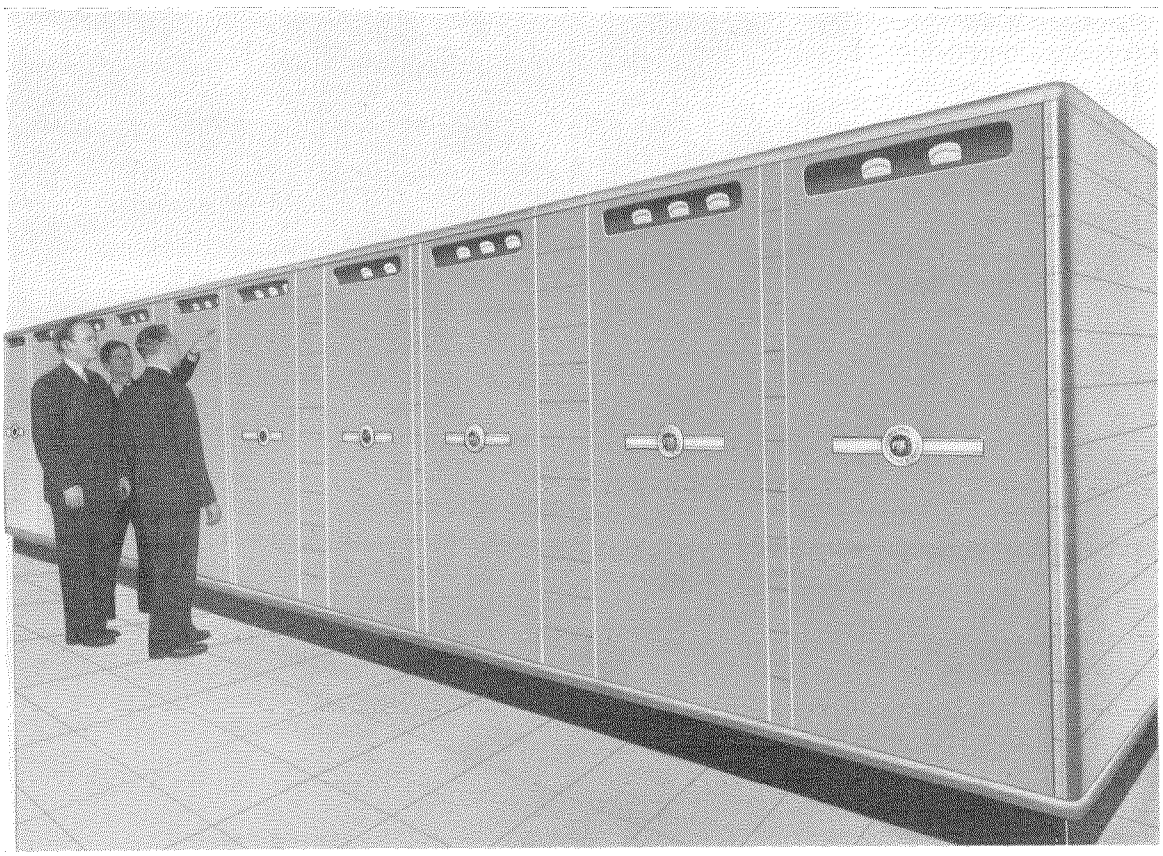
Recent Telecommunication Developments

HIGH-DEFINITION COLOR-TELEVISION TRANSMITTER—A modern ultra-high-frequency television transmitter, designed and built in the laboratories of Federal Telephone and Radio Corporation, now Federal Telecommunication Laboratories, Inc., was installed during January, 1946, on the 71st floor of the Chrysler Building in New York City for the Columbia Broadcasting System.

This transmitter has a peak output of 1 kilowatt and an average output of 600 watts. Starting with a crystal oscillator at 6.805 megacycles per second, 3 frequency doublers and 2 triplers produce an output frequency of 490 megacycles. The final and 3 preceding stages use 6C22 water-cooled triodes designed in the laboratories.

The final radio-frequency stage is modulated by a 6C22 operated as a cathode follower and driven by another 6C22. The low output impedance of the cathode follower and its high current capabilities permit a flat response over a frequency band from 0 to 10 megacycles. The preceding video-frequency amplifiers permit normal modulation with an input of 2 volts.

Scanning is at 525 lines, interlaced, and at 60 frames per second. Red, blue, and green are transmitted sequentially. Each interlaced scanning field corresponds to a different color and each color is transmitted twice during 3 successive frames, after which the process is repeated. Sound transmission, using the same equipment, occurs during the blanking pulse for line retrace.



PULSE-TIME-MODULATION MOVIE—A color motion picture with accompanying sound on "Pulse-Time Modulation Radio-Relay System" was presented by Federal Telecommunication Laboratories, Inc. on January 24, 1946 as a "paper" at the Winter Technical Meeting of the Institute of Radio Engineers in New York City. During the 2 days following the formal showing of the picture, hourly and, later, half-hourly projections were made in a smaller room for the benefit of many who were unable to see the original presentation. About 7000 members and guests attended the convention which was undoubtedly the largest technical radio meeting ever held.

The motion picture outlines the basic theory of pulse-time modulation and describes the equipment used in the 80-mile radio relay circuit which has been in experimental operation over a triangular path from New York City with relay points at Telegraph Hill and Nutley, New Jersey. For an article on this system, see page 159 of this issue.

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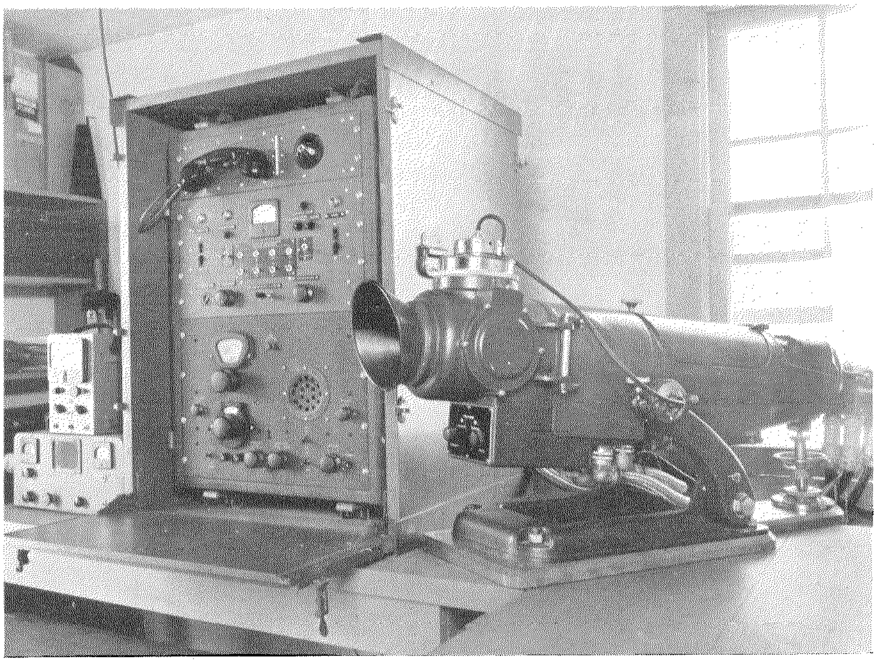
HIGH-FREQUENCY AUTOMATIC DIRECTION FINDERS—A demonstration of high-frequency automatic direction finders was given on January 10, 1946, by Federal Telephone and Radio Laboratories, now Federal Telecommunication Laboratories, Inc., at its experimental station at Great River, Long Island, New York.

These equipments were designed primarily for locating enemy submarines. To preserve secrecy, these submarines used high-speed radiotelegraph transmissions of such brief duration that prewar direction finders were useless.

Automatic direction finders give reliable bearings on a radiotelegraph transmission of but a few dots and in practice are effective on any signal that can be received. In addition to locating enemy craft, marine installations are highly useful for general navigation and air-sea rescue work.

Fixed antennas are used and automatic indication is obtained by means of a motor-driven goniometer and a cathode-ray tube. The direction from which a signal is received is shown by the position of a propeller-shaped pattern on the cathode-ray tube. By simply pressing a button, this pattern can be modified momentarily to show which of the 2 lobes should be read against a calibration scale projected around the circumference of the cathode-ray-tube screen.



A separate equipment for each of 4 bands is required to cover the long-distance communication spectrum from 1 to 30 megacycles per second. There are over 1000 land installations of this type of equipment throughout the world and an even larger number of shipboard sets. A typical operating position for a land installation is illustrated.

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FTR NOMOGRAPHS—Federal Telephone and Radio Corporation, as stated in Electrical Communication, Vol. 22, No. 3, presented a folder of nomographs to participants in the Institute of Radio Engineers' 1945 Winter Technical Meeting. In view of its favorable reception, an additional set of 16 nomographs was presented at the I.R.E. 1946 Winter Technical Meeting, New York, N. Y.

Some of the nomographs included in the new set are:

Bridged T and H Attenuators
Minimum Loss Pads
Circular Wave Guide Attenuation

a. $TM_{0,1}$ (E_0) mode
b. $TM_{1,2}$ (E_1) mode
c. $TE_{1,1}$ (H_0) mode.

On the reverse side of the new nomograph sheets, along with basic equations, examples illustrating their use are given.

Although quantities are limited, copies of both sets of nomographs may be obtained by writing to the Editor, Electrical Communication, 67 Broad Street, New York 4, New York.

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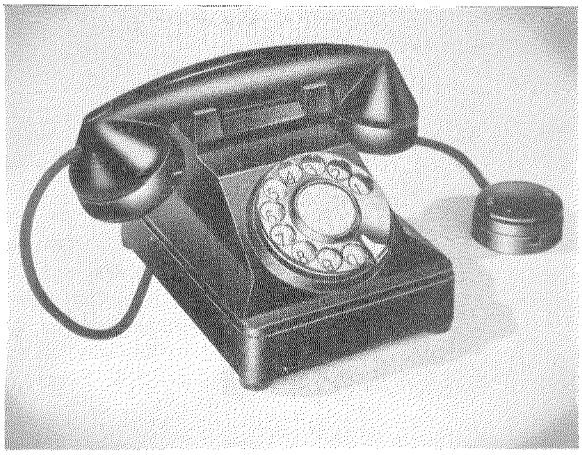
NEW FTR-803 DESK TELEPHONE—Redesign of set housing permits addition of switching keys on flat surface in front of cradle, when required. Like its predecessor the set embodies the simplified construction,[1] the interconnecting medium being a moulded plastic block into which is incorporated the bare bus wiring, the gravity switch complete with plunger, and all connecting terminals for the line, handset and dial cords, as well as the several circuit elements. Supplementary wiring is thus eliminated. The circuit components themselves are fitted with spring brass split (spade) terminals that slip directly under the screw heads of the connecting terminals.



[1] "Simplified Subscribers' Telephone Sets" by E. S. McLarn, *Electrical Communication*, v. 21, n. 1, pp. 3–12; 1942.

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Contributors to This Issue

PAUL R. ADAMS

Paul R. Adams was born on June 16, 1907. Although both his parents were Americans, they were temporarily abroad at the time so that he is, paradoxically, a native-born American citizen with Antwerp, Belgium, as his birthplace.

He graduated from Princeton University in 1929, with a B.S. degree. Formally his major was listed as physics, but to a large extent his work corresponded to the electrical engineering course, and he studied engineering as far as possible without conflicting with the physics major.

During most of the following 6 years, Mr. Adams worked for the North Electric Manufacturing Company, first as a laboratory assistant and later as a circuit-design engineer on automatic telephone switching equipments.

In 1935, he joined the patent department of the I.T. & T. System. While so employed, he studied patent law and passed the civil service examination for Patent Agent, entitling him to prosecute applications before the U. S. Patent Office. In 1939, he completed a 4-year law course at Fordham Law School, being graduated with an LL.B. degree, and in that same year was admitted to the Bar of New York State.

In 1942, Mr. Adams transferred to the patent department of International Telephone and Radio Manufacturing Corporation. Shortly afterward, he was transferred to the engineering staff which was an early predecessor of Federal Telecommunication Laboratories.

Since 1942, he has been engaged continuously in work on aerial navigation systems and equipment; first as assistant project engineer, then as project engineer, and later as systems engineer. At present he is in charge of the Aerial Navigation Division of Federal Telecommunication Laboratories.

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ANDREW ALFORD

Andrew Alford was born on August 5, 1904, at Samara, Russia. In 1924 he was graduated from the University of California, and from 1925 to 1927 he was a university Fellow and graduate student there. During 1927 and 1928, Mr. Alford was a teaching Fellow in physics at the California Institute of Technology.

He was a research engineer with the Fox Film Corporation, West Coast division, from 1929 to 1931; a geophysical prospecting and consulting engineer from 1931 to 1934; an engineer with the Mackay Radio and Telegraph Company from 1934 to 1941; head of the air-navigation laboratory of the Federal Telephone and Radio Corporation, 1941 to 1943; and head of the direction-finder and antenna division, Radio Research Laboratory, Harvard University, from 1943 to date.

Mr. Alford is a Fellow of the Institute of Radio Engineers.

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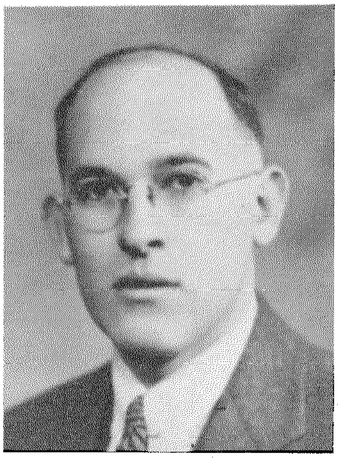

ROBERT I. COLIN

Robert I. Colin was born in Brooklyn, New York, on Feb. 16, 1907. He attended Cornell University as a student in engineering and physics under two New York State scholarships. During his senior year he was on the physics staff as an undergraduate assistant. He received the A.B. degree in 1928, and was elected to the honorary scholastic society Phi Kappa Phi.

The next year, under an exchange fellowship of the Institute of International Education, he attended the University of Frankfurt A/M, Germany, majoring in physics; and visited many European countries. From 1929 to 1933, he was a graduate assistant on the physics staff of New York University, teaching and taking graduate courses. He left with an M.S. degree after doing an experimental thesis in the field of electron-optics. From 1934 to 1939, he was instructor in physics and related subjects at the Hebrew Technical Institute. From 1941 to 1944 he was instructor, then head, of the Aircraft Electrical Systems Branch of the Army Air Forces Technical School, first at Chanute Field, Illinois, and then at Yale University.

J. KRUITHOF

Arnold M. Levine

Mr. Colin entered the Federal Telecommunication Laboratories in September, 1944, as a technical writer, then senior engineer, where he did technical studies, wrote proposals, and shared in the development of a number of proposals in the field of radio air navigation aids, especially for long distances, including the "Navaglobe" system.

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J. Kruithof was born in Rotterdam, Holland, on November 6, 1894. He received the degree of Electro-Technical Engineer from the Delft Technical High School in Holland in 1922 and of Doctor in applied sciences from the Ghent University in Belgium in 1945.

Dr. Kruithof is chief engineer for switching systems for the Bell Telephone Manufacturing Company, Antwerp, Belgium.

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Arnold M. Levine was born on August 15, 1916, at Preston, Connecticut. In 1940, he received the M.S. degree in electrical engineering from the State University of Iowa.

On graduation, he joined the sound department laboratories of the Columbia Broadcasting System in New York City. In August, 1942, he came to Federal Telecommunication Laboratories where he has been engaged in work on radio circuits and systems.

Mr. Arnold is an Associate of the Institute of Radio Engineers.

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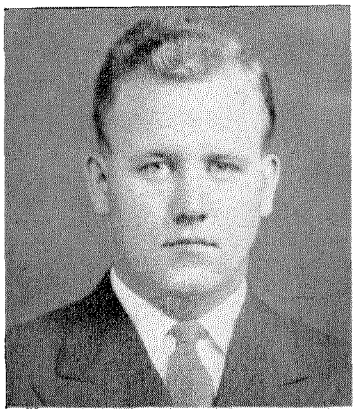
Frank J. Lundburg was born on December 28, 1916, at Ashton, Idaho. He received the B.S. degree in electrical engineering in 1940 from Purdue University, and from 1940 to 1941 he was a student engineer in the general engineering department of the Columbia Broadcasting System.

From 1941 to 1942 Mr. Lundburg worked in the short-wave division of the same department, and from 1942 to date he has been associated with the Federal Telecommunication Laboratories. Since 1943 he has been doing graduate study at Stevens Institute of Technology.

Mr. Lundburg is an Associate Member of the Institute of Radio Engineers.



Frank J. Lundburg

Chester B. Watts, Jr.

Chester B. Watts, Jr. was born at Washington, D.C., on June 16, 1918. He received the B.S. degree in 1940 from the Massachusetts Institute of Technology. From 1940 to 1942 he was associated with the radio navigation laboratory of the Federal Telephone and Radio Laboratories, and since 1942 he has been at the Aircraft Radio Laboratory, Wright Field, Dayton, Ohio.

Mr. Watts is an Associate member of the Institute of Radio Engineers.

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For biographies and photographs of H. Busignies, D. D. Grieg, and A. G. Kandoian, see Volume 23, Number 1, page 110.

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FEDERAL TELEPHONE AND RADIO CORPORATION, Newark, New Jersey

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COMPAÑÍA STANDARD ELECTRIC, S.A.C., Santiago, Chile

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CHINA ELECTRIC COMPANY, LIMITED, Shanghai, China

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LE MATÉRIEL TÉLÉPHONIQUE, Paris, France

LES TÉLÉIMPRIMEURS, Paris, France

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, Berlin, Germany

SÜDDEUTSCHE APPARATEFABRIK GESELLSCHAFT M.B.H., Nuremberg, Germany

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STANDARD VILLAMOSSÁGI RÉSZVÉNY TÁRSASÁG, Budapest, Hungary

TELEFONGYÁR R.T., Budapest, Hungary

FABBRICA APPARECCHIATURE PER COMUNICAZIONI ELETTRICHE, Milan, Italy

SOCIETA FINANZIARIA ELETTROTELEFONICA, Milan, Italy

SOCIETA ITALIANA RETI TELEFONICHE INTERURBANE, Milan, Italy

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STANDARD ELECTRIC COMPANY W. POLSCE SP. Z.O.O., Warsaw, Poland

STANDARD ELECTRICA, Lisbon, Portugal

STANDARD FABRICA DE TELEFOANE SI RADIO S.A., Bucharest, Rumania

COMPAÑÍA RADIO AEREA MARITIMA ESPAÑOLA, Madrid, Spain

STANDARD ELÉCTRICA, S.A., Madrid, Spain

AKTIEBOLAGET STANDARD RADIOFABRIK, Stockholm, Sweden

STANDARD TELEPHONE ET RADIO S.A., Zurich, Switzerland

JUGOSLAVENSKO STANDARD ELECTRIC COMPANY AKCIONARNO DRUSTVO, Belgrade, Yugoslavia

TELEOPTIK A.D., Belgrade, Yugoslavia

Telephone Operating Systems

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COMPAÑÍA TELEGRÁFICO-TELEFÓNICA COMERCIAL, Buenos Aires, Argentina

COMPANHIA TELEFONICA PARANAENSE S.A., Curitiba, Brazil

COMPANHIA TELEPHONICA RIO GRANDENSE, Porto Alegre, Brazil

COMPAÑÍA DE TELÉFONOS DE CHILE, Santiago, Chile

CUBAN TELEPHONE COMPANY, Havana, Cuba

MEXICAN TELEPHONE AND TELEGRAPH COMPANY, Mexico City, Mexico

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, Buenos 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, San Juan, Puerto Rico†

† Radiotelephone and Radio Broadcasting services.

Cable and Radio Telegraph Operating Companies

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THE COMMERCIAL CABLE COMPANY, New York, New York[1]

MACKAY RADIO AND TELEGRAPH COMPANY, New York, New York[2]

ALL AMERICA CABLES AND RADIO, INC., New York, New York[3]

THE CUBAN ALL AMERICA CABLES, INCORPORATED, Havana, Cuba[1]

SOCIEDAD ANÓNIMA RADIO ARGENTINA, Buenos Aires, Argentina[4]

[1] Cable service. [2] International and Marine Radiotelegraph services. [3] Cable and Radiotelegraph services. [4] Radiotelegraph service.

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