Overseas Radio Extensions to Wire Telephone Networks *

By LLOYD ESPENSCHIED and WILLIAM WILSON

The development of intercontinental telephony through the agency of radio links connecting between the land networks is traced and its present trends indicated. A description is given of the facilities employed by the Bell System for overseas connections and connections to ships at sea. The transmission results secured with these facilities are set forth and some peculiar short-wave phenomena discussed. International problems of frequency use and conservation are briefly summarized. A fairly comprehensive bibliography of technical papers on transoceanic telephony is included at the end of the paper.

Introduction

THE progress which long-distance electric communication is making in tying the world together is perhaps nowhere more interestingly illustrated than in the developments which are now taking place in the interconnection of widely separated wire telephone networks by means of overseas radiotelephone links. It was only a few years ago, in 1927, that telephone service was first extended across the barrier of the North Atlantic and a beginning made in the interconnection of the great telephone networks of North America and of Europe. Rapid progress has been made since then in the further development of the North Atlantic facilities and in the extension of radiotelephone links from these wire telephone networks outward in other directions, until today such links span a large portion of the globe.

Since it is the nature of telephony that the circuits are employed personally by the telephone users it is necessary that these interconnecting links be of a high standard of transmission effectiveness and be free from interference. Also it is important that they be reliable in operation and continuously available during the operating periods, for the usefulness of telephone service is in part dependent upon its being immediately available on call. Although these requirements are not yet being fully met, the circuits already in operation are very effective and are proving to be valuable additions to the world's communication facilities.

The progress which is being made and the problems which are arising in the establishment of these systems and in the coordination

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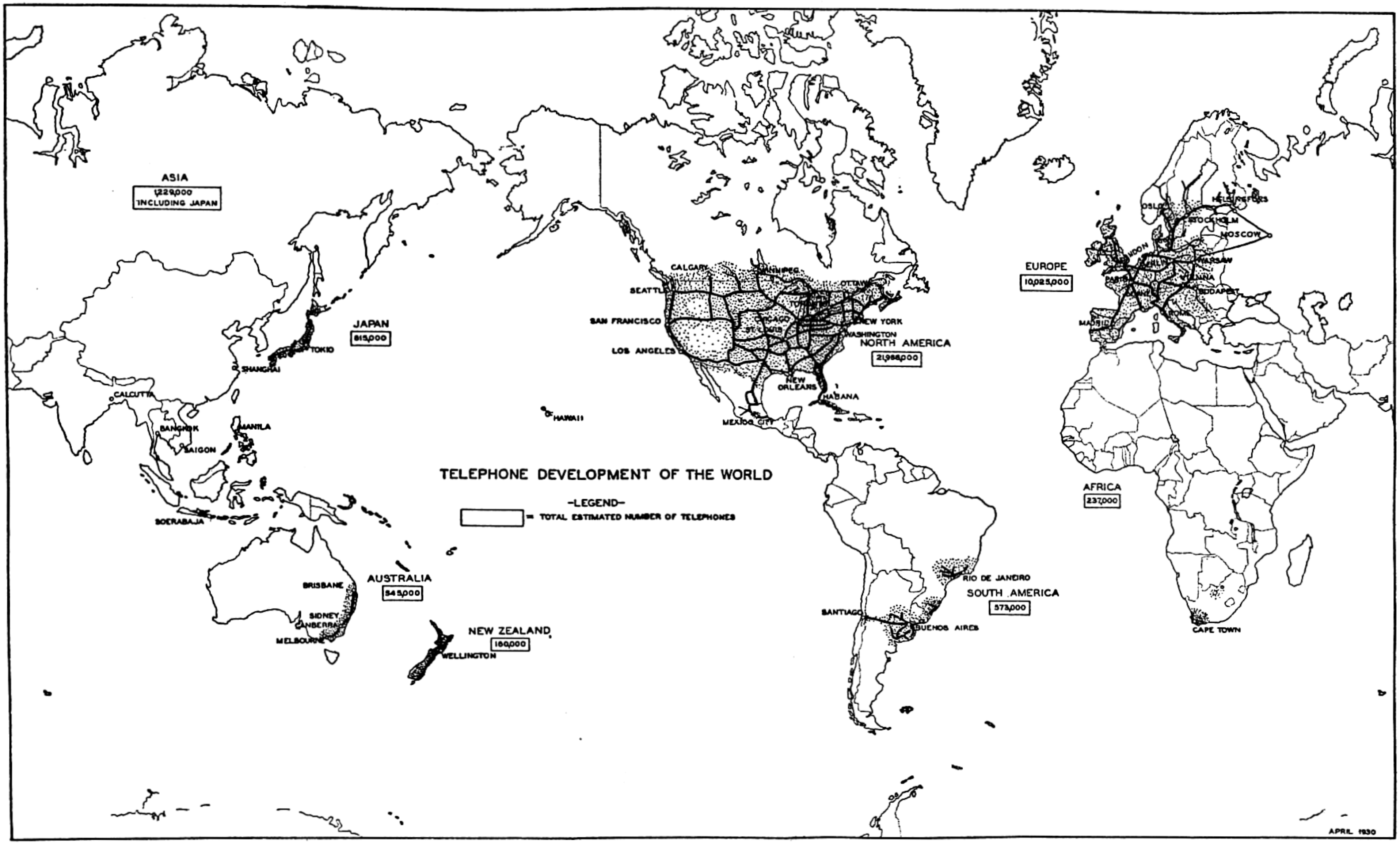
of them into a world-wide telephone network appeal to the imagination and challenge the best efforts of communication engineers. Especially is this development of interest to radio engineers since in this pioneering stage the interconnecting links are being forged by radio. Work is also going forward in the development of new types of submarine telephone cables for this purpose and undoubtedly such cables will in time play a large part in fortifying the more important of the world routes. The radio part of the picture is, however, quite enough in itself and this paper is, therefore, largely confined to this phase of the subject.

There is given first, a sketch of the wire telephone networks and the interconnecting links as they exist today, second, a picture of the transmission results which are being obtained in the operation of some of these overseas links, and finally, a discussion of the more important phenomena and problems involved in the radio transmitting medium.

The Existing World Telephone Picture

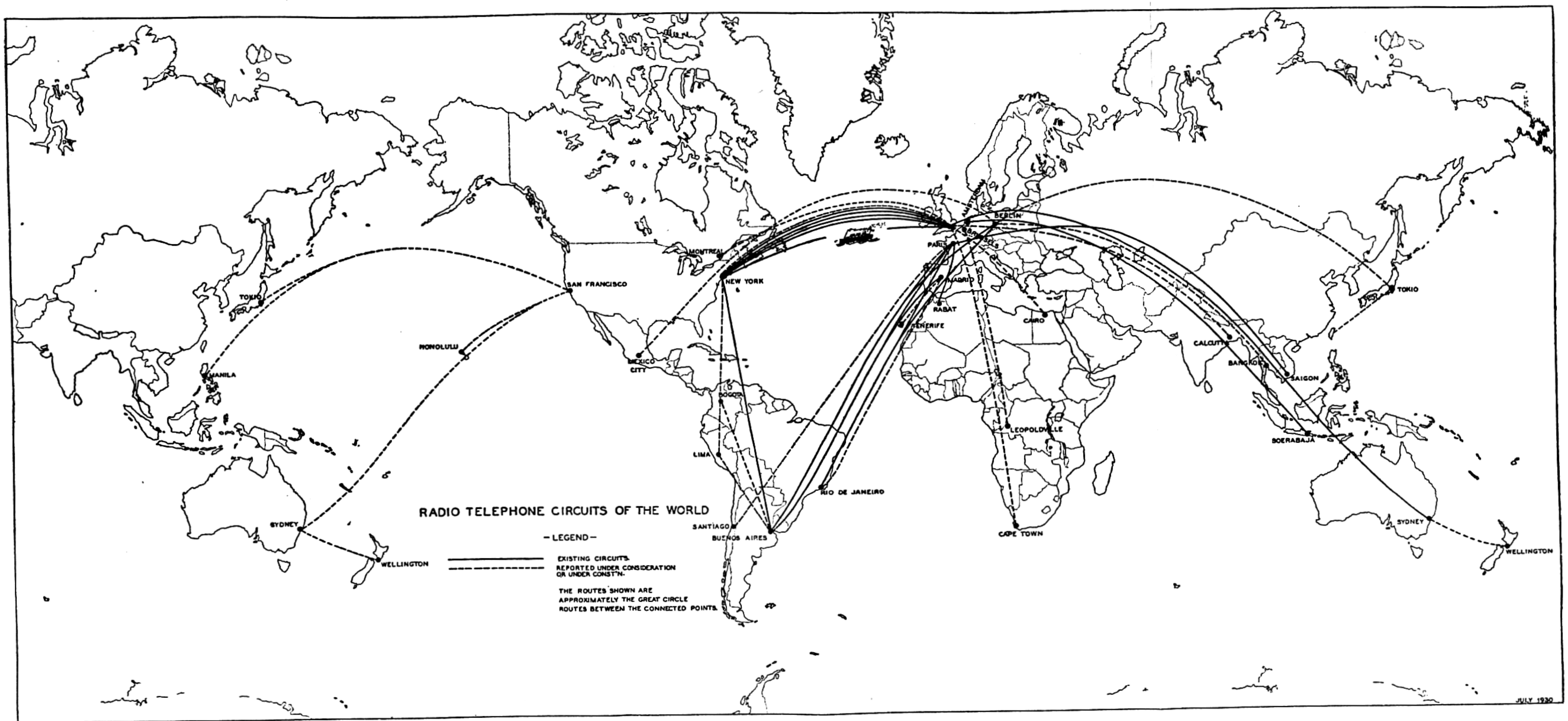
A simplified picture of the present telephone development of the world is given in the map of Fig. 1. Only the principal areas of telephone development are indicated, by the shaded portion, and only the more important routes of the wire networks have been sketched in. The figures give the approximate number of telephone subscribers in each continental area.

It is, of course, these networks which give direct access to millions of people in offices and homes and permit of the personal contact which characterizes telephone communication. It is natural, therefore, that they should be the foundation of the world-wide system which is growing up. The larger of these networks already spread over national boundaries so that the engineering problem is primarily one of interconnecting the networks, generally comprising groups of countries, rather than that of directly interconnecting by radio all of the component countries. The points within each network at which the interconnections are made may be expected to be determined largely by considerations of traffic and of operating efficiency. The differences of time and of languages between these widely separated areas, and, of course, the expense of providing reliable interconnections over these distances, are factors which will naturally limit the volume of use to be made of these connections. That they are destined to fulfill a very real need is already proven, however, by the services which are now being given.



TELEPHONE DEVELOPMENT OF THE WORLD
-LEGEND-
= TOTAL ESTIMATED NUMBER OF TELEPHONES
ASIA
1,229,000
INCLUDING JAPAN
JAPAN
815,000
TOKIO
SHANGHAI
CALCUTTA
BANGKOK
SAIGON
MANILA
SOERABAJA
AUSTRALIA
545,000
BRISBANE
SIDNEY
MELBOURNE
NEW ZEALAND
160,000
WELLINGTON
HAWAII
NORTH AMERICA
21,986,000
CALGARY
SEATTLE
SAN FRANCISCO
LOS ANGELES
NEW YORK
WASHINGTON
NEW ORLEANS
HABANA
MEXICO CITY
SOUTH AMERICA
573,000
RIO DE JANEIRO
SANTIAGO
BUENOS AIRES
EUROPE
10,025,000
STOCKHOLM
MOSCOW
WARSAW
MADRID
AFRICA
237,000
CAPE TOWN
APRIL 1930

Fig. 1


RADIO TELEPHONE CIRCUITS OF THE WORLD
—LEGEND—
EXISTING CIRCUITS.
REPORTED UNDER CONSIDERATION OR UNDER CONST'N.
THE ROUTES SHOWN ARE APPROXIMATELY THE GREAT CIRCLE ROUTES BETWEEN THE CONNECTED POINTS.
TOKIO
MANILA
SYDNEY
WELLINGTON
HONOLULU
SAN FRANCISCO
MEXICO CITY
MONTREAL
NEW YORK
BOGOTA
LIMA
SANTIAGO
BUENOS AIRES
RIO DE JANEIRO
PARIS
BERLIN
MADRID
RABAT
TENERIFE
CAIRO
LEOPOLDVILLE
CAPE TOWN
CALCUTTA
BANGKOK
SAIGON
SOERABAJA
JULY 1930
Fig. 2

Development of Interconnecting Links

The present status of the development of these transoceanic radiotelephone links is illustrated in Fig. 2. There are shown the circuits which are in operation and also the projects which have been reported as under consideration or under construction. These telephone paths will be observed to correspond in general with the routes followed by the ocean telegraph and radiotelegraph services, in fact with the trade routes of the world, along which community of interest has been built up. Thus a certain orderly arrangement of the services is being realized naturally.

In general, there may be said to be five major groupings:

1. The North American-European connections. These are, of course, of outstanding importance because of the economic and social interest which exists between the two continents and because they connect with the large telephone wire networks on both sides of the Atlantic. North America and Europe combined account for about 32 million telephones out of a world total of about 35 million. The present situation on the North Atlantic route is discussed later on.
2. North America-South America.
3. South America-Europe.
4. Europe to Africa, Asia, and Oceania. The connections to Africa and to Oceania represent the interest which some of the European nations have in associated commonwealths and in colonies.
5. North America to Pacific points and the Far East. These are in the construction and project stage.

Most of these services are being given on a part time basis although that across the North Atlantic has been found to require 24-hour service and that between North and South America is for the full business day. Some of the circuits from Europe to South America and to the East Indies are not yet connected fully into the wire telephone network. The circuits which are in operation between South America and Europe instead of connecting into the European network by means of a single station are shared on a part time basis by several stations located in different countries in Europe, as is indicated by the forked lines in the figure.

One advantage of the use of radio for these services, particularly in this pioneering stage during which traffic over many of the routes is likely to be small, is the ability to share the use of a transmitting channel as between a number of receiving points where wire lines are not available. A representative case of this kind would be that of an important central station linked with a continental wire network from which it is desired to establish connections with a number of smaller outlying points. This possibility is not as simple as it may appear, however, because there enter the problems of directive antennas, of shifting frequencies if widely different distances are involved, and of not permitting the return transmission to be materially weaker than the outgoing transmission which means the use of relatively powerful stations at the outlying points. In general, these short-wave stations represent rather large investments and in working out interconnecting arrangements of this kind it is important to fit together the schedules at the various stations so as to minimize lost circuit time and to avoid leaving stations in idleness.

North Atlantic Facilities

Of the four circuits which now exist across the North Atlantic, as indicated in Fig. 2, one is the long-wave circuit, with which the service was originally started, and three are short-wave circuits. The dashed line, shown in the figure, between New York and London indicates an additional long-wave circuit which is planned. There is also indicated in the figure the ship-to-shore telephone service on the North Atlantic which connects with the land line network on either side.

The transatlantic long-wave system has already been the subject of technical papers [1] and need not be described in detail. It operates on a single side-band carrier suppression system in a frequency band centering at 60 kc. The single side-band system is used to minimize the frequency space occupied. The single band is used alternately for transmission in the two directions by means of voice actuated switching devices at the New York and London terminals. For the purpose of minimizing the principal limitation of long waves, that of "static," the receiving stations are located as far north as is reasonably possible and use is made of directive receiving antennas.

The three short-wave circuits which have been provided on the North Atlantic route add materially to the traffic capacity but are erratic in their behavior and their usefulness is dependent, in a large measure, upon being operated in combination with the more stable long-wave circuit. All three short-wave circuits are affected similarly by the adverse conditions accompanying magnetic storms, whereas long-wave transmission is not materially affected by these conditions except at night.[2] The second long-wave circuit is planned to provide a more balanced combination of facilities as well as to add to the total

[1] See attached bibliography.

[2] Bibliography 6, 14, 15.

circuit capacity across the Atlantic. In this connection, it should be noted also that a new type of submarine telephone cable is under development and is planned to be laid across the North Atlantic when completed. While this cable will provide only one two-way circuit, it is expected to be free from atmospheric disturbances and to fortify greatly the telephone service between North America and Europe.

The ship-shore telephone service which is being given on the North Atlantic includes a land station connection with the land line network in both the United States and in England and through these land stations service is given to most of North America and Western Europe. Four of the larger transatlantic vessels are equipped. The service may be expected to include in time additional shore stations and many other vessels. It is an example of a class of service for which radio alone is available, that of extending telephone service to moving craft at sea or in the air.

Short-Wave Technique

With the exception of the long-wave circuit across the North Atlantic, all of the links indicated in Fig. 2 are of the short-wave type. As to these different short-wave stations throughout the world, there is, of course, considerable difference between them in the requirements which are being met and the performance obtained. However, the same fundamental principles are being followed in all of the countries and the short-wave telephone technique may be said to be rather remarkably alike throughout the world. Transmission is on the ordinary double side-band basis since the necessity for narrowing the band is not of great importance in the present state of the art and the difficulty of single side-band operated at high frequencies is very much greater. In general, the transmitters are of the vacuum tube type employing master oscillators which are stepped up in frequency and in power for the final transmission; directive antennas are employed for both transmitting and receiving, and in the receiving apparatus use is made of the double detection principle with its advantages in giving stable operation with high amplification and high selectivity.

In the case of the radiotelephone stations which connect with the United States, the short-wave technique is further characterized by the use of transmitting sets which are provided with a piezo-crystal oscillator with temperature control for stabilizing the transmitting frequency, and the use of interchangeable coils which permit the frequency of the transmitter to be changed in keeping with the requirements for the different times of the day and year. The carrier output of 15 kw. corresponds to a peak output of about 60 kw. The final power stage of such a set is shown in Fig. 3. The units marked 1, 2, and 3 are the water jackets for three of the six double-ended, 10-kw. tubes, the other three being on the other side of the mounting. The circuit is of the push-pull type.

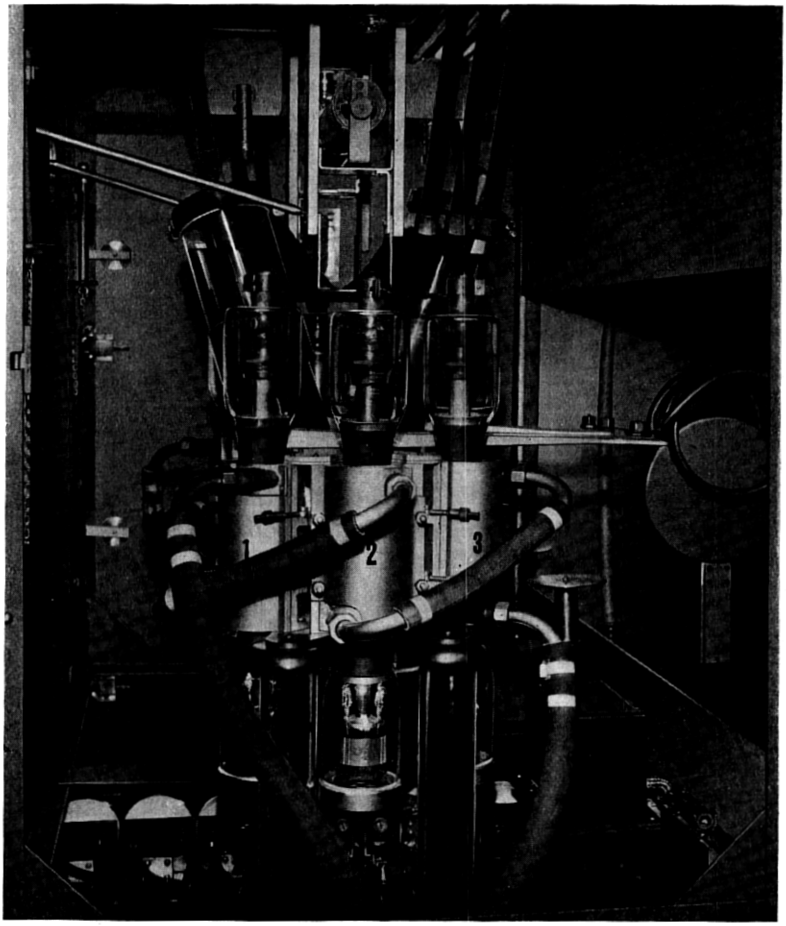


Fig. 3—Short-wave radiotelephone transmitting center of the American Telephone and Telegraph Company, Lawrenceville, N. J. Six 10-kw. tubes used in one of the output stages of a transmitting set. Coupling coils on right, monitoring amplifier boxes at lower right.

The radio receivers employed in the United States are built so as to have low intrinsic noise and sufficient gain to enable very small field strengths, of the order of 1 μv. per m., to be detected and raised to the required telephone speech level. They are equipped with automatic gain control which minimizes the fading variations in speech volume. One of the radio receivers employed at the Netcong, N. J., receiving station is illustrated in Fig. 4. The antenna leads are brought in beneath the floor in the concentric pipes which are seen to

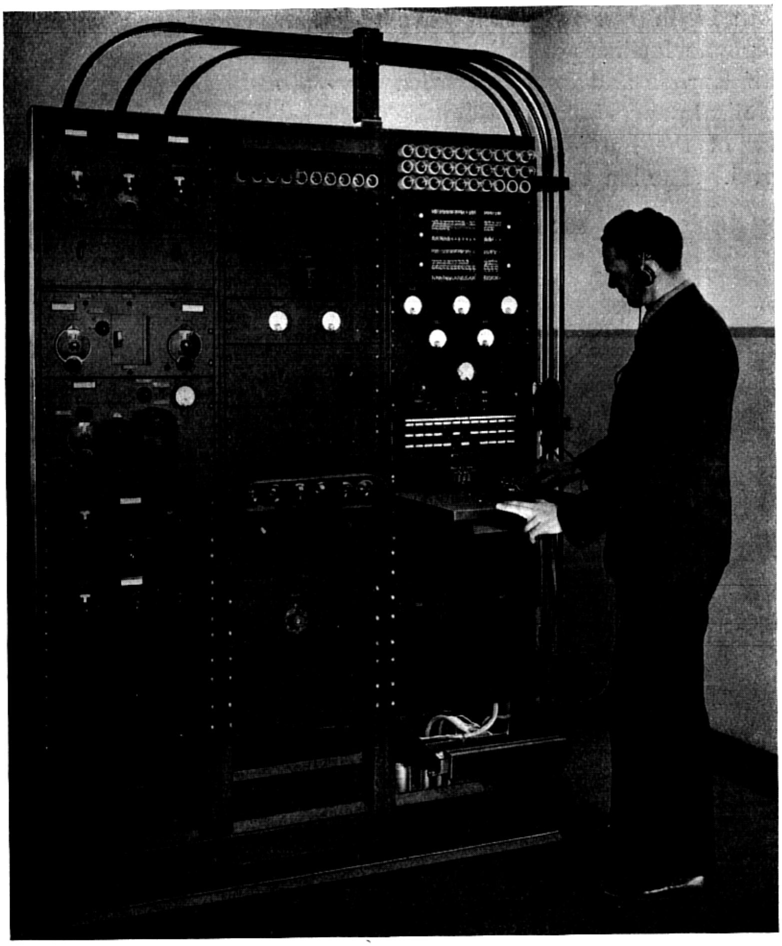


Fig. 4—Short-wave radiotelephone receiving center of the American Telephone and Telegraph Company, Netcong, N. J. Radio receiver for South American circuit. Antenna concentric pipe transmission lines enter set overhead.

rise at the right and connect with the input of the set on the upper left-hand panel. The first two vertical bays are the radio set proper, including the automatic gain control. The third bay, on the right, includes the volume indicator and control and the line connecting equipment.

In general, three wavelengths are used, one around 19,000 kc. (16 meters), one around 14,000 kc. (21 meters) and one around 9,000 kc. (33 meters), and each transmitter and receiver is arranged so that it can be connected at any time with a directive antenna designed for each of these frequency ranges. The transmitter antenna gains are about 17 db over a one-half wave antenna. These short-wave radiotelephone facilities which connect the American telephone network with Europe and South America have already been the subject of technical papers [3] and need not be described in further detail. An air view of the Lawrenceville, N. J., transmitting station is given in Fig. 5. The longer of the two lines of towers supports the antennas

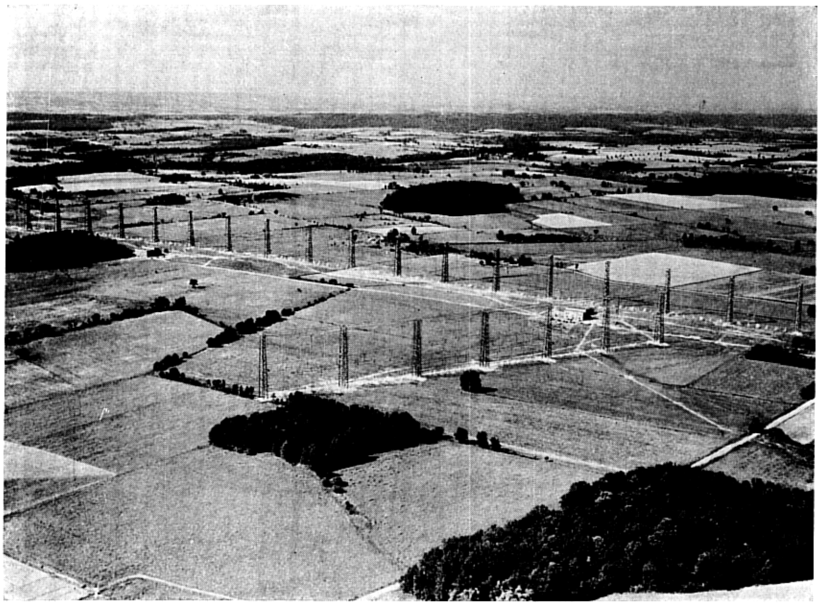


Fig. 5—Lawrenceville transmitting station. Aerial view—South American antenna in the foreground; European antenna in the background. Two buildings each containing two transmitters are shown.

for the three short-wave circuits to England, and the shorter line of towers the antennas for the single circuit to the Argentine. Some idea of the magnitude of the plants employed for these short-wave circuits may be had from this photograph. The longer line of antennas is approximately one mile long, consisting of twenty-one 185-ft. towers. Substantial fireproof buildings are provided for the transmitting sets and auxiliary equipment. Probably every operating agency which has

[3] See bibliography.

had experience with short-wave operation realizes that the cost of such radio facilities is proportional to the standard of service and to the degree of reliability and exactitude of operation which is undertaken in the terminal stations.

Joining of a Radiotelephone Link with Wire Network

The manner of joining the transoceanic radio links with the wire network to meet the requirements of through two-way transmission is an interesting and important development in itself. In general this technique is an outgrowth of wire telephone practice and is so new as not yet to have been fully applied to all of the radiotelephone links in existence.

The problem is that of how to form the two oppositely directed speech channels which comprise the radiotelephone link itself into the usual two-way telephone circuit suitable for use as a regular telephone toll line and for termination before long-distance traffic operators at each end.

The transmission equivalent of the radio paths may be continually changing over a considerable range due to fading. It is undesirable that noise or speech on the incoming channel be reradiated on the outgoing channel. Any tendency for the system to sing must be avoided. It must be possible to change the amplification looking into the transmitters over a wide range so as to get a fully modulated output from them, irrespective of the length of the connected lines or the volumes of the talkers' voices. Furthermore, in some cases, as where the same radio-frequency band is used for transmission in the two directions, the radio transmitter tends to interfere with the receiver at the same end.

A solution of these conflicting requirements necessitates that only one of the radio paths be connected to the wire network at a time. This fundamental principle at one stroke wipes out singing, reradiation or echoes, and permits independent adjustments of amplification in the two radio paths. To apply it, it becomes necessary to employ voice-current-operated switching devices which connect alternately the sending or receiving radio channel to the wire line as the subscriber talks or listens, automatically following the conversation and serving the needs of the subscriber without his volition.

Various mechanisms for carrying out this function have been devised. Some employ mechanical relays for switching while others use vacuum tubes, but in principle they are much alike. The broader ideas involved are illustrated in Fig. 6. When the circuit is quiescent, i.e., neither subscriber speaking, the receiving radio channel is connected and the transmitter disconnected. Speech coming from the wire line connects the transmitter and disconnects the receiver. The positive switching action is, therefore, dependent upon the impulses of speech from the land line. This arrangement is preferred to the reverse one of depending upon impulses of speech receiver over the radio channel. This is because the system must operate on speech only and not noise, and the speech-to-noise-ratio is usually higher and more dependable on the wire line than on the incoming radio channel.

This single function of switching-over in response to the subscriber's voice is the principal and basic function of such devices. There are, however, many auxiliary features incorporated to guard against false

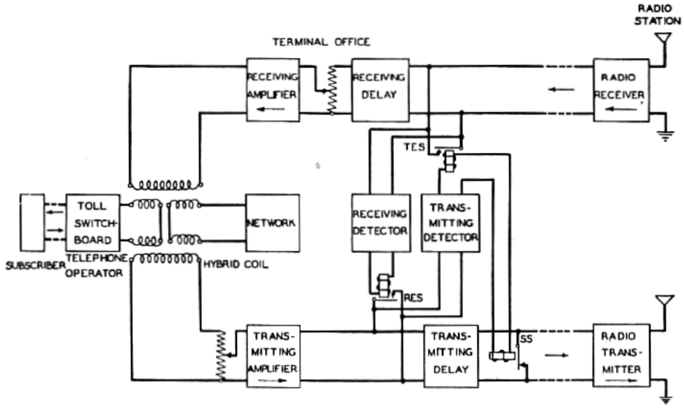


Fig. 6—Circuit diagram illustrating operation of voice-operated switching device, Note: Voice currents coming from the line, rectified in the transmitting detector. clear the transmitting path by removing short circuit at *SS* and short-circuiting receiving path at *TES*. Switch at *RES* is operated by received radio speech or noise to prevent echoes in the wire lines from reaching transmitting detector.

operation by noise currents and speech current echoes which greatly increase the ability of the arrangement to operate satisfactorily under conditions of severe noise or weak speech. These have been described elsewhere [4] more completely than would be appropriate in this discussion.

Viewed from the radio standpoint these voice-operated devices are of great importance since they permit radio links to be used as trunks in wire networks without their having to meet the requirements which wire line trunks must meet. At the present stage of development it would be practically impossible to provide radio circuits meeting wire line standards.

[4] See bibliography 7.

Transmission Results

We now come to a consideration of these transoceanic links which is perhaps the most important one from the standpoint of the service given and of the engineering development required. It is that of the general transmission effectiveness and of the continuity of service which is given. So far as the radiotelephone circuits operating out of the United States are concerned, this phase of the subject is pretty well summarized by the charts given in Fig. 7. These show from top to bottom the continuity of *two-way transmission* which has been obtained over the past year, (1) on the long-wave transatlantic circuit, (2) on one of the short-wave transatlantic circuits, and (3) on the short-wave circuit which operates with Buenos Aires. The last named circuit has been in operation only since the spring of this year.

The black areas show in each case the hours of the day during which the circuit was commercially usable. The white gaps indicate periods during which no operation was attempted and for which there are no data. The dotted-in lines show the periods during which the circuit was found to be commercially unusable, i.e., the lost time periods.

The following points are to be noted:

1. The long-wave circuit, shown at the top, is poorest during the summer months. This is because of atmospheric disturbances due to lightning. Throughout the year shown, the long-wave circuit was available for service about 80 per cent of the time
2. The North Atlantic short-wave circuit, center figure, was fairly good last summer but suffered much lost time during the spring months of 1930. The poor behavior during the spring is apparently due to unusually high solar activity. Such related phenomena as aurora disturbances in the earth's magnetic field, and earth currents have been affected similarly. For the year shown this short-wave circuit was commercially available about 64 per cent of the operating time. Similar experience was had on the other two transatlantic short-wave telephone circuits, one of which was operated over a longer period of the day than that shown.
3. The combination of the North Atlantic of the long-wave and short-wave circuits gives a much improved result as compared with either one alone. As is indicated in the diagrams, last summer when the long wave circuits suffered from "static," the short-wave transmission was fairly good; conversely, this last winter and spring when the short-wave transmission suffered severely from magnetic storm effects, the long-wave circuit was the mainstay of the service.

4. The short-wave transmission between New York and Buenos Aires, as depicted by the bottom chart of Fig. 3, will be seen

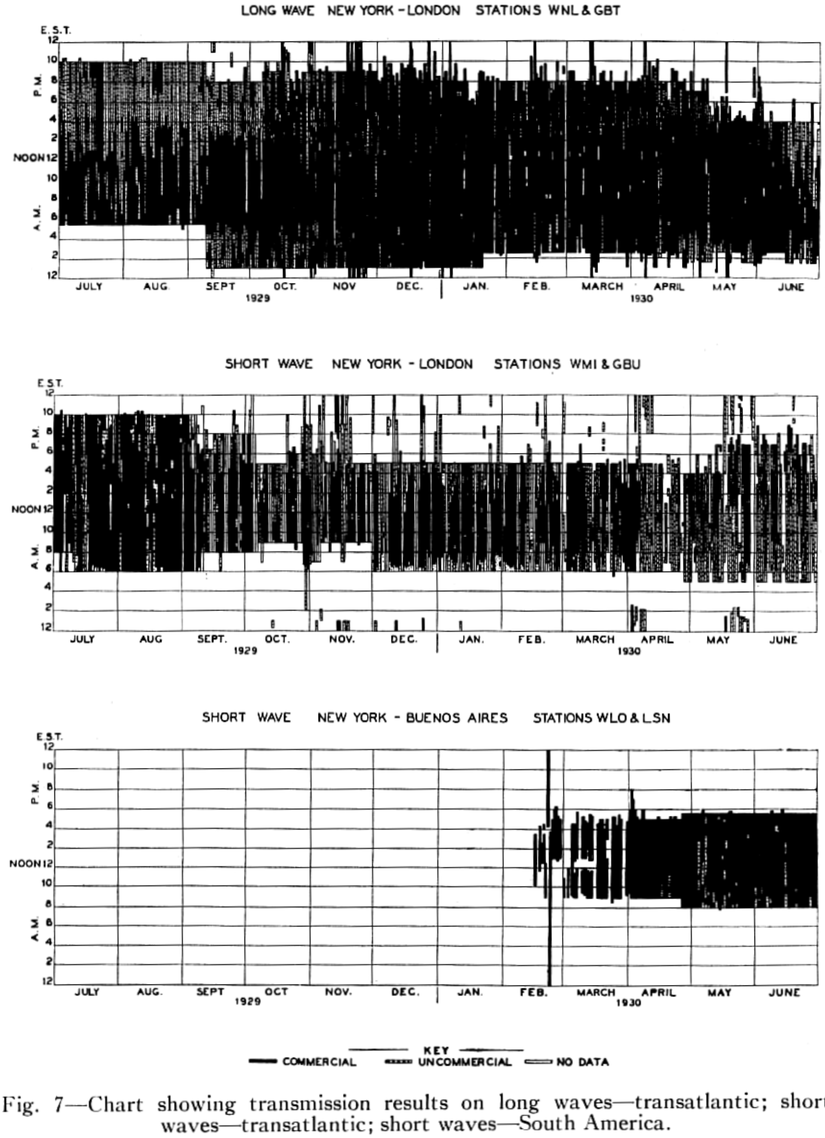


Fig. 7—Chart showing transmission results on long waves—transatlantic; short waves—transatlantic; short waves—South America.

to be more reliable than short-wave transmission across the North Atlantic. The single short-wave circuit between New York and Buenos Aires has, since the initiation of this service last spring, been commercially usable about 97 per cent of the operating time.

The difference in short-wave transmission east and west across the North Atlantic and that across the tropical zone, shown in Fig. 7, is quite in keeping with the general experience of other operating agencies and is already a well recognized fact in short-wave transmission. There is obviously a radical difference in the character of the transmission paths involved which requires further survey and analysis.

Typical Magnetic Storm Effect

It will be noted from the second diagram of Fig. 7 that the interruption of short-wave transmission across the North Atlantic sometimes continues for several days at a time. These periods have been found to correspond to disturbances in the magnetic state of the earth and to be accompanied by the appearance of relatively large differences of electric potential along the earth's surface. Measurements which have been carried out on the strength of electric field received across the Atlantic during such periods and simultaneous records which have been made of earth potentials shed some light on what happens during these periods.

There is shown in Fig. 8 observations which were made during a major effect of this kind which occurred in July, 1928. Short-wave transmission conditions appeared to have been normal both before and after the occurrence of this effect. The measurements were made at New Southgate, England, upon station WND, one of the radio transmitters at Deal, N. J., used before the present transmitting plant at Lawrenceville was built. The measurements were made on 18,340 kc. during the normal hours of daylight operation. The upper curve of the figure shows the variation in received field strength averaged over the daylight hours for each of the several days shown. Below the field strength curve there is plotted a record which was made during this same period of the earth potentials in the vicinity of New York. This is a smoothed transcript of a record taken on a continuously operated recorder connected in a grounded wire circuit which extended from New York westward to Reading, Pa., about 100 miles distant.

It will be observed that the time of minimum field strength coincided approximately with the time of maximum earth potential (the small wiggles of earth potential are to be neglected since they are due to disturbances set up by man-made electrical systems). The drop in the strength of the received field will be observed to be large, of the order 35 db. The effect upon transmission lasted several days, the recovery appearing to have been slower than the initial effect.

A high degree of coincidence has been found to exist between these adverse effects in short-wave transmission on the one hand, and on the other hand the appearance of earth currents and abnormalities in the earth's magnetic field. This is a subject which cannot be adequately treated in the present paper and it is hoped that a report upon it can be made to the Institute during the forthcoming winter. As is explained below radio transmission is believed to be largely dependent

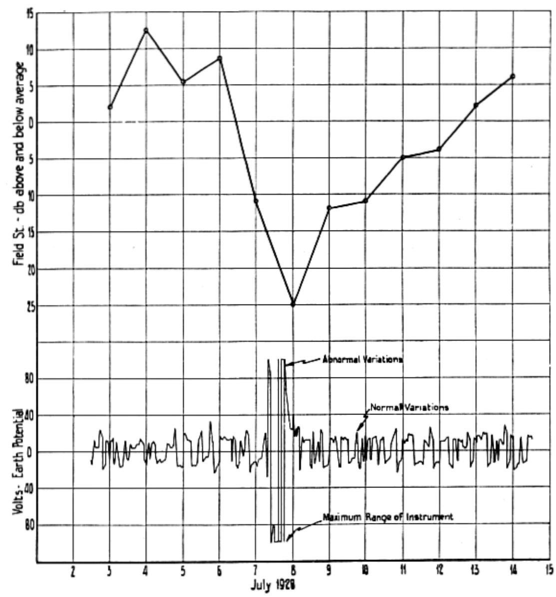


Fig. 8—Magnetic storm effects, showing drop in field strength and appearance of earth potentials.

on the state of ionization of the earth's atmosphere. Earth potentials are probably also affected by variation in this ionic state. Therefore, we have in such a recorder a useful check on the transmitting medium when transmission difficulties are encountered. Such earth potential observations may prove to be useful in exploring these conditions more generally throughout the world.

In Fig. 8 each point of the radio data was obtained by averaging the field strength of the carrier throughout a 24-hour period. Fig. 9, on the other hand, presents in a more detailed manner the way in which the field strength varied throughout each of seven days, between June 24 and July 1, 1930, on transmission from England to the

U. S. A. Within this period, there was a magnetic storm. No data were obtained on June 29. The original curves were obtained with an automatic recorder, receiving from station GBU of the British General Post Office during regular operation. In redrafting for pub-

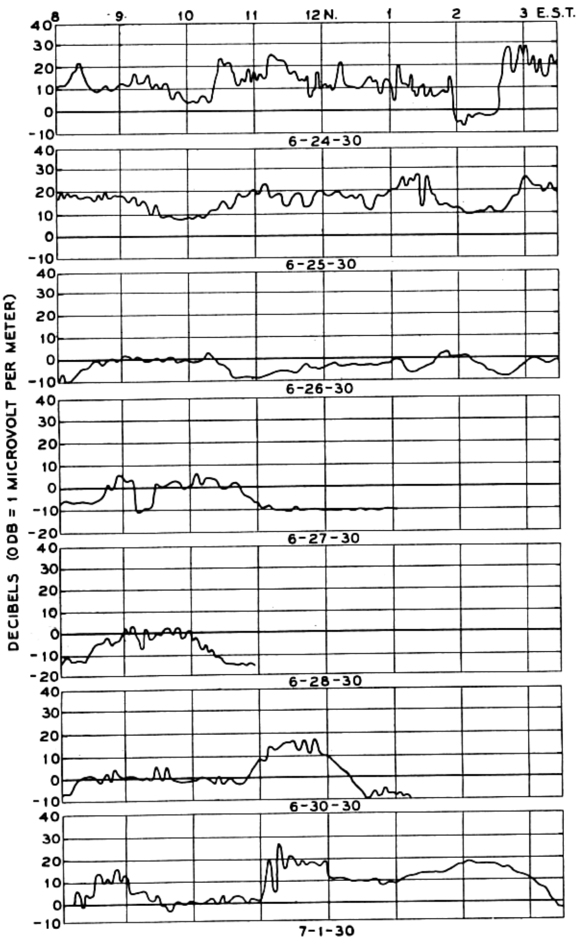


Fig. 9—Magnetic storm effect, oscillograms of received carrier.

lication, the rapid variations which are characteristic of fading have been eliminated and only the slow drifts are shown. It will be seen that the effect of the storm became evident on June 26, the average signal being 15 to 20 db lower than the preceding day. This condition continued on the 27th and 28th, on the 30th the signal averaged a little higher, and on July 1 a recovery had set in. The incompleteness of the record on three days is caused by the transmitting station shifting to a different frequency in an attempt to improve conditions. As to commercial transmission results over this channel during this period: the first two days were fair, the third day poor, the 27th, the 28th, 29th, and 30th very poor, and July 1 still rather poor.

The Problem of the Transmitting Medium

These adverse effects in short-wave transmission are ascribed to the nature of the medium through which the propagation of the waves takes place. The short-wave signals which reach a distant point are carried by waves which have traveled in the upper regions of the atmosphere, where a condition of ionization exists which causes the waves to move in a curved path and, finally, to arrive again at the earth's surface. The ionization in the upper part of the atmosphere varies with atmospheric conditions and hence its action on the waves which are passing through it varies from day to night, from season to season, in a more or less regular manner, on which are superposed fortuitous variations due to other conditions. The conditions in the upper atmosphere may be such that two or more waves arrive at a distant point from the same source after having traversed different paths. If the length of one of the paths is changing, the resulting signal from the two waves will pass through a series of maxima and minima in time, which process is known as fading. This complicated path condition is present at practically all times, since it is only on very rare occasions that short-wave signals do not fade in and out. Furthermore, there appear to be different kinds of fading corresponding to different transmission paths. For example, the fading on the North Atlantic short-wave circuits is of a deep slow variety as compared with the faster and more choppy type of fading experienced on the north and south circuit between New York and Buenos Aires.

To some extent this fading can be overcome by means of automatic gain control in the radio receiver which causes a steady signal to be delivered to the listener. However, this does not correct for the distortion which may be produced by interference between two transmission components. This distortion may result from a selective fading of the various frequencies in the voice band and an oscillogram showing this condition is given in Fig. 10 which is taken from a paper by R. K. Potter.[5] These are records of transmission across the North Atlantic of the voice band occupied by 10 suitably spaced tones of equal amplitude at the transmitting end. There is shown in the vertical columns a succession of snapshots which are separated

[5] See bibliography 19.

by intervals of about one-twelfth of a second. By following these columns down, the progressive change which occurs in the distortion of the voice band may readily be seen. The worst distortion occurs at

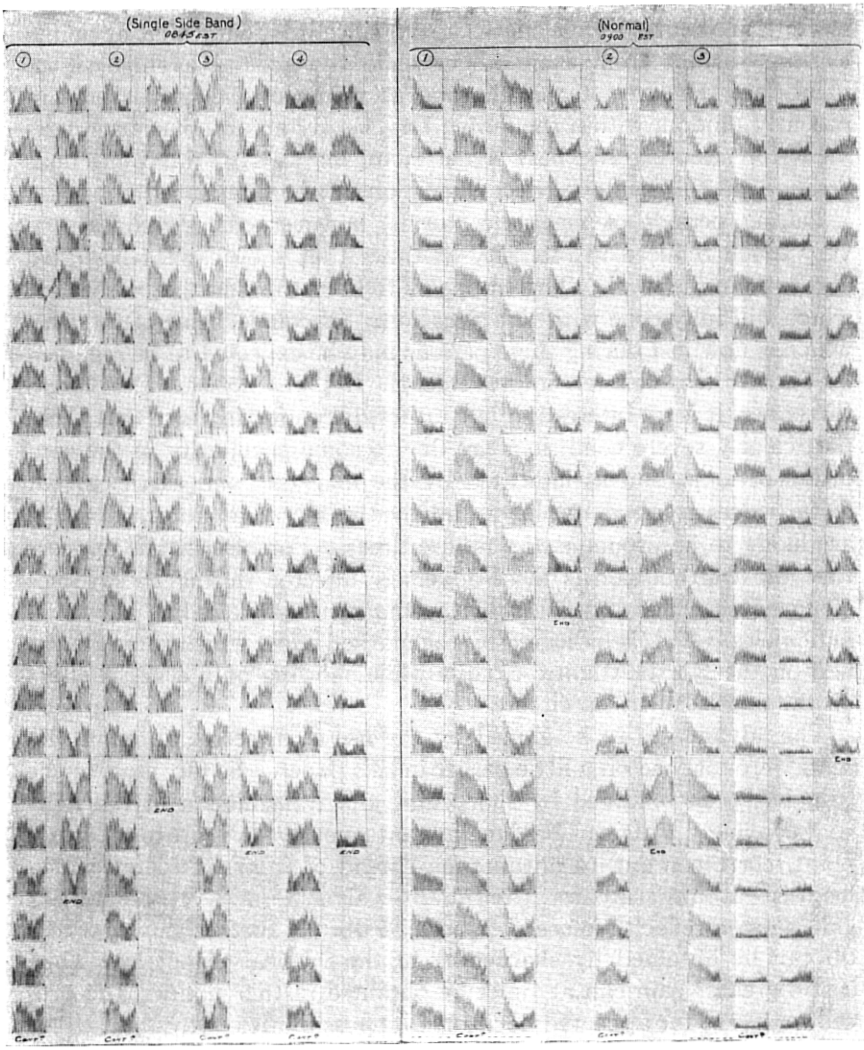


Fig. 10—Distortion of voice band in short-wave transmission.

times when the carrier itself is blotted out. Tests have indicated that the use of single side band is of value in minimizing this type of distortion. Experiments have been in progress for some time looking to the evaluation of gain to be expected along these lines from the introduction of a single side-band system and toward the development of single side-band equipment for use at these frequencies.

Another method which might be employed to reduce this type of distortion is to pick up the signal on a number of antennas spaced more than about 10 wavelengths apart, since it is found that at points this far distant from each other, while the general average signal values are the same, the instantaneous values of the signals are apparently random within the fading limits. By an automatic arrangement for selecting the best signal from, let us say, three antennas arranged in this manner, voice distortion can be diminished.

During periods of magnetic storms, however, the signals are so very much reduced in intensity at times that they cannot be heard above the noise level. There appears to be nothing in the present art which will fully cope with this situation. Of course, some of the time which is now lost during these periods may be expected to be regained by further transmission improvements. As was indicated earlier in the paper, it is an interesting but rather discomforting fact that these particularly severe conditions are due to some peculiarity in the condition of ionization as indicated by the magnetic and earth current disturbances referred to above and by the fact that aurora displays are likely to be pronounced at these times. Furthermore, it appears that the transmission is most adversely affected during these times along paths which pass near the aurora zones surrounding the magnetic poles. This is indicated by the marked effect which these storms had on the North Atlantic circuits while showing only a slight effect on the South American circuit.

The advantages to be gained by the use of directive antenna systems were touched on a little earlier in this paper. So far, most of the gain has been obtained by sharpening the transmission in the horizontal plane. This can be done advantageously only up to a certain point, corresponding to an antenna spread of from six to ten wavelengths—at any rate for transatlantic signals—and representing a gain when a reflector is used of about 15 db. A further gain of 3 to 5 db can be obtained by sharpening in the vertical plane; and while a still greater gain can at times be obtained in this manner, the procedure has so far appeared not worth its possibilities of trouble. This is due to the fact that with varying conditions in the upper atmosphere, the waves as they reach the receiving station apparently approach from different vertical angles and care must be taken not to build an antenna with such a sharp vertical characteristic that the received waves will fall on the antenna at such an angle that its calculated gain cannot be realized. We have, in fact, constructed several antennas sharp in the vertical plane, which have given as much as 16 to 20 db gain over a one half wave vertical antenna on local test but which have given for a signal from a distant point all variations of gain from this same value down to a loss of 2 db.

Planning the International Use of Frequencies

The problems of the transmitting medium discussed above are those which have been under study in connection with telephone transmission across the North Atlantic and between North and South America. Doubtless further observation and the exploration of other portions of the earth's surface will disclose a much more complete picture than it is now possible to present. It is important that further data be gathered not alone for the purpose of improving the transmission results obtained but also for use in agreeing internationally upon the most effective use of the frequency spectrum for different services in the interest of the world as a whole.

Of fundamental importance is the question of the frequencies which are best suited to different distances of transmission. The curves of Fig. 11 [6] give this relationship between frequency and distance in so far as it has been disclosed by measurements carried on between North America and Europe and South America, and also between the American continent and ships plying the Atlantic Ocean. In the construction of these curves use has been made also of data obtained by other agencies such as the Radio Corporation and the United States Navy Department. The curves are reproduced here merely for such use as they may be in connection with this problem of planning and with the hope of stimulating the contribution of corresponding data for other regions of the earth. It should be realized that actually each curve is the center of a considerable band of frequencies and that these bands merge one with another.

While experience has indicated that during the adverse transmission conditions which accompany a magnetic storm some improvement in transmission can at times be obtained by shifting the frequency. In general, these effects are found to extend over the entire high-frequency range now in general use, and shifting frequency does not dodge them.

In view of the extent to which transoceanic radio links, telegraph as well as telephone, are dependent upon the use of the higher frequencies, and of the importance of communications to the world as a whole, it is highly desirable that they be conserved for these longer distance uses. This has already gained recognition and the 1929

[6] See bibliography 22.

Hague Conference of the C.C.I.R. has recommended it as a principle. The carrying of it out in practice means that, in general, communications over the shorter distances should be carried out on the lower of the high frequencies (and possibly at the extreme high frequencies). It logically calls, also, for making the maximum use of existing wire networks for overland services, in order to free the radio channels for uses for which they are most needed. Finally, there is, of course, the need for coordinating the transoceanic links among themselves and minimizing unnecessary duplication.

In the Washington, 1927, Convention the world took a constructive step forward in organizing the use of radio channels by blocking out the high-frequency spectrum in respect to classes of service, thus:

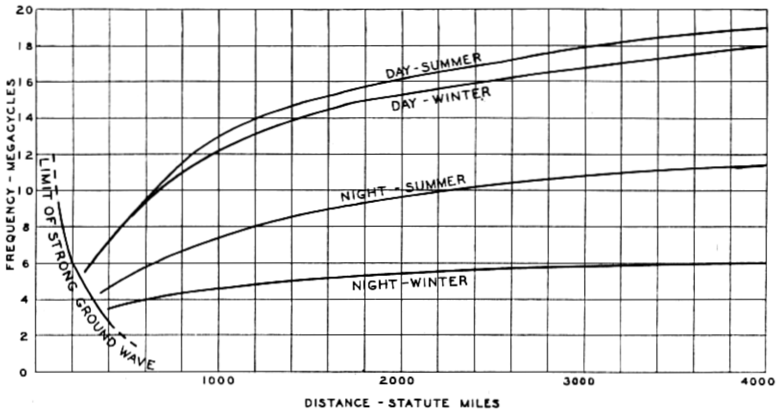


Fig. 11—Frequency-distance characteristic.

point-to-point, relay broadcast, mobile services. It is of interest to note that there is a further line of distinction which might be availed of for the purpose of reducing interference. As matters now stand, powerful and expensive stations which can well afford to live up to the highest standard of frequency stability, radio receiver selectivity, etc., are intermixed in the frequency spectrum with stations which cannot justify living up to these standards. Wide differences, in the caliber of station in accordance with the different needs is, of course, to be expected. This would appear to call for some grouping of stations in the various frequency bands in accordance with the frequency tolerance which they are prepared to meet. Some indication of the prevalence of interference on these short waves is given by the experience which has been had in operating the transatlantic short-wave telephone circuits during the first six months of 1930. Of some 3,000 operating hours in which the short-wave circuits were commercially useful, 110 hours, or about 3 per cent of the time, were lost due to interference from other stations. The frequencies of the interfering stations were found to differ from their registered frequencies by varying amounts up to hundreds of kilocycles.

The Hague 1929 Conference of the C.C.I.R. recommended that the frequencies of fixed stations operating in the 6,000 to 23,000-kc. range be held to 0.05 per cent tolerance and improved to 0.01 per cent as soon as possible. That this is not an unreasonable requirement for large stations is indicated by the following results of measurements made on the four short-wave telephone transmitters at Lawrenceville, N. J., during the periods of regular operation for the first half of 1930. Of 2826 measurements of the frequencies of these transmitters which were made at a measuring bureau 99.75 per cent were within the $\pm$ 0.05 per cent deviation, and 89.1 per cent were within the $\pm$ 0.01 per cent.

The existence of the problems of the transmitting medium and of the reduction of interference is a reminder of the need which exists for further quantitative studies of radio transmission throughout the world and of radio station performance, in the interest of the more effective use of the radio channels of the world.

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