Transatlantic Telephony—the Technical Problem

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SYNOPSIS: This paper, which, as it was read, was prefatory to the joint meeting, describes in rather non-technical terms the engineering problems involved in developing the transatlantic radio trunk by means of which the American telephone system of some 18,000,000 stations can communicate with the English telephone system of about 1,500,000 telephones, and also with the telephone systems of other European countries.

WE wish to give you a picture, necessarily very briefly sketched, of the physical makeup of the transoceanic telephone circuit, why it has been given its present form, and what further improvements are expected as the result of development work now under way.

The problem in brief is suggested by Fig. 1. A telephone system in America of some 18,000,000 stations, and distances of upwards of 3,000

Fig. 1—Map showing U. S. and European telephone systems separated by ocean

miles. A telephone system in England of about 1,500,000 telephones and the possibilities already partly realized of wire extensions to the other European nations. Three thousand miles of ocean between these two systems.

The establishment of a connection across the ocean presented two problems. First, the problem of setting up the radio circuit between the United States and England and second, the problem of making this radio circuit function as a link between these two widely extended telephone systems.

Fig. 2 shows the geographical layout of the long wave transoceanic circuit. The course followed by the currents in a connection is as follows: voice currents originating at any substation in America are transmitted to New York City over the wire circuits in the usual way and thence also by wire to the sending station at Rocky Point, Long Island, where they are radiated into space. These waves are picked

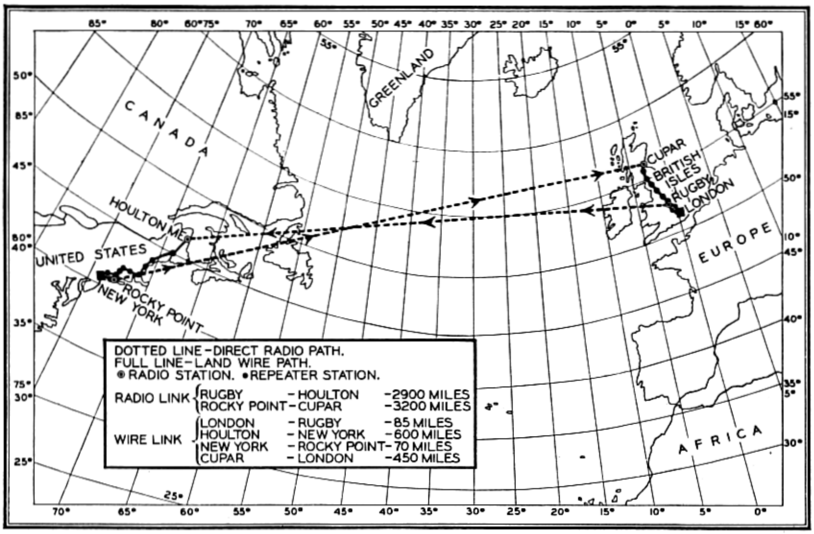


Fig. 2—Showing long wave routes

up at Cupar, Scotland, and transmitted by wires to London from which point they go by the usual wire connections to the subscriber in England or on the continent.

The answering voice waves are transmitted from the European subscriber by wire to London and thence by wire to Rugby, England, at which point they are radiated into space. The waves are picked up at Houlton in the northern part of Maine and transmitted by wires to New York City and thence by wires to the American subscriber.

You will note that the east and westbound radio systems are entirely separate from each other. Please note also that the receiving points in both countries are carried as far north as convenient—to Houlton, Maine, in this country, and to Cupar, Scotland, in the British Isles.

The radio and wire plant in Great Britain is owned and operated by the Post Office Department of the British Government.

As a supplement to the long waves there is a short wave circuit being formed which is so far only partially in use. In Fig. 3 the heavy lines show the long wave and the lighter lines the short wave routing. The short wave circuit from the United States to London was employed as an emergency routing during the severe static season last summer extending from Deal Beach, N. J., to New Southgate, London. The British Post Office in January started sending on a return short

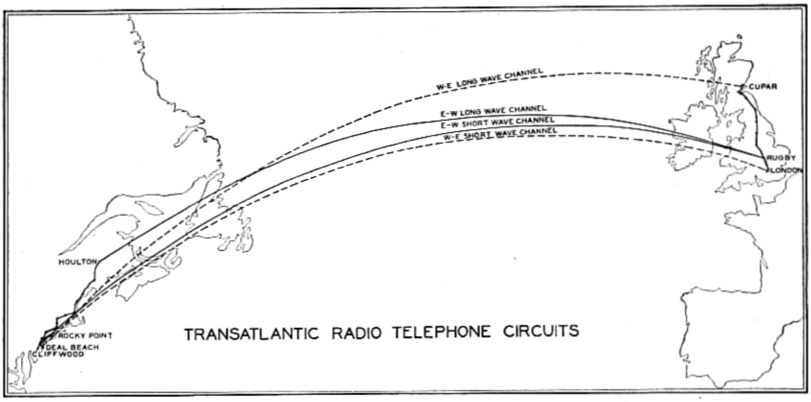


Fig. 3—Showing both long and short wave routes

wave circuit from Rugby, England, which is now being received at Cliffwood, N. J., but is not yet ready for service.

The right-hand drawing of Fig. 4 shows, necessarily on a logarithmic scale, approximately the frequency ranges covered by radio as we now know it. At the lower end are the long waves used in long distance

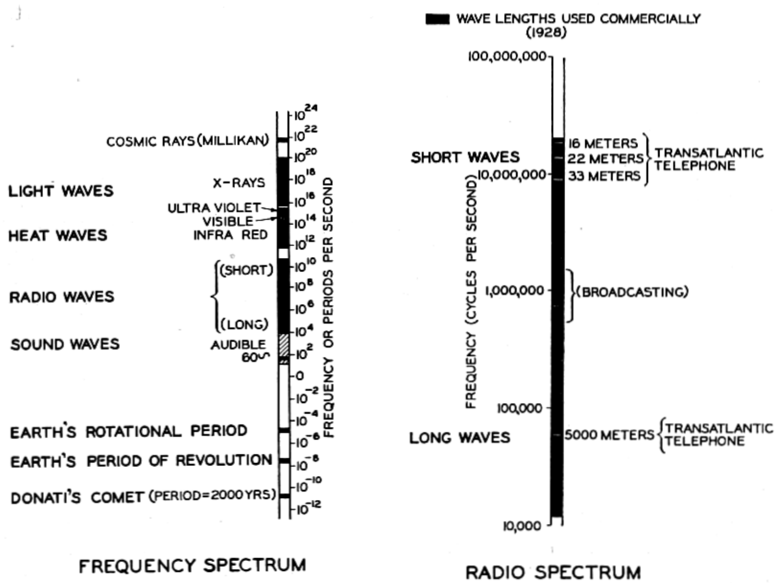


Fig. 4—Showing two plots on a logarithmic scale, one the radio frequency range, the other a general plot of frequencies

telegraphy extending down to nearly 10,000 cycles. At the upper end are the short waves already more or less exploited extending to about 10 meters, that is, 30,000,000 cycles.

It is interesting to note that one frequency range around 60,000 lying near the lower end of the scale and another frequency range extending from about 10,000,000 to 20,000,000 near the upper end of the present scale appear to be the most suitable for transoceanic transmission.

The left-hand figure has no bearing on our present subject. It is, however, rather interesting. It shows the whole gamut of frequencies with which we are familiar. This plot has near its lower end a frequency of one cycle per 2,000 years which is supposed to characterize a particular comet. From this it proceeds through the frequencies corresponding to solar periodicities, through the frequencies used in commercial power systems, through the voice frequencies, the wire carrier, the radio frequencies, the longer heat waves, the visual light rays, ultra-violet rays, X-rays and to the very hard rays sometimes called cosmic rays with which Dr. Millikin's name is here associated because of the investigations which he has carried out regarding them. This whole matter of frequency range and the relation of each part to human needs is of the greatest significance and interest.

In considering now how these long and short radio waves are handled in forming the transoceanic circuit, we will look first at the transmitting stations and antennæ, next at what happens to these waves in space and then at the receiving antennæ and stations.

At the transmitting end Fig. 5 shows a picture of the long wave antenna at Rocky Point, which well suggests the characteristics of these long waves. A frequency around 60,000 cycles corresponds to a wave length of about three miles and needs these physically large structures to effectively radiate the power into space. This antenna has six towers each 400 feet high. These long waves are in a frequency range which is much used and relatively narrow so that it is essential that the frequencies be employed the most economical way possible. This has resulted in the employment for the long waves of what is known as a single side band carrier suppression method of transmission, a refinement of transmission which, so far as I know, is not employed anywhere else in radio services although it is employed to a large extent in carrier over our wire circuits. With ordinary radio telephone transmission such as is used in broadcasting there is a constant steady frequency emitted even when no speech is being sent out and somewhat over 2/3 of the total energy radiated is in this steady carrier frequency which, of course, transmits no message. In the system here employed, however, this steady frequency is practically eliminated so that when there is no speech to be transmitted practically no energy whatever leaves this antenna. Furthermore, in ordinary

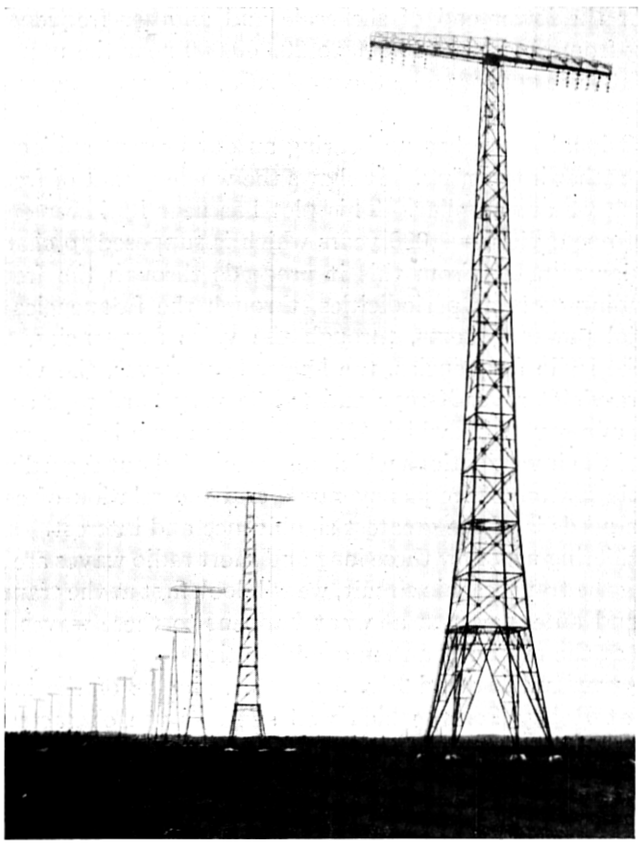


Fig. 5—A picture of Rocky Point sending antenna

transmission when there is, say, a 1,000-cycle tone to the voice, this appears in the transmission as two frequencies 1,000 cycles above and 1,000 cycles below the carrier frequency. This evidently is an ineffective use of the available frequencies so that one of the so-called frequency side bands in this system is eliminated. In this way a single tone in the voice is represented by a single frequency in the transmission from the station. A further frequency economy by the use of the same frequency range for talking in two directions is brought out below.

Fig. 6 shows the large vacuum tubes used in the last stage of the Rocky Point long wave radio transmitter. As many as 35 such tubes are employed in parallel capable of putting into the antenna something

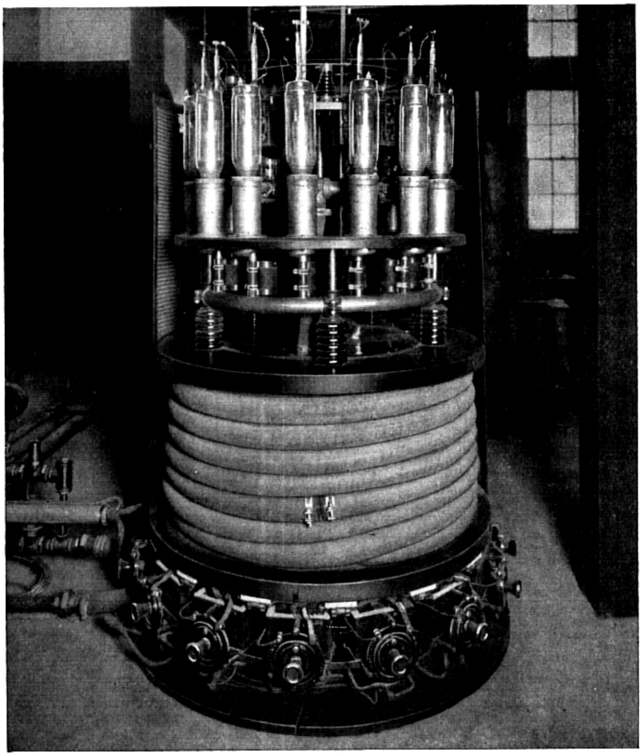


Fig. 6—Showing last power stage

over 200 killowatts which, as already noted, is worth something over six times this amount in the form of ordinary radio transmission.

This is the only picture I shall show of any of the apparatus involved in this work although such apparatus represents, of course, a tremendous amount of fundamental investigation and development and design. In a picture of apparatus, however, you can see little but assembly of cases and wiring and occasional vacuum tubes, and this gives you no adequate idea of what is going on electrically inside of the devices. An interesting feature of the transmitting apparatus in this system is that in the process of suppressing the carrier and stripping off one of the side bands, a double frequency transformation is required. For example, a 1,000-cycle tone coming into the station appears first as 32,200 cycles and next as 59,500 cycles, which is the frequency transmitted.

Fig. 7 gives us in contrast one of the short wave sending antennæ. This particular one is for a wave of 22 meters wave-length, that is,

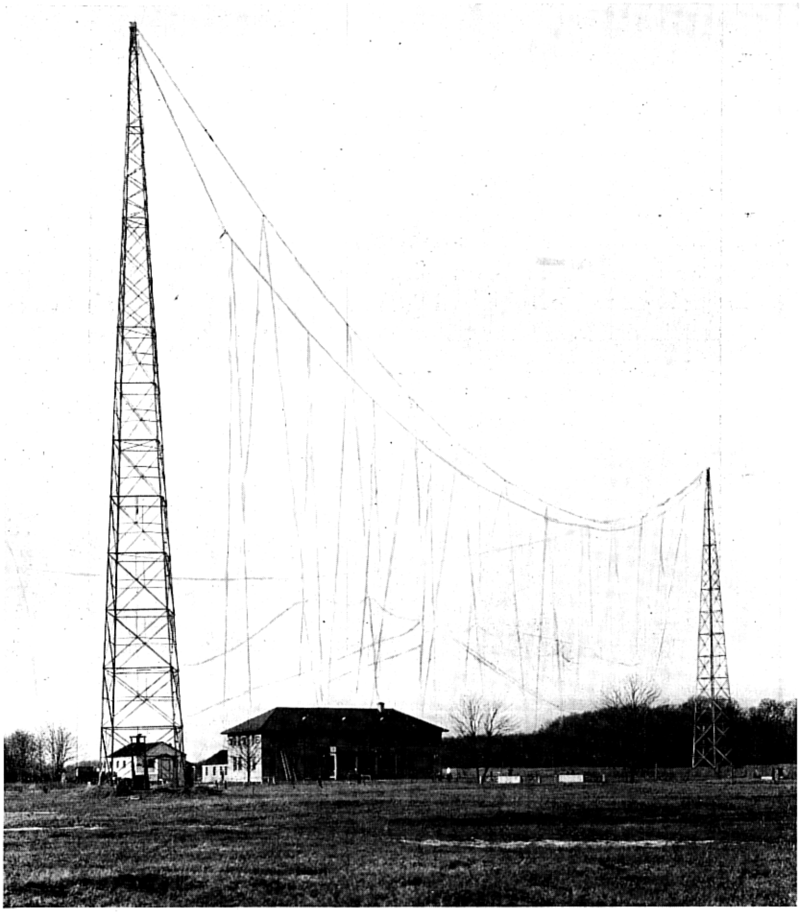
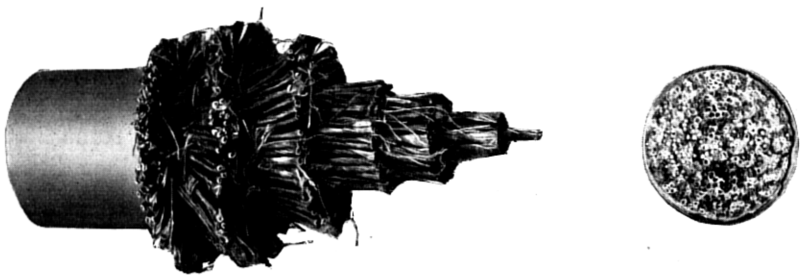


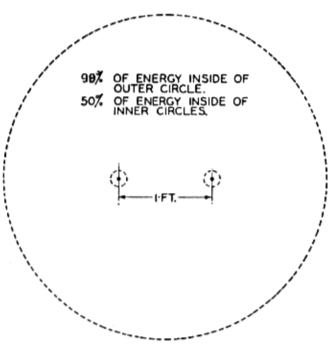
Fig. 7—Deal Beach sending antennæ

about 70 feet, corresponding to a frequency of around 14,000,000 cycles. These shorter wave-lengths lend themselves readily to directional sending and the resultant possibilities of conserving power in that way. The form of antenna shown is essentially a group of vertical antennæ with a transmission line connecting at points of equal phase. With this particular antenna, energy received in England is increased by about ten times as compared to that received from a non-directive system.

Assuming we have put the power into proper frequency form and radiated it into space, the next question is how does it fare in traversing the great distances before it reaches the receiving points. We can hardly state this as a technical problem since there is nothing the engineer can do to control it. He can find out merely what nature does to such waves and try to arrange his transmitting, and particularly his receiving systems to meet the characteristics of the waves.



Section of New York–Chicago cable



Energy distribution with No. 8 B. W. G. open line circuit carrying A. C. currents

Fig. 8—Cross-sections of wire line with energy circles and cross-section of cable

We could think of no slide to show this space transmission unless possibly a picture of the world rotating in space such as we have seen adorning popular articles on radio. We will suggest the matter, however, by contrast with wire transmission.

The left-hand part of Fig. 8 shows a cross-section of a pair of copper wires spaced a foot apart on a pole line, which is the standard telephone wire arrangement. On such a circuit 98 per cent of the energy is transmitted inside of the outer dotted circle. The right-hand part of the slide shows two views (one a cross-section) of a typical telephone toll cable of somewhat under three inches diameter. Practically all the energy for about 300 telephone circuits is transmitted inside this sheath.

While both the radio and the wire transmission involve similar electromagnetic waves, there could hardly be a greater contrast in the method of handling waves than that between the radio transmission we are considering in this paper and transmission employing such wire methods and spanning the comparable distance of say San Francisco to New York.

Recently in visiting the short wave receiving station in New Jersey I was shown oscillographs taken on radio telegraph transmission in which each telegraph dot was followed about a tenth of a second later by what appeared to be an echo. The first transmission came some 3,000 miles from England. The second transmission had gone the opposite direction around the world and had travelled some 22,000 miles before reaching the same receiving point. In such long distance radio we may then have a situation in which each individual signal sets up oscillations, perhaps measurable oscillations, in space surrounding practically the whole earth.

Contrast this to the toll cable shown in the picture which, as already noted, contains about 300 circuits. Such cable is used now commercially for distances up to around 1,500 miles and is permissible for 3,000-mile distances such as we are here considering. In such cables each message is practically confined to a strip of space extending between the terminals of the cable and smaller around than a lead pencil. In the radio case we have literally all out of doors but there is little we can do to control it. In the cable case the channel is reduced to the meagerest dimensions but this so reduced space we can pretty nearly call our own, surrounded and shielded as it is by a sheath and containing carefully balanced circuits. Such space is only occasionally penetrated by outside disturbances when some of our power friends set up unusually strong electrical fields in its immediate neighborhood. By loading, by amplifiers, by equalization of various sorts, this meager space is guarded and controlled and rendered efficient and constant.

We are still somewhat in the dark as to how kind nature has been to us regarding short waves and what degree of reliability we can ultimately get from a circuit employing them. There is nothing yet in the picture, however, to suggest a reliability for long or short wave radio approaching that of a cable circuit for similar distances.

A large number of measurements have been made of the strength of the radio fields laid down in England from the long and short wave stations in America and similarly in America from the English stations. Along with such data is taken the amount of noise interference present at the receiving points. Fig. 9 shows data taken in this way. The curve which reaches the highest point shows for a typical summer's day the field strengths received on the long wave from America. The

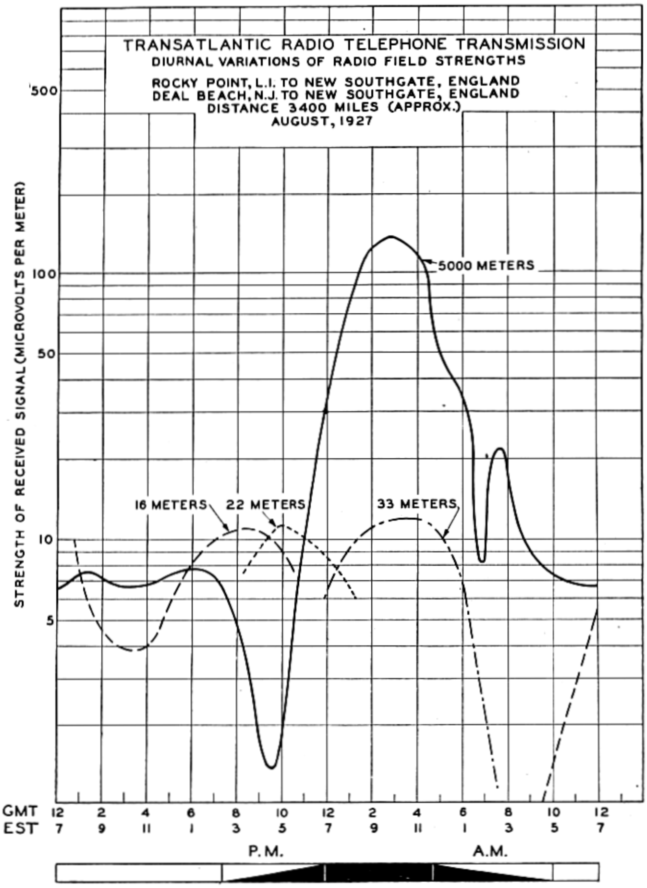


Fig. 9—Long wave curve and corresponding short wave curve of received field strength

other curve shows the field strengths received on short waves employing three wave-lengths, 16, 22 and 38 meters, and taking for each time of day the one of these which was best suited to the conditions.

On this typical day all the wave-lengths were operating well. It will be noted, however, that there are times when the long wave is low and some one of the three short waves is more effective and other times when none of the three short waves are high but the long wave is effective. Furthermore, all of these waves vary a good deal so that on certain days for hours shown operative on these curves one or more might be entirely out of service. This chart indicates the tremendous advantage in employing a number of separate wave-lengths varying a good deal in their characteristics and choosing at any one time that wave-length which is giving the best performance.

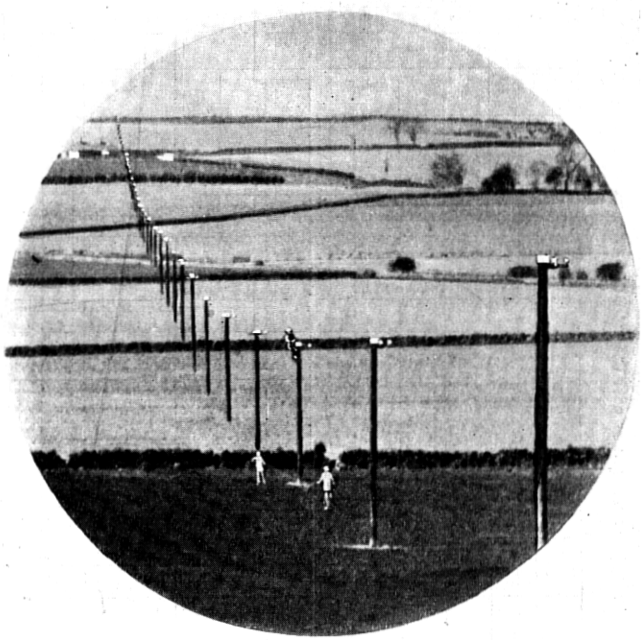


Fig. 10—Showing receiving antenna at Cupar

Having followed the radio transmission as the waves radiate into space and traverse space to the receiving end, we come to the matter of receiving stations. Fig. 10 shows a view of the wave antenna at Cupar, Scotland, used for receiving long waves. This complete antenna arrangement is made up of two pole lines such as shown, each about 3 miles long; a third may be added. These pole lines are placed parallel to each other with separations of about two miles. A pole line joins the two together and connects them to the receiving stations.

It is fortunate that in America (and the same is true to a considerable extent in England) the signals come in from a northerly direction and the static tends to come in from almost the directly opposite direction. The directivity brought about by such antennæ has, therefore, a very large effect. It is estimated that under average conditions the present antenna gives as much improvement as would an increase in power of about 100 times. Furthermore, receiving at Houlton, Maine, rather than in the vicinity of New York, by getting to a more northerly latitude, is equivalent to a power increase of 50 times. The antenna location and directivity, therefore, is equivalent to a transmitted power increase of 5,000 times. The receiving set employed with these antennæ at Houlton is of a double demodulation type, of very high selectivity.

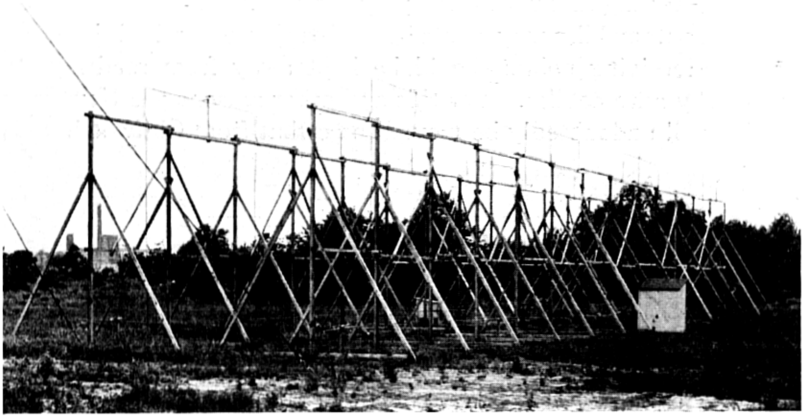


Fig. 11—Picture of receiving antenna in Cliffwood

Fig. 11 shows a receiving antenna at Cliffwood, N. J., of the type used for short waves. It is constructed of a wooden framework on which are held two parallel sets of conductors made up by bolting together lengths of copper tubing. Possibly you can make out the form of the two sets of conductors. Each set consists of vertical elements a quarter of a wave-length high and a quarter of a wave-length between successive elements. The first element is connected to the second by a conductor connecting the upper ends of the elements, the second is connected to the third by a conductor connecting the lower ends and so on.

The whole effect gives a degree of directivity equivalent to an increase in power of about 15 times. This general question of short wave receiving is a fruitful field for investigation and for the ingenuity of the engineers. A large number of arrangements have been devised and a good many of them tried. Considerable further work is under way.

At the time when the short waves are in trouble apparently either one of two conditions may obtain. In the first of these there may be considerable field received from the distant transmitting station but this field is made up of the result of transmission over several paths so that the waves received over the different paths react on each other, causing a rapidly fluctuating interference pattern somewhat similar to that well known with light waves.

There are other times, however, when either the field which reaches the receiving point is not of sufficient magnitude to be picked up or is below the static noise level at the particular time.

One interesting fact with these very short waves is that the ignition system in automobiles may create large disturbances and it is important that the receiving points should be kept away from roadways frequented by automobiles. For this and other reasons the New Jersey location will undoubtedly be moved somewhat from Cliffwood.

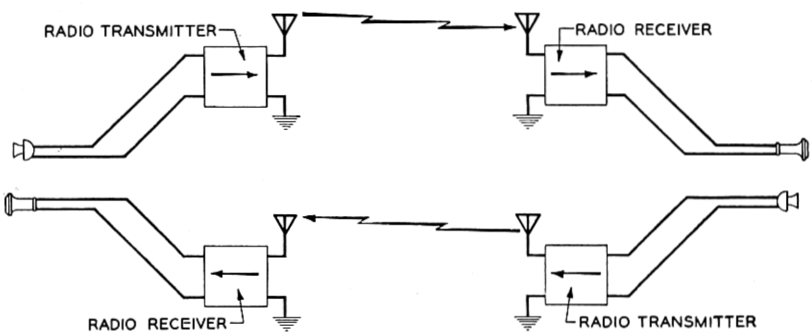


Fig. 12—Indicating diagrammatically east and west transmission on separate channels terminated in ordinary transmitters and receivers

So much then for the question of the radio circuits themselves. The problem remains of making them serve as a link between the two-wire systems on the two sides of the Atlantic. If the problem were merely transmission from one particular subscriber's set to another particular subscriber's set, the very simple arrangement shown in Fig. 12 would be feasible. In this you will note the eastbound and westbound transmission each starting with a telephone transmitter at one end and extending to a telephone receiver at the other are kept entirely separate. Two people could evidently carry on a conversation over this circuit without further complications. In fact this was the way in which the first two-way tests were carried out.

Since eastbound and westbound short wave channels are at entirely different frequencies, there would be no interaction between the east and west-going circuits when used in this way. For the long waves, however, since the east and westbound circuits are at the same frequencies, each transmitting station would send considerable energy into the receiving station on the same side of the ocean, thus giving to each subscriber a heavy side tone of his own speech. This effect, however, could be considerably reduced by separating the transmitting and receiving stations and arranging the directive antennæ of each receiving station so it would receive as little as possible of the corresponding transmitting station. Even with the long waves, therefore, a conversation could be held in this simple way.

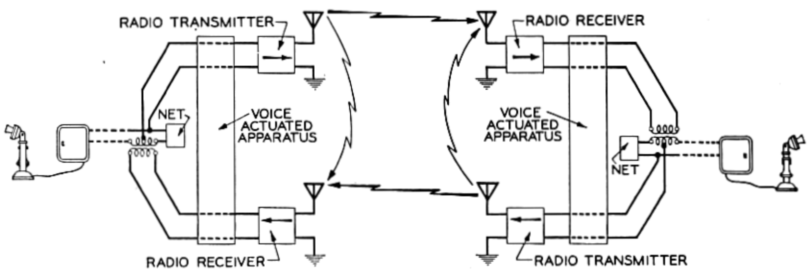


Fig. 13—Transoceanic circuit schematic

When the east and westbound radio circuits are brought together, however, for a connection to a wire circuit at each end, we have introduced some very serious difficulties. Consider first the simpler case of the short waves where the eastbound and westbound transmission are at different frequencies.

The voice waves reaching London from an American talker will be reflected in part either at the London office where the east and westbound channels are brought together or at some point before reaching the European subscriber. Unless means are taken to prevent it, this reflected energy can then pass to the English transmitting station and be transmitted back to America. At the American end a similar partial reflection can take place throwing part of the energy back again to England. In this way, according to circuit conditions, it is possible for the whole circuit either to build up and act as a widely flung oscillator or if the damping at the moment makes this impossible, the speaker and the listener can be much interfered with by electrical echoes and distortion.

In the case of long waves there is the added difficulty as already noted that each transmitting station can throw a good deal of power into the receiving station on its own side of the ocean, thus bringing in the possibility of local oscillations and distortions.

For either the long or short waves then it is very advantageous, in fact practically necessary, to employ switching devices actuated by the voice waves themselves to prevent the effects just stated. In this diagram you will note drawn so as to involve the wire connections both to the transmitting and the receiving station at each end a rectangle which is labeled "voice-actuated apparatus." This is so arranged that when there is no transmission on the circuit the wires connecting to each of the transmitting stations are short-circuited, making both transmitting stations inactive. Speech coming in then at one of the ends from a telephone subscriber operates a relay which opens the wire circuit to the transmitting station at his end and at the same time short-circuits the receiving path at the same end.

One interesting phase of this voice-operated switching mechanism is the employment of a delay circuit. At the New York terminal of the circuit, when the voice currents reach it from some distant subscriber and after these voice currents have actuated the switching

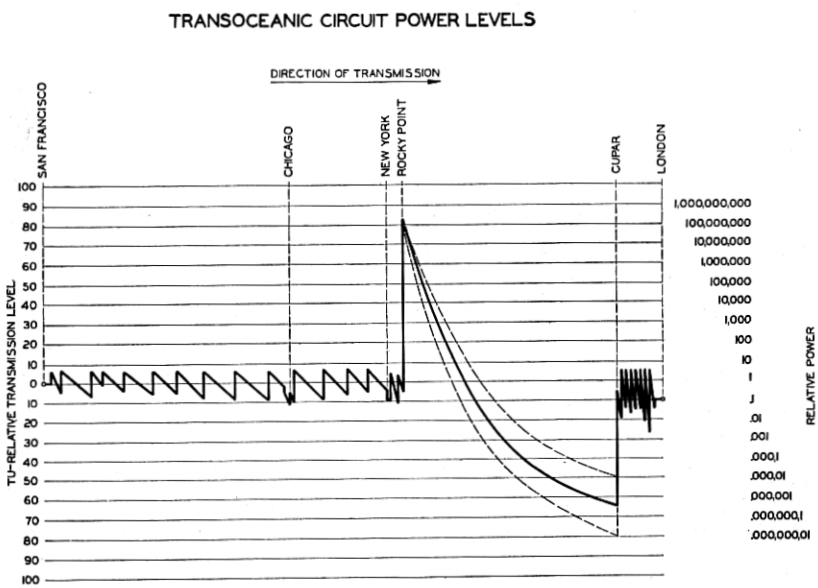


Fig. 14—Diagrams showing energy levels

mechanism noted above, they pass into an artificial line down which they travel, are reflected and travel back to the sending end of the artificial line. In this way the voice waves are allowed to idle away two one-hundredths of a second during which time the switching mechanisms have performed the operations just noted and have thus put the circuit into shape for the voice waves to go forward.

Fig. 14 shows the shifts in power level in going from one end of the circuit to the other for a connection from San Francisco to London. The zero of the scale corresponds to the power level at which power is given out by an ordinary substation set when actuated by a loud voice. The power ratios compared to this are shown at the right on a logarithmic scale.

The comparatively small ups and downs in the power level corresponding to transmission over the wire lines represent, of course, the line attenuations and successive amplifications by telephone repeaters. The highest power level is naturally at the output of the radio transmitter where it is about one hundred million times the starting level At the English receiving station it has been dropped to about the same ratio below the zero of the scale.

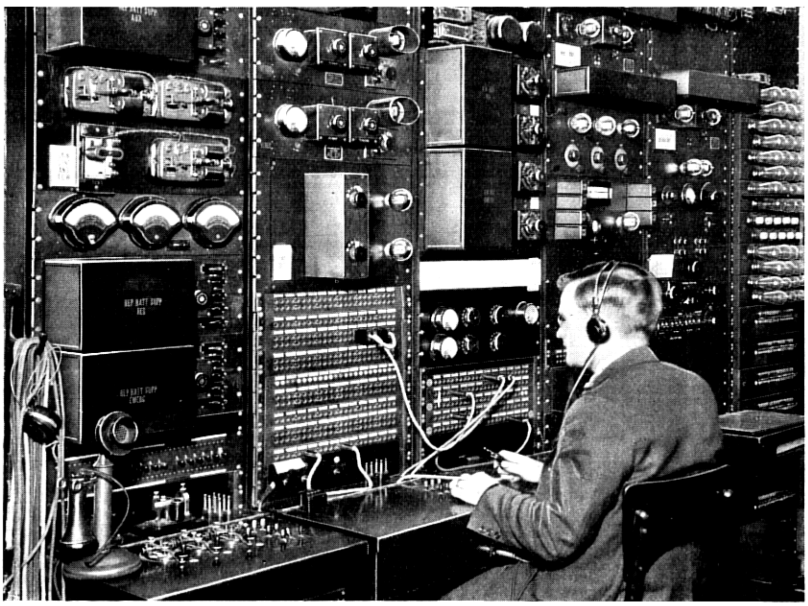


Fig. 15—Technical operators' position

In view of the character of radio, in particular its variable nature, the circuit is under constant supervision during operation by two technical operators, one located in New York and one in London. Fig. 15 shows the special terminal equipment, meters, etc., and the technical operator at the New York end.

It is evidently desirable that the transmitting station shall always put out maximum power whether the speaker has a loud or a weak voice or is near or distant from the transmitting station. One of the duties of the technical operator is to bring this about. By proper indicating meters he knows the power level of the speech going to his transmitting station and he keeps this at the point where it will just completely load the transmitting station.

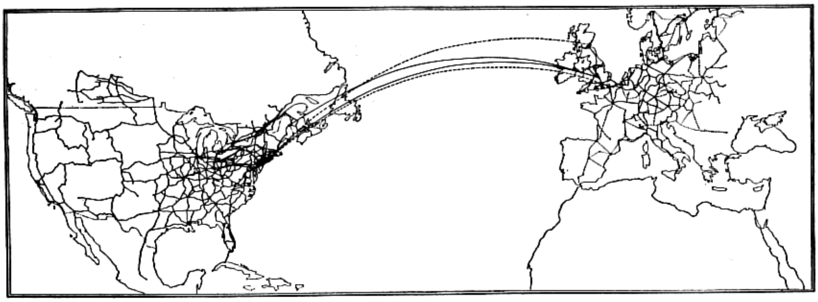


Fig. 16—Fig. 1 with radio connections added

With this brief discussion then let us assume we have progressed from the conditions of our first illustration to the conditions shown here in which the two great telephone systems are joined together by the radio links.

To complete the story, a few more words as to the changes and improvements which development work now under way is expected to give.

As the system stands to-day it does not offer the privacy which ordinary wire connections offer. While ordinary broadcasting sets are not of the proper type to receive messages from this system, it is comparatively easy, with sets designed for the purpose, to pick up one side of the conversation over the system by listening to the transmitting station in the same country as the listener. Because of the voice-actuated devices, the other side of the conversation has to be picked up directly from the distant country, which is a much more difficult thing to do.

To give this system a high degree of privacy is difficult, particularly with the long waves. The frequency range in which the long waves are situated is, as already stated, narrow and well filled so that any proposition that widens the required frequency range, such for example as shifting the carrier frequency rapidly, cannot be employed. Methods have been developed, however, and equipment is far advanced on a system that is expected to give conversations over this radio channel a sufficient degree of privacy. Certain features of the new privacy method will probably be in experimental use within a few months. It will be at least six months and possibly a year before the complete privacy system is in full operation.

The feature of this whole transatlantic service which worries the engineer most, however, is the matter of reliability. After the engineer has done the best possible in transmitting and receiving stations he is confronted by the fact that transmission through space and noise conditions vary so much that thousands of times as much transmitting power as would be sufficient under good conditions may be inadequate to get through under poor conditions. His only defense is to use a considerable number of wave-lengths which tend not to get into difficulties at the same times or under the same conditions.

Considering first the short waves we find as already noted there is sufficient difference between the transmission characteristics of different parts of the range, between say 10 meters and 30 meters, so that the reliability is considerably improved by designing the stations to use any one of three or more frequencies in this range.

We shall be very happy if by such use of a number of short wave-lengths and by further improvements in technique the reliability of short wave channels can be made such as to some day eliminate altogether the necessity of the long wave channel with its much more extensive plant. There are a number of projects going ahead in the world for the establishment of long distance transoceanic telephone circuits employing short waves alone. With a reasonable further development of the short wave art such service will undoubtedly prove well worth giving.

Telephone service is, however, necessarily an exacting service, particularly since the subscribers participate directly in each connection. Moreover we are dealing here with the joining of North America and Europe which, commercially and otherwise, is of so large importance as to justify perhaps much more exacting technical requirements than any other transoceanic connection.

So far, the data available regarding the short waves do not suggest that they ever will give a reliability of service comparable to that for similar distances over land wire circuits. It is our present expectation, therefore, that the giving of suitable service between America and Europe will require the continuation of the long waves even though such waves demand a much more extensive and complicated plant than do the short waves. In addition to the long waves we shall also want the very best we can get from the short waves. By the combination of this one long and several short waves we believe that ultimately the service, except for the three summer months of high static, will be but little interfered with by electrical weather, and that even for these months the service will be operative for better than 90 per cent of the time.

You will understand, of course, that the connection to-day from London will be entirely by long waves, the short waves not being ready for commercial operation. The connection from America to England will also in all probability be by long waves, although the short waves are being held in readiness as an emergency routing.