Transoceanic Telephone Service—Short-Wave Equipment

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The application of short-wave radio transmission to transoceanic telephone circuits is developing apparatus and stations designed specifically to meet the needs of these services. This paper describes from the radio point of view the important technical features and developments incorporated in the new transmitting and receiving stations of the American Telephone and Telegraph Company located respectively at Lawrenceville and Netcong, New Jersey, and it outlines some of the radio problems encountered in the station design.

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SHORTLY after transatlantic telephone service was opened in January, 1927 the long-wave radio circuit between New York and London was supplemented, first by an experimental short-wave radio link in the west-east direction and later by a short-wave link in the east-west direction.[2] From this beginning, as an auxiliary to the long-wave circuit, the short-wave system has been improved steadily so that its average performance throughout the year now more nearly approaches that of the long-wave system and it has become an important part of the transoceanic facilities. The relative merits of the two systems, their combined usefulness, and their transmission features are the subject of another paper and will not be discussed here. For the present purpose it will be sufficient to note that there are now in operation between New York and London, one long-wave and three short-wave two-way circuits and that within a few weeks a short-wave circuit will be available between New York and Buenos Aires.

The radio transmitting units for the New York end of these four circuits are located at the new station which the American Telephone and Telegraph Company has recently established at Lawrenceville, New Jersey. The receiving units are concentrated at Netcong, New Jersey. The factors entering into the selection of these station locations are outlined in another paper and therefore need not be mentioned further. This paper is limited in scope to a necessarily brief description of the transmitting and receiving systems and apparatus, a discussion of technical features in the station layouts, and an outline of the major problems encountered in the station design. Comprehensive treatment of individual units is properly left for other entire papers. It will be convenient to deal with the transmitting and receiving sta-

[1] Presented at the Winter Convention of the A. I. E. E., New York, N. Y., Jan., 1930.

[2] O. B. Blackwell, A. I. E. E. JOURNAL, May 1928. B. S. T. J. April 1928.

tions separately and in each case to consider briefly the system and apparatus of one channel before describing the general station plan.

Transmitting System

The four channels at Lawrenceville are equipped with independent transmitters using certain auxiliary apparatus in common. Each channel involves a radio transmitter with its associated power plant and wire equipment, and a group of directive antennas designed and adjusted for the specific wave-length assignments of the channel.

The general method of transmission, with the exception of directional sending, is the same as that employed for program broadcasting stations in that the radiated signal contains the carrier and both sidebands. Systems in which one or more of these components are suppressed at the transmitter appear to offer further means of improving short-wave transmission, and the necessary apparatus for the practical application of such systems when operating at frequencies in the order of 20,000

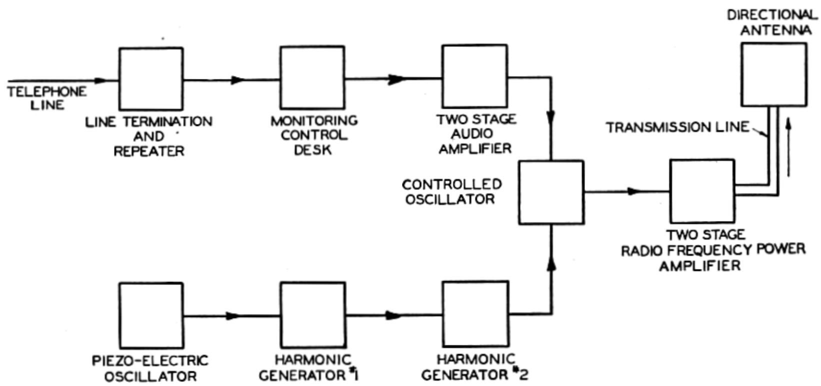


Fig. 1—Block schematic of transmitting system.

kilocycles is undergoing development. However, throughout the development of the transmitters as now installed at Lawrenceville the possibility of future major modifications in the method of transmission has been kept in mind. For this reason the modulator-amplifier system was adopted. In this system the signal which is to be radiated, is prepared by modulation processes at relatively low power levels and thereafter amplified the requisite amount. The amplifier and its power plant, representing a large proportion of the investment in equipment, can be continued in service with no appreciable alterations, even though the system of transmission and the modulating apparatus undergo radical changes.

The general scheme of transmission is shown in Fig. 1. After passing through the line terminal and control apparatus, which includes standard repeaters, the voice currents are further amplified and employed to modulate the plate voltage of an oscillator consisting of two 250-watt tubes connected in a push-pull circuit and oscillating at the frequency of the carrier which is to be transmitted. The frequency of such an oscillator, if not carefully controlled, will wander outside of the assigned frequency band, thus causing interference with other services and it will also suffer variations during the modulation cycle which contribute to fading phenomena encountered at the distant receiving station. In order to reduce these effects the oscillator is held in step at the desired carrier frequency by means of a second oscillator which is electrically removed from the reactions normally influencing and tending to vary the frequency of the controlled oscillator. Every precaution is taken to maintain accurately the frequency of the second oscillator and among other things it is governed by a piezo-electric quartz crystal whose temperature is regulated closely.

Since it is impractical to use crystals cut sufficiently thin to oscillate directly at frequencies in the range 10,000 to 20,000 kilocycles, thicker crystals of lower frequency are used in combination with harmonic generators which multiply the crystal frequency first by two or three and then by one or two as the case requires. By virtue of the wide differences between the input and output frequencies of the harmonic generators these intermediate steps tend to isolate the crystal oscillator from the other radio circuits and thus aid in stabilizing the frequency.

The modulated radio frequency output of the controlled oscillator is applied to the grids of a two-stage power amplifier employing water-cooled tubes designed for operation at these frequencies. The first stage contains two tubes and the second stage contains six. The tubes are arranged in push-pull circuits, the entire system being carefully balanced to ground. The carrier output power from the last stage is 15 kw. With 100 per cent modulation this corresponds to 60 kw. at the peaks of the modulation cycle. In other words, a radio telephone amplifier of this type, rated at 15 kw. when provided with a sufficiently large d-c. power source, could be used as a 10,000-kilocycle continuous wave generator of 60 kw. capacity.

The radio signal delivered by the amplifier is conveyed to the antenna by means of a 600-ohm open wire transmission line. The antenna itself is both a very efficient radiator and a highly directive one.

Transmitting Equipment

At the transmitting station the apparatus for each channel comprises, (1) wire terminal equipment and repeaters, (2) a voice frequency control desk, (3) the radio transmitting set containing the oscillators, modulators, and power amplifier, (4) a power control board, (5) rectifying apparatus and filters for supplying direct current at 10,000 volts, (6) motor-generators for providing various circuits with direct current, (7) water circulating pumps, tanks, and cooling units.

The wire terminal equipment and repeaters at the transmitting station are standard units mounted on relay racks beside the voice frequency testing apparatus common for all channels.

The voice frequency control desk provides facilities by which the attendant can monitor the incoming voice currents and the outgoing radio signal. Means are provided for observing the volume of these signals. Oscillators are provided for the purpose of quickly checking the performance of the system during line-up periods and for sending Morse signals over the radio link when required. The control desk

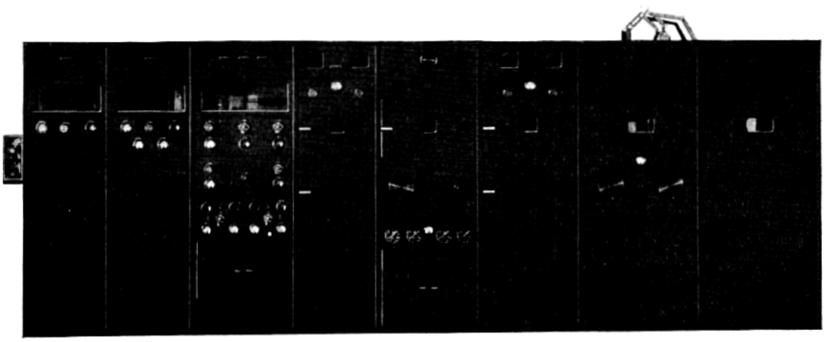


Fig. 2—Front view of short-wave radio transmitter of type used at Lawrenceville.

is also equipped with apparatus for direct telegraph communication with the technical operator at New York.

The radio transmitter consists of seven independently shielded units mounted on a common sub-base to form a single assembly, 4 ft. by 20 ft. by 7 ft. high. Some of the units are subdivided into several small shielded compartments. Very effective electrical screening or shielding between the various parts of a short-wave transmitter is essential. Otherwise stray fields introduce unwanted feedback couplings which produce distortion effects and spurious oscillations. Fig. 2 is a front view of the transmitter. Beginning at the left there are two units for speech amplification, one for radio frequency generation and modulation, one unit each for the first stage, the interstage circuit and the last stage of radio-amplification, and a double-sized unit for the output circuit. It is interesting to note that the over-all length of this assembly is as much as five eighths of a wave-length at the highest frequency in its operating range, which is 9000 to 21,000 kilocycles. Each transmitter is required to operate at several assigned frequencies within this range and to change in a few minutes from one to another. This is done by changing coils and varying condensers in the oscillator and amplifier circuits and switching to different quartz crystals. Except in cases where two assigned frequencies are in harmonic relationship, it is necessary to provide a crystal for each of the frequencies. The crystals are mounted in an oven and continuously maintained at 50 deg. ± 0.05 deg. cent. by recording regulators. In order to avoid long interruptions to service in the event of a crystal failure or other circumstance requiring the opening of the oven and the subsequent reestablishment of temperature equilibrium, the ovens and crystals are provided in duplicate.

The electrical problems which are encountered by the engineer designing a power amplifier for these high frequencies arise largely from the inherent stray or distributed capacities and inductances which are far less important at lower radio frequencies. For example, between the anodes of the amplifier circuit there exist capacities, which are composed of capacities within the tube itself, the direct capacities between the tube water jackets, the mounting plates and the like. The total value of this composite capacity in the last stage is approximately 100 m.m.f. This value cannot be appreciably reduced by any change in design which now seems desirable. The reactance of 100 m.m.f. at 20,000 kilocycles is about 80 ohms. Thus the engineer is confronted at the outset with a generator (the tubes) which has an internal impedance in the order of 2000 ohms but across whose terminal is shunted inherently an 80-ohm reactance. Fortunately, this obstacle can be surmounted by introducing resonance effects but nevertheless it places very important limitations on the design of the associated circuits. These problems become more difficult with increase of either power or frequency. Increase in power requires higher voltages and currents and thus larger elements, spaced farther apart. The augmented bulk increases both stray capacities and unwanted inductance of leads. Higher frequencies increase the magnitude and therefore the relative importance of these effects.

The power control board has nine panels equipped with the necessary instruments and apparatus for controlling and distributing all power to the transmitter. The motor-generators, pumps, fans, oil circuit breakers, and other apparatus are remotely controlled from this point. A system of relays and signal lamps provides protection and indicates the location and general nature of any trouble. With the exception of the application of high-voltage direct current, the entire system starts up and shuts down in the proper sequence in response to the manipulation of a master control switch.

Direct current at 10,000 volts is supplied to the anodes of the power amplifier tubes by a transformer and rectifier using six standard two-electrode thermionic tubes. The rectified current is filtered separately for each stage of the amplifier. This is necessary to prevent distortion by interstage modulation caused by the common impedance of the rectifier. Effects of this nature become important as the requirements placed on unwanted modulation products become more stringent.

Transmitting Antennas

The antennas at Lawrenceville all have comparatively sharp directional properties. Such antennas are readily realized when dealing with radio waves of very short wave-lengths. Although the fundamental principles involved in producing these directional effects have been known for many years, economic limitations effectively prevented their application to transmitting antennas for long wave-lengths. These limitations are altered immensely in the case of antennas for short wavelengths and, when the useful propagation properties of short waves became known, great stimulus was given to the development of antennas for directional sending and receiving. The same type of antenna can be used, of course, for both purposes but, since the objectives when sending and receiving are somewhat different, the tendency has been to develop arrangements adapted to each case.

Directional transmission is a very large subject and will only be touched upon sufficiently to describe in a very general way the antennas at Lawrenceville. There are many possible arrangements and combinations and the engineers must choose from these the ones most suitable for their purpose. In general all of the schemes depend upon producing interference patterns which increase the signal intensity in the chosen direction and reduce it to comparatively small values in other directions.

One of the methods of obtaining a sharply directive characteristic is to arrange a large number of radiating elements in a vertical plane array, spacing them at suitable distances and interconnecting them in such a manner that the currents in all the radiating members are in phase. A simple way of accomplishing this result and the one which is now being employed at Lawrenceville depends upon the manner in which standing waves are formed on conductors. It is generally known that current nodes and current maxima will recur along a straight conductor whose length is an exact multiple of one half the wave-length of the exciting e.m.f. and that the phase difference between successive current maxima is 180 deg.[3] Such a conductor when folded in a vertical plane as shown in Fig. 3 and with its length adjusted slightly to compensate for the effects of folding, satisfies the aforementioned requirements for producing directional radiation. The arrows in Fig. 3 indicate the relative directions of current flow and the dotted line indicates

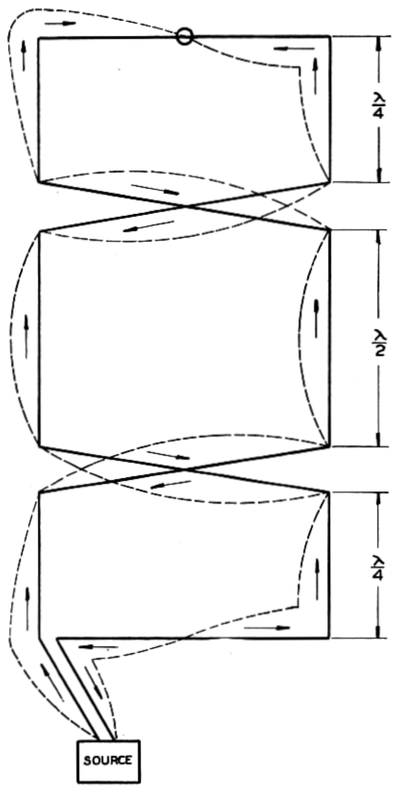


Fig. 3—Conductor bent to form one section of simple directive antenna. The type used for transmitting at Lawrenceville.

the current amplitudes along the conductor. It will be noted that the instantaneous currents in all the vertical members are in the same direction and that in the cross members their directions are opposed. Due to these current relations and the physical positions of the elements, the cross members radiate a negligible amount of energy whereas the vertical members combine their effects for the directions perpendicular

[3] This assumes of course that the conductor is in space free from objects affecting its electrical properties and that the ends are free or properly terminated to produce reflections.

to the plane of the conductor. In other directions destructive interference reduces the radiation from the vertical members. The system is equivalent to four Hertz oscillators driven in phase, and arranged in two groups one half wave-length apart, the two oscillators of each group being placed one above the other. Both computation and experiment have shown that with this system of radiation there is an improvement of approximately 6 db. In other words the same signal intensity in the chosen direction is obtained with one fourth of the power required by a one-element radiator. A second similar conductor system placed directly behind the first in a parallel plane one quarter wave-length away, will be excited parasitically from the first conductor and will act as a reflector, thereby creating a unidirectional system. It has been found that the reflector further reduces by 3 db the power required to maintain a given signal intensity in the desired direction, thus bringing the total gain for the system up to 9 db. This is also in agreement with the theoretical computations.

It is obvious that the system in Fig. 3 can be extended vertically to include more radiating elements by increasing the length of the conductor and it can be enlarged horizontally by placing several units alongside each other, care being taken to obtain the desired phase relations by transmission lines of the proper length. In this way large power savings may be effected. At Lawrenceville the maximum gain is about 17 db (a power ratio of 50) over a vertical halfwave oscillator. The enlarged system lends itself readily to mechanical support and forms so-called exciter and reflector "curtains" which are suspended between steel towers appropriately spaced. Aside from other considerations, which will be mentioned in connection with station layout, the size of the antenna is influenced by the complex and variable nature of the wave propagation through space. At present this determines the degree of directivity which is most useful for the average conditions.[4]

The closed loops of each unit corresponding to Fig. 3 greatly facilitate the removal of sleet. In addition to loading the antenna mechanically, ice, having a dielectric constant of 2.2 at these high frequencies, adversely affects the tuning. At Lawrenceville sleet is removed by heating the wires with current at 60 cycles. This is accomplished without interfering with the service by employing one of the less familiar properties of a transmission line. The same property also is used to effect impedance matches wherever the transmission lines are branched. If a line, exactly one quarter wave-length long, of surge impedance Z_0 is terminated with a load Z_R, the sending-end impedance Z_s is equal to

[4] J. C. Schelleng, "Some Problems in Short Wave Telephone Transmission." Presented to the Institute of Radio Engineers at a meeting Nov. 6, 1929.

Z_0^2/Z_R. If Z_R is a pure resistance the sending-end impedance is a pure resistance. Hence a quarter wave-length line may be used to connect two circuits of different impedances and these impedances may be matched by controlling the value of Z_0 either by varying the diameter of the conductors or their spacing. Likewise, if Z_0 is fixed and Z_R is made very small, then Z_s will be extremely large.

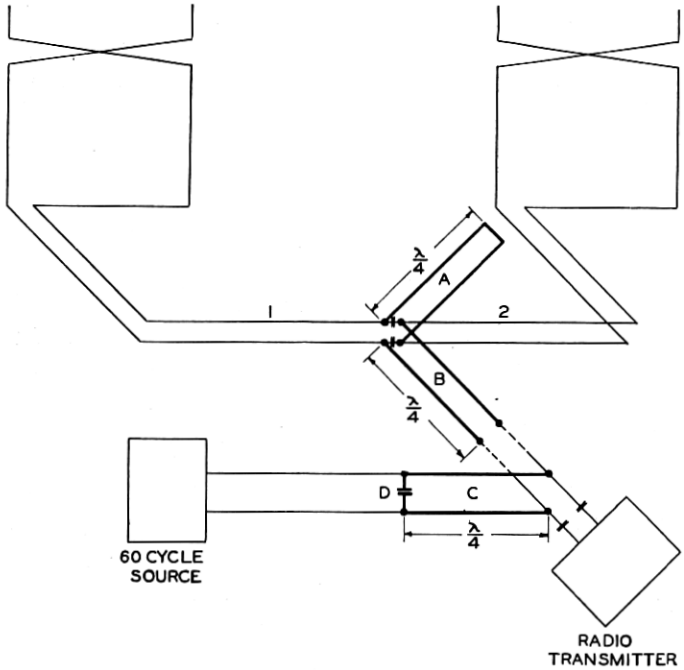


Fig. 4—Antenna sleet-melting circuit.

In Fig. 4 two units of the type shown in Fig. 3 are excited through transmission lines 1 and 2 of equal length in order to give the correct phase relations in the radiating elements. The lines are joined in parallel by condensers of low impedance at radio frequencies and they are connected in series for 60-cycle currents by the quarter wave-length line A which, being short-circuited at the one end, presents a very high impedance to radio frequency currents at the other end and therefore behaves like an anti-resonant circuit. The quarter wave-length line B serves as a transformer and is adjusted to match the impedance at the junction of lines 1 and 2 with that of the radio transmitter. The quarter wave-length line C is effectively short-circuited for radio frequencies by the condenser D and acts the same as A. These quarter wave lines consist of short lengths of pipe mounted on frames under the antenna curtains as shown in Fig. 5.

Transmitting Station

Among the first radio problems encountered in the design of a transmitting station for several channels are those concerning the size, shape, and number of antennas, their directions of transmission, their

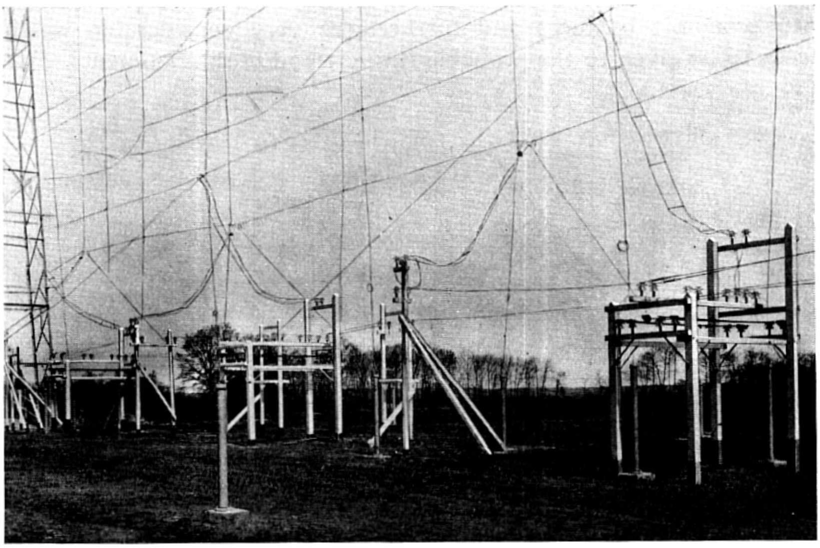


Fig. 5—Section of antenna system at Lawrenceville, showing lower portion of curtains and quarter wave transmission lines used as transformers and anti-resonant circuits.

relative positions from the point of view of mutual interference, and their grouping around the transmitters.

The number of antennas required for each channel is determined by the hours of operation and the average grade of service which the system is expected to render. For service covering a large portion of each day several wave-lengths are necessary. Transmitters Nos. 1, 3, and 4 at Lawrenceville each are assigned three frequencies. No. 2 has five assignments in order to improve the likelihood of at least one channel being available throughout the entire day at all seasons.

The size and shape of the antennas are, of course, determined by the directivity wanted, by the type employed, the frequency assignments, and by considerations of cost. They are governed also by the necessity of connecting several antennas to the same transmitting set. This involves both the spacing and arrangement of antennas to avoid adverse mutual reactions and it requires that attention be given to the losses in the connecting transmission lines, which are by no means negligible. Operating economies suggest concentrating all the transmitters at one point but the cost per kilowatt hour of modulated high-frequency power must be taken into account when considering the use of long transmission lines. It should be recognized, of course, that in the early applications of a comparatively new art, it is impossible to approach anything like accurate evaluation of all the factors entering into economic balances and furthermore very considerable weight needs to be given to the probable future trend of developments.

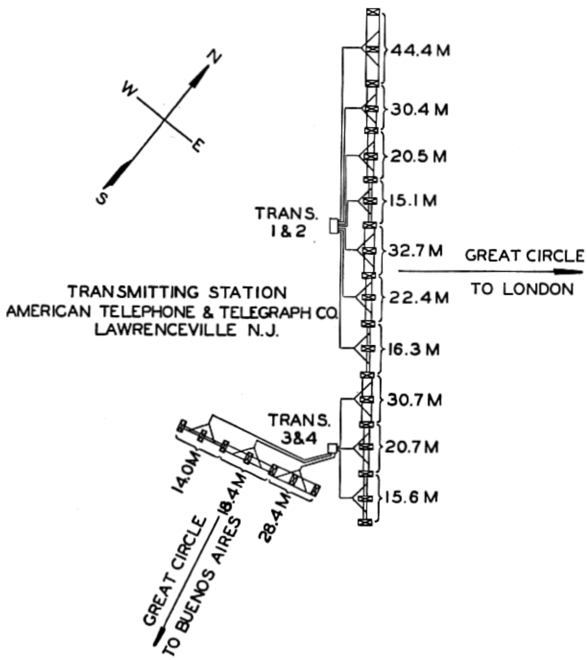


Fig. 6—Arrangement of antennas at Lawrenceville transmitting station.

At Lawrenceville all of the antennas for the three channels to England are arranged in a straight line about one mile long. The direction of this line is perpendicular to the great circle path to Baldock, England, where the signals are received, (Fig. 6). The antennas for the fourth channel are similarly arranged in a line 1500 ft. long and they are directed for transmission to Buenos Aires, Argentine.

Placing several antennas in a single line reduces the cost of the supporting structure, and all the antennas have a clear sweep in the direction of transmission. By locating them in proper sequence with respect to wave-lengths it is possible without objectionable interference, to place the antennas end-to-end and thus use supporting towers in common. Due to the wide difference in wave-length between adjacent antennas and their right-angle position with respect to the line of transmission, their proximity has no appreciable effect different from that of the towers. The proper selection of tower spacing in respect to wave-lengths makes it possible to erect a uniform supporting structure. This has the advantage of flexibility and will permit future alterations of either the location or size of a given antenna. At present, each antenna occupies the space between three towers.

In order to avoid undue loss in the transmission lines the radio transmitters are grouped in two buildings. The buildings each contain two transmitters and are identical in layout, in so far as the radio equipment is concerned. Building No. 1 has additional space for the central wire terminating and testing equipment. This apparatus is contained in an electrically screened room which effectively prevents high-frequency fields from interfering with the proper functioning of the apparatus.

Receiving System

Short-wave reception is characterized by less difficulty with static than that encountered with long waves. On the other hand it suffers interference from sources such as the ignition systems of passing airplanes and automobiles, which ordinarily do not disturb long-wave systems. Frequently the incoming radio waves suffer wide and rapid swings in intensity and there are variations in the apparent direction of arrival. On account of the extremely high frequencies the apparatus and antenna structures are very different from those for the long waves; otherwise the general schemes of reception are similar, directional effects and double detection methods being employed for both.

The radio wave is collected by means of a directional antenna array whose prime function is to improve the ratio between the desired signal and unwanted noise or other interference. This it does in two ways: *viz.*, (1) by increasing the total signal energy delivered to the receiver and (2) by discriminating against waves whose directions of arrival differ from the chosen one. Increasing the total energy collected from the incoming message wave permits the detection of correspondingly weaker signals because there is an apparently irreducible minimum of noise inherent to the input circuits of the first vacuum tube in the receiver [5] and this noise establishes a lower limit below which signals cannot be received satisfactorily. Since, under many conditions, the

[5] J. B. Johnson, *Physical Rev.*, July 1928.

directions of arrival of static and other disturbances including unwanted radio signals are random, it is obvious that sharp directive discrimination aids very materially in excluding them from the receiver. On the other hand, the antennas are not sharply resonant systems and they do not distinguish between waves from substantially the same direction and closely adjacent in frequency. This duty is left to the circuits of the radio receiver.

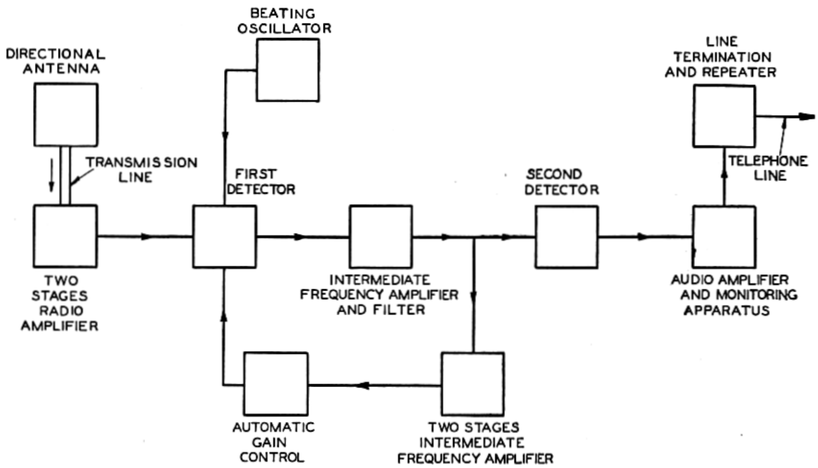


Fig. 7—Block schematic of receiving system.

Having collected the signal with a directional antenna the energy is conveyed to the receiving set by means of concentric pipe transmission lines of small diameter. The use of concentric conductors simplifies the prevention of direct signal pick-up by the lines, it reduces losses and prevents external objects from influencing the transmission properties, thus allowing the line to be buried in the ground or placed a few inches above the surface where it will have no appreciable adverse effect on the antenna performance.

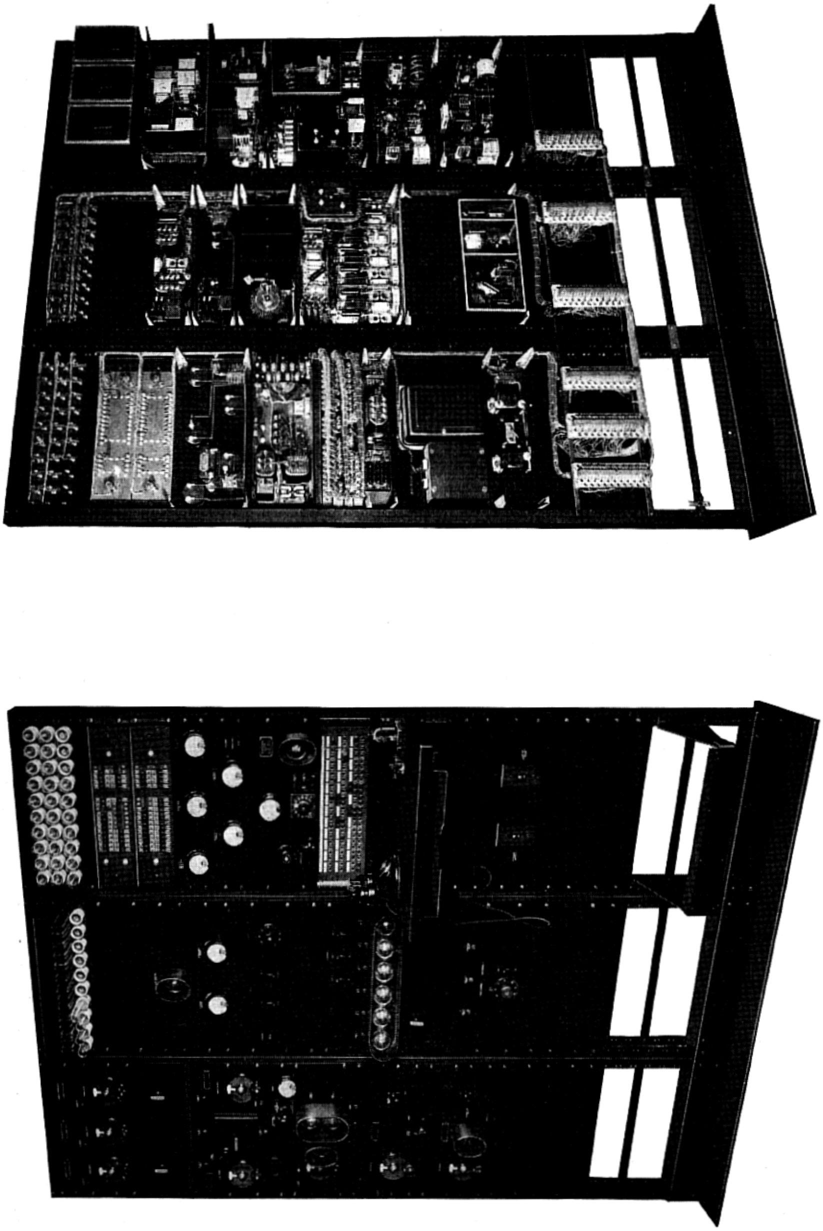
Referring now to Fig. 7, the radio currents arriving over the transmission line are first amplified by two stages of radio amplification involving tuned circuits which discriminate further in favor of the wanted signal. The signal delivered by the radio amplifier is at a suitable level for efficient demodulation and is applied to the grid of the first detector. By means of a beating oscillator whose frequency is suitably adjusted, the first detector steps the signal carrier frequency down to a fixed value of 400 kilocycles from one in the range 9000 to 21,000 kilocycles which depends, of course, on the distant transmitting station assignment. The intermediate frequency signal at 400 kilocycles then passes through a combination of amplifiers and filters which further exclude the unwanted interference. The wanted signal reaches the second detector where it is demodulated and the voice currents reproduced. The latter are then amplified and applied to the telephone lines.

A portion of the output from the intermediate amplifier which would normally go to the second detector grid, is diverted and further amplified. It is then supplied to a device which automatically tends to maintain the receiver output volume constant by controlling the bias potential of the first detector grid circuit. The time constants are adjusted so that this gain control does not respond to the normal variation in signal power corresponding to speech modulation. Otherwise of course, there would be serious distortion effects. This device partially offsets the ill effects of wide fluctuations in signal intensity but it does not overcome the deterioration in signal quality which usually accompanies the low field strengths during such fluctuations.

Receiving Equipment

At the receiving station the apparatus for each channel comprises (1) the radio receiving set, (2) a power plant for the receiver, (3) wire terminating equipment and repeaters. The latter are located at a central point in the station along with certain voice frequency testing apparatus used in common by all channels and supplied with power from a common source.

A radio receiving set which embodies the above described system and of the type installed at Netcong is shown in Fig. 8. It consists of a large number of individually shielded units mounted on panels and assembled on three self supporting racks of the type commonly employed in the telephone plant. This permits the use without modification of certain standard pieces of equipment, such as jack strips, fuse panels, meter panels, audio frequency filters, and the like. It also permits the removal and repair or substitution of units with a minimum of delay. The set is required to receive signals at three fixed frequencies in the range 9000 to 21,000 kilocycles. This involves connections with three antennas through three separate transmission lines. The tuning of the antenna and transmission line terminations are rather lengthy processes requiring precise adjustments. In order to facilitate quick changes from one operating frequency to another without intricate tuning operations, the first stage of radio amplification is provided in triplicate and the switching is done between the first and second stage. Thus the antennas are permanently connected to the set and their adjustments remain undisturbed. The circuits of the second



A B

Fig. 8—Short-wave radio receiver, (A) front view, (B) rear view.

stage require tuning when the frequency is changed. Hence to tune the receiver on any one of the assigned frequencies the attendant merely moves the dials of the second stage to predetermined settings, switches the grid circuit to a first stage which is already tuned and connected with the proper antenna and he adjusts the beating oscillator to obtain an intermediate frequency of 400 kilocycles. Screened grid tubes are used for the first two stages of amplification. A key shelf is provided with telephone and telegraph facilities. The power plant consists of standard 24-volt and 130 batteries, rectifier charging units and automatic regulators.

Receiving Antennas

In discussing antennas for directional sending it was mentioned that an identical antenna could be used for receiving purposes, but since the requirements in the two cases are not the same, quite different structures have been developed, although the methods of obtaining directivity are alike. In the sending case the reduction of random radiation ceases to be profitable when the increment thus added to the energy, which is radiated in the direction of the distant receiving station, is a relatively small part of the total. In the receiving case, although the response to the wanted signal may not be increased appreciably by further improvement in the directive pattern, the reduction in noise and interference from random directions justifies additional improvement. Expressed another way, the objective in the transmitting case is a high gain compared to a nondirectional antenna, whereas in the receiving case the objectives are, first, a high average signal-to-noise ratio and, second, a gain sufficient to override the noise inherent to the receiving set. Satisfying the first accomplishes the second.

Improvement of the average directional discrimination means a nearer approach to ideal conditions. Whereas steel towers, sectionalized cables, guys and the like, when properly located relative to the conductors of a sending antenna, do not cause any appreciable power loss, their presence near the receiving antenna may prevent the realization of the extreme directive properties which are wanted. Moreover, there is need for much greater rigidity in the positions of the conductors. For this reason the antennas at Netcong are supported on wooden frames constructed like large crates.

Due to the variable conditions surrounding the propagation of short waves in space, the vertical angle of arrival of the signal wave at the receiving station frequently changes considerably throughout a twenty-four hour period and is not always the same from day to day. In order to combat this variable condition, it appears desirable to select an antenna arrangement which does not have sharp directional properties in a vertical plane passed through the horizontal direction of arrival. The type of antenna selected for Netcong meets this requirement by having only a single horizontal row of quarter-wave vertical elements in one plane. Another solution, of course, would be to provide several antennas of different characteristics and to shift about from one antenna to another as the conditions warranted.

Fig. 9 is a general view of one of the Netcong receiving antennas. Like the transmitting antennas, the conductors are arranged in two parallel planes one quarter wave-length apart in order to obtain a unidirectional system. The conductor in each plane is bent and ter-

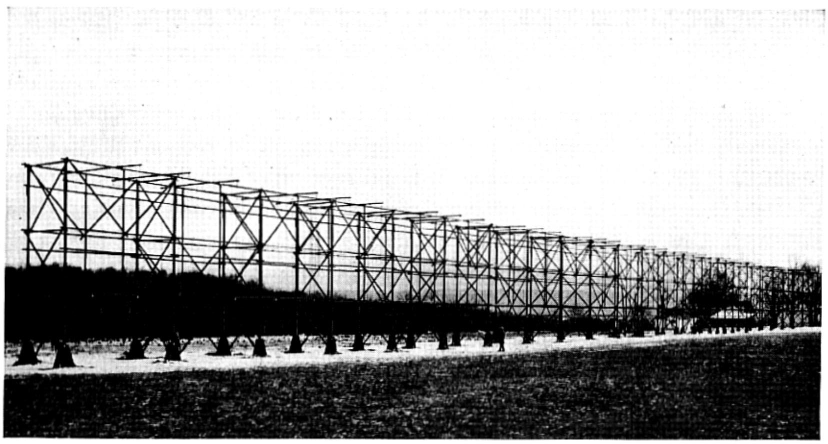


Fig. 9—One of receiving antennas at Netcong. (24.7 meter wave-length.)

minated as indicated in Fig. 10 but is much longer than that shown. The vertical members are marked A. As in the transmitting case the directional effect depends upon the manner in which standing waves occur along the conductor. A signal wave arriving broadside to the array, induces voltages in the vertical members which are identical in phase and amplitude.

Because the vertical members are interconnected alternately at the top and bottom by members of one quarter wave-length and the last horizontal members are one eighth wave-length, the net effect of the induced voltages is the establishment of standing current and voltage waves along the conductor. The receiver is connected at a voltage anti-node and the current which flows through it is proportional to the sum of the voltages induced in the vertical members. In the case of a signal wave arriving from the horizontal directions parallel to the plane of the array, the voltages in the vertical members are in successive quarter-phase relationships, no standing waves are produced, and no current flows through the receiver. Because current nodes occur at the center of each horizontal member, the loss by reradiation from these members is negligible. This is an important feature which contributed to the selection of this type of antenna for Netcong.

The size of the antenna is determined largely by the manner in which the signal waves arrive although costs cannot be wholly neglected. The useful length is limited by the fact that random fading occurs at distances as short as ten wave-lengths and it is doubtful if an antenna this long would realize the computed improvement. The cost per decibel gained is small for the initial steps, but it mounts very rapidly as the length of antenna increases. The height also is limited by cost

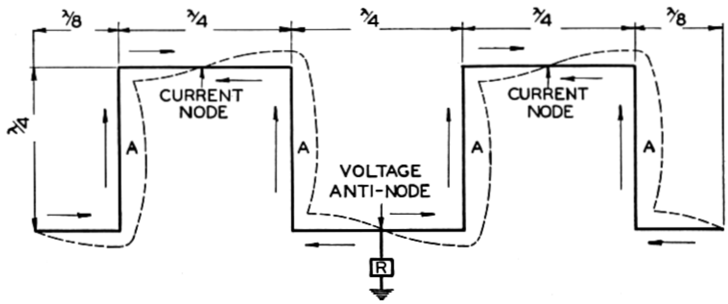


Fig. 10—Diagram of simple directive receiving antenna.

and by the necessity of allowing for considerable variation in the vertical angle of arrival as discussed in a previous paragraph.

The antennas at Netcong are six wave-lengths long and the lowest conductors are about 10 ft. off of the ground. The gains over that of a half wave vertical antenna are in the order of 16 db (power ratio of 40). The average improvement in signal-to-noise ratio is of the same order. There are certain null points toward the sides and rear for which the ratio of directional discrimination is very large.

The transmission lines are constructed of inner and outer copper tubes respectively 3/16 in. outside diameter and 5/8 in. inside diameter The tubes are held concentric by torroidal shaped insulators made of Isolantite, a ceramic product similar to porcelain and well adapted for high-frequency voltages. This same material is used for insulating purposes throughout the transmitting and receiving antennas. Transmission lines are supported a few inches above the ground and are connected to earth at short intervals. The lines vary in length from

200 to 1500 ft. One of the interesting problems in connection with their design is the provision of means for allowing variation in length with temperature. Ordinary expansion joints introduce difficulties with electrical contacts and impedance irregularities. To avoid these the lines are made 10 per cent longer than otherwise necessary and they follow a sinuous course which permits the necessary bending. Sharp turns are not permissible because experiments have shown that they cause reflection disturbances. The measured loss in 1000 ft. of line at 20,000 kilocycles is 2 db.

Receiving Station

The radio problems encountered in the layout of the receiving station, in general, include most of those already mentioned in connection with the transmitting station, but their solution in some instances is quite different. In addition there are requirements imposed by sources of radio noise both within the station itself, and in the surrounding area which is beyond the control of the station.

The number of antennas is determined, of course, by the frequency assignments of the distant transmitting station. Where two assignments are within 100 kilocycles it is possible to use the same antenna for both, but thus far, this has not been done at Netcong.

The size of the antennas is not limited appreciably by the length of transmission lines because other factors make it necessary to separate them rather widely. On this account and also because the receiving apparatus and its power plant are small, comparatively inexpensive units, it is economical to place the receivers in small buildings centrally located with respect to the group of antennas for one channel. In this case the lengths of transmission lines are not controlling factors and the dimensions of antennas are governed primarily by the considerations previously outlined when describing the individual antenna. The small height of the antenna permits them to be placed in the line of reception of other antennas spaced ten wave-lengths or more away and of widely different frequencies such as those of one channel. Antennas adjusted for the same order of frequency are separated more than this. On the other hand, to avoid adverse reactions no two are placed adjacent and end-to-end as at the transmitting station. The end-to-end separation at Netcong is in the order of four wave-lengths. The areas surrounding antennas are cleared of trees and kept free of all overhead wires or conducting structures to avoid reflection effects which disturb the directional characteristic of the antenna systems.

The locations of antennas are also influenced materially by the necessity of avoiding interference from the ignition systems of internal combustion engines. This imposes a requirement that the station site be isolated from air routes and roads carrying heavy traffic. The antennas are placed as far as possible from secondary roads which cross their line of reception.

The layout at Netcong is shown in Fig. 11. There are thirteen antennas arranged in four groups with a receiver building for each group. A headquarters building located at the road entrance contains the wire terminating equipment, line repeaters, and voice frequency

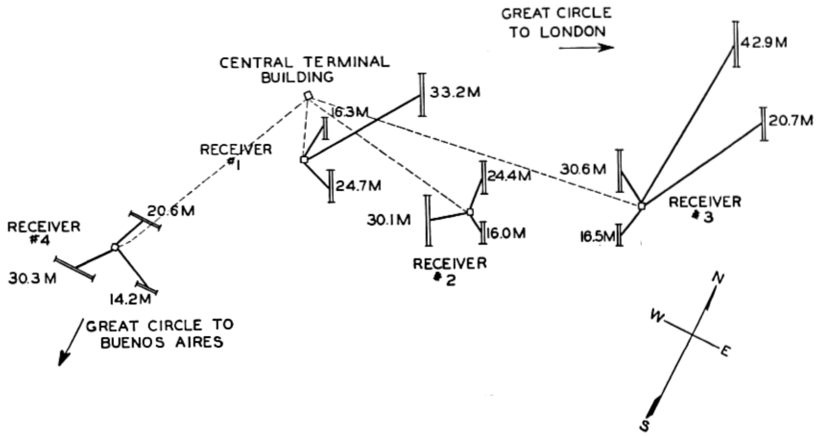


Fig. 11—Arrangement of receiving antennas at Netcong receiving station.

testing apparatus. The power plant at each receiver and the entire central terminal apparatus at the headquarters building are placed in electrically shielded rooms to prevent radio noise disturbances emanating from them and reaching the receivers directly or via the antennas.

The radio stations described herein are pioneer commercial applications in the development of short wave telephone transmission. Although progress has been rapid and far-reaching our knowledge of the behavior of short waves is by no means complete. It is reasonable, therefore, to expect that the future holds many improvements and that the information obtained by further fundamental investigations may materially alter both our views of the transmission phenomena and our ideas of what the apparatus and stations should be.