

# SIMULTANEOUS SENDING AND RECEIVING\*

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The first part of this paper dealing with duplex telephony and the "bridge receiver" was printed before America's participation in the war, but the publication of the same was withheld at the request of General Squier and Commander Hooper after a demonstration of the system to these officers in Schenectady. The author also had the opportunity to make a demonstration of the bridge receiver on the battleship "New York" in accordance with the request of Commander Hooper; and it is his understanding that further applications of the system of simultaneous sending and receiving to war ships have been made by the Navy.

The object of this development was briefly to provide means for neutralizing the overwhelming intensity of the transmitted signal so as to make the receiving set sensitive to the faint impulses of the distant signal. Popularly speaking, the corresponding equivalent in sound waves would be to have an ear which could be so adjusted that a person could stand close to a steam whistle without hearing the whistle but listen to a person speaking from a distance of a few hundred feet (about a hundred meters). A successful solution of this problem was found as described. This method of reception which is characterized by a static bridge neutralization may be properly classified as the "bridge receiver."

## THE BARRAGE RECEIVER

During the war the same problem presented itself again in a form which called for a new solution. Distances are only relative, and a steam whistle located in Germany might make

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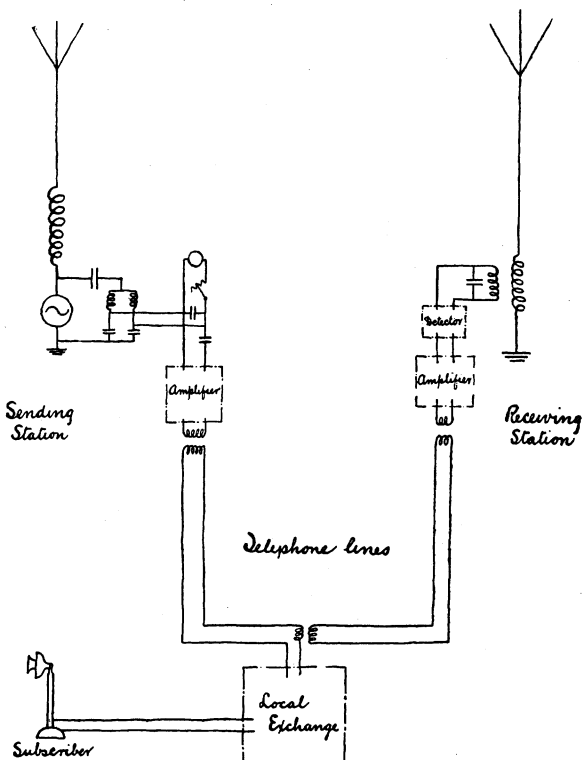
† In connection with the experimental work referred to in this paper, the author wishes to acknowledge the co-operation of Mr. H. H. Beverage and Mr. B. Bradbury.

such a noise that it would completely drown out both in England and France the sound of the voice calling from America. To find a way to counteract such a contingency was seriously considered by the Inter-Allied conference in February, 1918; and appeals for a solution were conveyed to the author by the French representative in this country, Lieutenant Patenot. The solution to this problem which was adopted by the American as well as the French Government after the first demonstration, has become known as the "barrage receiver." This name appears appropriate because the word "barrage" has not only the military meaning which has become so familiar but also the original meaning of toll or stoppage prevention. Thus the barrage receiver may be used not only in time of war to counteract the offensive barrage of an enemy radio station, but it may be used to multiply the number of peaceful communications that may be carried on simultaneously without disturbing each other.

#### DUPLEX RADIO TELEPHONY

\*Everybody who has experimented with radio telephony has undoubtedly observed that the interchange of ideas is not satisfactory if it is necessary to manipulate a switch of some kind in order to change the equipment from sending to receiving. Even if an automatic device is used for performing the change-over, the two parties are apt to say "hello" simultaneously, then wait for an answer simultaneously, then say "hello" again, and finally give it up in despair. It can, therefore, be said that one of the most important problems from the point of view of making radio telephony practical and useful for the general public is to devise a simple method of duplex operation, whereby the speaker is able to hear the voice of the other party in the same way as this is done on the wire lines. In the work that has been done to attain this end several possibilities have presented themselves and have been tried out. It should first be mentioned that Fessenden worked out a system of duplex telephony whereby the same antenna could be used for sending and receiving at the same time. As shown by the patent records, this was accomplished by a system of neutralization in the receiving circuit whereby a high degree of selectivity is attained between the sending and receiving wave lengths. In deciding upon the possible methods of attacking the problem experimentally the above method was left out of consideration on account of the practical difficulties that it appeared to present.

\*The first method that yielded practical results was the use of separate sending and receiving antennas, located sufficiently far apart, so that the selectivity of ordinary receiving instruments could be depended upon for differentiation between the wave lengths of the sending and receiving stations. Each pair of sending and receiving stations were interconnected by a wire line and furthermore connected to the exchange of the local telephone system, so that any subscriber on the telephone system could be connected to the radio system. With this arrangement the radio system has the same relation to the subscriber as a toll line. The radio operator takes the place of the toll line operator, and to the subscriber the method of communication is the same as a conversation over the toll line. The diagram of connections is shown in Figure 1. It may be noted that the lines from the sending and receiving stations are introduced in series with the subscriber's line. While a shunt connection can be made which



\*FIGURE 1—System of Duplex Radiotelephony Connected with Local Telephone Exchange

is theoretically equivalent to a series connection if resistance, inductance, and capacity are carefully equalized, it was found that the series connection could more easily be arranged so as not to interfere with the quality of articulation. The subscriber and the sending station are connected like two ordinary subscribers on a central exchange with the only difference that a transformer with its primary winding connected across the line from the receiving station is, by its secondary, permanently introduced in series with the line to the sending station. A telephone current originating in the receiving station is thus transformed into a current flowing in the closed circuit between the subscriber's instrument and the instrument in the sending station. A telephone current originating in the subscriber's instrument will follow exactly the same path. It thus follows that the current originating in the receiving station will be transmitted by the sending station in the same way as the current carrying the voice of the local subscriber. Consequently both sides of the conversation are transmitted by each sending station and a third party might hear both speakers by tuning in on either of the two wave lengths; this conclusion was confirmed by the tests. Another conclusion can also be drawn from the above reasoning. If the amplification in the receiving station should be made great enough to produce a telephone current in the subscriber's line of greater intensity than the current originally produced by the speaker, this same current will be relayed again thru the sending station and come back to the speaker in intensified form and would again be transmitted from the first sending station. A cumulative effect would thus be created which would result in self-exciting inarticulate oscillations such as may be obtained by holding a receiver in front of a microphone. Any trouble from this source is entirely avoided by keeping the amplification within a certain critical value, whereby the retransmission becomes so rapidly converging as to cause no noticeable interference.

\*While the system of duplex radio telephony described will probably prove the most practical for communication over long distances between subscribers of the local telephone exchanges, there are other promising fields for radio telephony for which interconnection with wire telephone exchanges is neither desirable nor practical. Such applications are communication between ships, emergency communication between sub-stations of electric power systems, radiotelephonic train dispatching, supervising stations for forests, and, in general, communication between

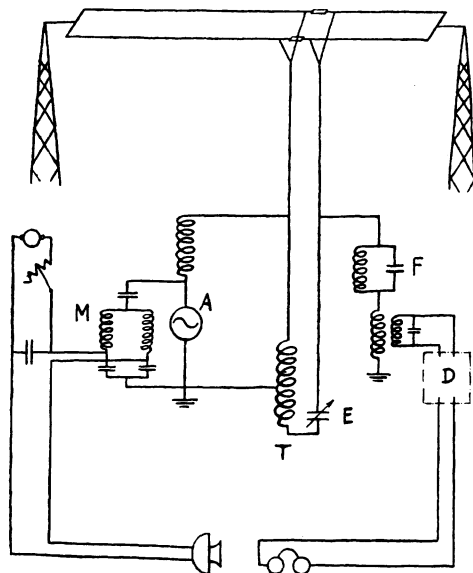
isolated settlements in unbroken countries. In all these cases, it is essential that the sending and receiving equipment should be a unit controlled by the same operator. There is, on the other hand, no object in combining the transmitted and received telephone current in the same circuit because the operator may speak into a microphone and receive thru a headphone which two instruments have no electrical connection with each other. The most desirable arrangement under these conditions would, no doubt, be to have a duplex system as indicated by Fessenden, whereby the same antenna could be used simultaneously for sending and receiving. Another possibility of using the same antenna was considered: to use the same set of wires as a loop antenna for the one function and as an open antenna for the other function. For various reasons, however, the following solution, which will be described in greater detail, was found the most practical.

#### NEUTRALIZED RECEIVING ANTENNA MOUNTED ON THE SAME MAST AS THE SENDING ANTENNA

\*If two sets of wires are mounted on the same masts, the radiation from one set to the other is obviously so strong that the overpowering of an ordinary receiving set by the transmitted energy would be almost of the same order of magnitude as if the identical wires were used. The quantitative relations may be better appreciated by mentioning specific figures. In the tests made in Schenectady, the receiving antenna consists of five wires mounted as an umbrella around the main mast, while the sending antenna consists of two wires extending from this mast to another building. The capacity to ground of the sending antenna is 0.003 microfarad, the receiving antenna 0.0011 microfarad, and the mutual capacity such that 10,000 volts on the sending antenna produces 500 volts on the receiving antenna when it is disconnected. While it is obvious that an antenna oscillating with 500 volts continuous waves could not be used with ordinary methods of reception, the system for neutralization which will be described has proven so effective that an ordinary receiving set can be used for receiving signals from such distances as the Pacific coast (2,500 miles or 4,000 km.) without any appreciable interference from continuous wave radiation from the main antenna of 20 amperes and 10,000 volts.

\*Two methods of neutralization have been used: inductive neutralization and static (capacitive) neutralization. While both methods have been used successfully, the capacitive

neutralization is much preferable both on account of accuracy of adjustment and simplicity. A diagram of inductive neutralization is shown on Figure 2. The transformer *T* is used to create a potential of opposite phase to the potential of the sending antenna. The negative potential thus created is transferred to the receiving antenna thru the exposure condenser *E*. The



\*FIGURE 2—System of Duplex Radiotelephony with Inductive Neutralization

M—Magnetic Amplifier  
A—Alternator  
T—Neutralization Transformer

E—Exposure Condenser  
F—Frequency Trap  
D—Detector

negative potential thus impressed upon the receiving antenna thru the transformer and the exposure condenser is adjusted so as to counterbalance exactly the direct exposure from antenna to antenna, thus leaving the receiving antenna at ground potential. The phase relation of the transformer is, however, not exactly  $180^\circ$ , and a residual potential is left on the receiving antenna which is sufficient in most cases to interfere with reception unless further precautions are taken. If, however, a frequency trap *F* is introduced the neutralization becomes good enough so that an ordinary receiving set can be used.

The arrangement shown on Figure 2 was used to demonstrate duplex radio telephone conversation between Pittsfield and Schenectady (50 miles or 80 km.)

## THE BRIDGE RECEIVER

The system of capacitive neutralization is shown diagrammatically on Figure 3. The receiving antenna,  $A_2$ , is connected thru a shielded primary loading coil,  $T_2$ , to a counterpoise condenser,  $C_3$ . This loading coil is coupled aperiodically to the secondary of a receiving set of any ordinary type. The counterpoise condenser is connected thru the exposure condensers  $C_1$  and  $C_2$  to the sending antenna.

The function of the capacitive neutralization can be best explained by showing the diagram as a Wheatstone bridge as in Figure 4. The exposure condensers and the counterpoise condensers form an artificial circuit duplicating the potential drops between the sending antenna, the receiving antenna, and ground. By adjusting the exposure condenser two equipotential points are found between which the receiving set is connected in a manner analogous to the Wheatstone bridge, hence the name "Bridge Receiver."

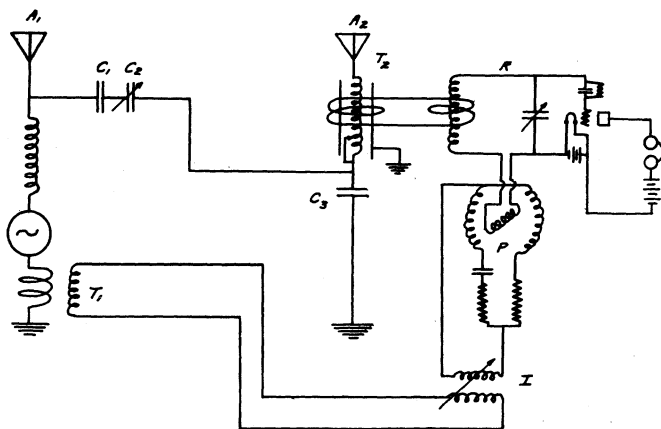
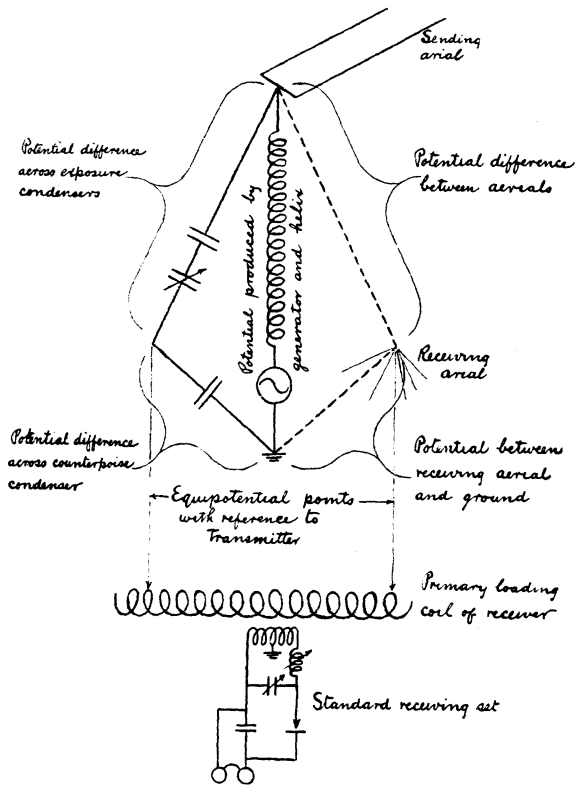


FIGURE 3—System of Duplex Radiotelephony with Bridge Receiver (Capacitive Neutralization)

\*The neutralization by this method is so sharp that the influence of the two antennas on each other is reduced much below other sources of disturbance. The principal remaining disturbances caused by the transmitting system are the magnetic strays within the building. In so far as these strays are in phase with the antenna radiation, they are automatically taken care of in neutralizing the antennas. When neutralization is made for minimum disturbance, the neutrali-

zation effect is adjusted so as to compensate the sum of the outdoor and indoor radiation. However, in so far as the indoor strays are out of phase with the capacitive neutralization, a residual effect remains that must be taken care of by other means if it is objectionable. The local magnetic strays cause disturbance principally by interlinking with the secondary loading coil of the receiving set. Evidence of this was found in the fact that the primary neutralization cannot be appreciably

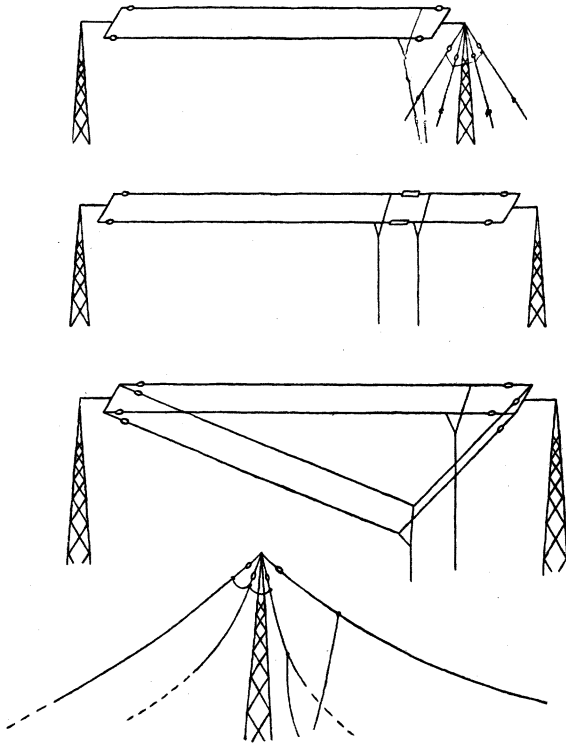


\*FIGURE 4—System of Duplex Radiotelephony with Capacitive Neutralization

improved upon by the use of a frequency trap. It has furthermore been shown that the local strays can be effectively neutralized by intercepting the strays on a moderate sized wire loop in the neighborhood of the receiving set and impressing the potential so generated on a little coil mounted with an adjustable coupling close to the secondary loading coil of the receiving set.

Figure 3 shows how the final neutralization is accomplished in a more exact way by a phase rotator,  $P$ , coupled to the transmitting set.

Figure 5 shows some simple types of antennas that may be proposed for duplex work. The combination of horizontal and umbrella is the arrangement used for the tests described.



\*FIGURE 5—Antenna Systems for Duplex Radiotelephony

Figure 6 is a photograph of a bridge receiving set, consisting of three units. The bridge coupler shown on the left is the shielded primary tuner shown as  $T_2$  in Figure 3. The receiving set shown at the right of the bridge coupler in Figure 6 is an ordinary type of regenerative receiver. The primary of the receiving set is not tuned, but is adjusted to serve as part of an aperiodic coupling between the tuned primary of the bridge coupler and the tuned secondary of the receiving set. On the

right of the receiving set is the plotron detector unit. The three units shown in the photograph are separate and may be used in different combinations if desired.

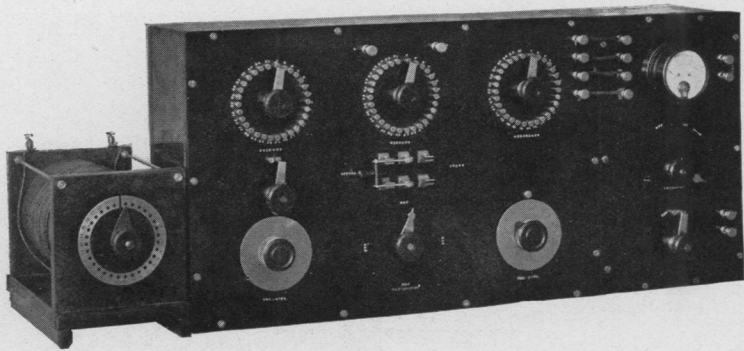


FIGURE 6—Bridge Receiving Set for Duplex Radio Telegraphy

#### THE BARRAGE RECEIVER

The barrage receiver is fundamentally a uni-directional receiver. The principle of uni-directional reception was first developed by Bellini and Tosi. While the uni-directional Bellini-Tosi receiver has been used as a direction finder, it has, to the knowledge of the author, not been used to any extent for reception of long distance signals. The Bellini-Tosi receiver is based on the principle of receiving the signal thru two antennas of different characteristics and neutralizes the signals received from one direction by a system of balancing. The principle followed by the author in devising the barrage receiver was—

(1) That the antennas or energy collectors should be aperiodic, because the balance of two tuned circuits is fundamentally very delicate and difficult to adjust for a perfect balance.

(2) That the balancing should consist in neutralizing the electromotive forces in the aperiodic antennas before those electromotive forces have had a chance to create oscillating currents. The phase shifting device should therefore be aperiodic.

(3) The two or more antennas should be of the same character; in other words, it is preferable to balance a magnetic exposure against another magnetic exposure rather than against an electrostatic exposure.

The uni-directional Bellini-Tosi receiver works on the principle that the electromagnetic and electrostatic exposures are  $90^\circ$  out of phase. The barrage receiver takes advantage of

the geographic phase displacement in the wave as it travels over the surface of the earth. In the first barrage receivers which have been installed, the antennas consist of two insulated wires laid on the ground a distance of two miles (3.2 km.) in each direction from the receiving station. It was originally intended by the author to mount the wires on poles, but the easier procedure of laying the wires on the ground was adopted at the suggestion of Lieutenant-Commander A. Hoyt Taylor, and the arrangement has proven entirely satisfactory. The barrage receiving set, photographs of which are shown in Figures 7 and 8, consists of a standard receiving set, combined with a phase rotator set. Figure 8 shows the receiving set proper lifted out

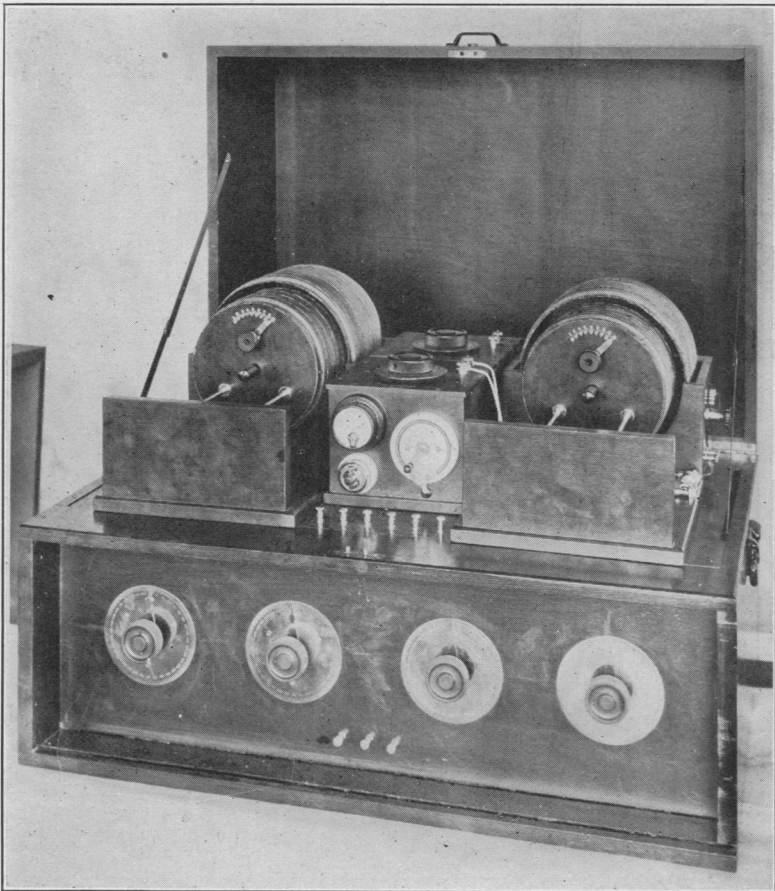


FIGURE 7—Radio Receiving Set with Barrage Section

of the box. This part of the set is arranged so that it can be used as an ordinary receiving set. When used as a barrage receiver, a condenser is used in place of the antenna and the set is coupled to the aperiodic antenna by the phase rotator set.

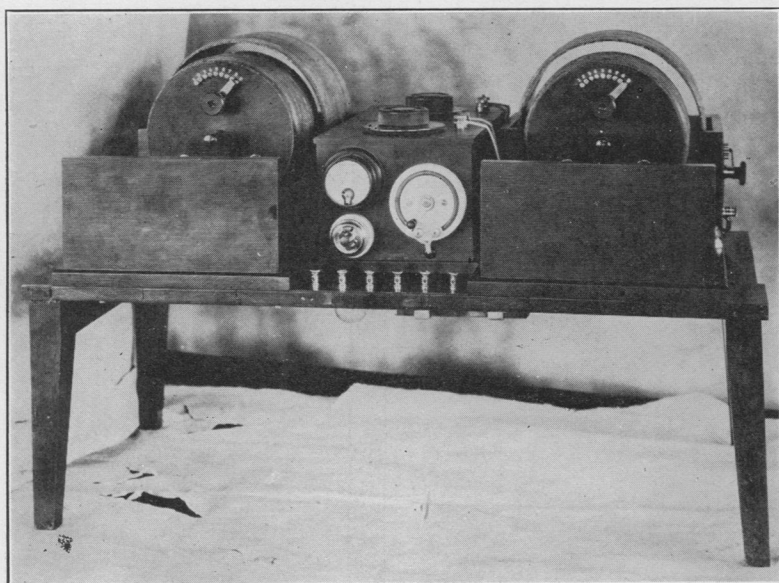


FIGURE 8—Radio Barrage Receiving Set

The diagram of the phase rotator set is shown on Figure 9. Each antenna is connected to ground thru an intensity coupler, the secondaries of the intensity couplers are connected to the primary of the phase rotators. Each phase rotator is built on the principle of a split phase induction motor or induction regulator. A single phase current introduced in the primary is split into a quarter-phase current which produces the equivalent of a rotating magnetic field inductively related to the secondary. By adjusting the position of the secondary coil, the electromotive force induced in it may be made to assume any desired phase relation to the primary voltage. The receiving set proper when used with the barrage receiver has all the normal characteristics of a standard receiving set. A signal originating in any direction whatever may be neutralized by adjustment of the intensity couplers and phase rotators. This adjustment is very easy to

perform, even by an inexperienced operator, and is perfectly stable after it has been made.

An experimental barrage receiving set was operated for several months of the summer and fall of 1918, about three miles from the New Brunswick, New Jersey, radio station. Records were kept on the reception of European stations during the operation of the New Brunswick station. As the New Bruns-

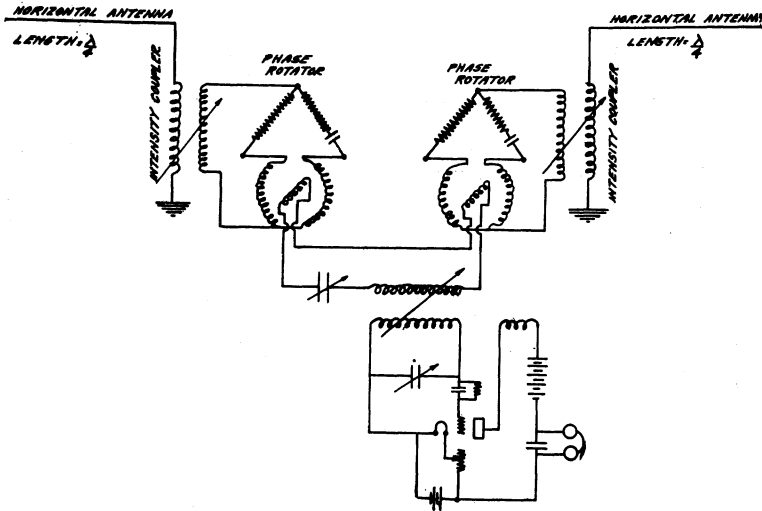


FIGURE 9—Antennas and Receiver of Radio Barrage Set

wick wave is 13,600 meters and the Carnarvon, Wales, wave is 14,200 meters, the reception of Carnarvon was the hardest test to which the set could be put. It was found that in spite of the overwhelming intensity of the New Brunswick signals on an unbalanced receiver, the barrage receiver could be adjusted so that the transmitted wave not only did not interfere with the Carnarvon signals, but the New Brunswick signals could be made entirely inaudible. During these tests it was found that the directive characteristics of the barrage receiver was a material help in reduction of interference by static and strays, as it was found very frequently that solid copy could be obtained by proper directive adjustment, while the signals were practically unreadable with ordinary methods. Statistics of this will be presented in some later paper as the barrage receiver was not originally designed for stray elimination. The improvement of reception of signals by the use of the barrage receiver depends upon the

highly directive qualities of this receiving system. For comparison with other methods of directive reception, a tabulation of directiveness is given. In this comparison the symmetrical elevated antenna which receives equally from all directions is designated at 100 per cent. The percentages of directivity are calculated from the areas of the corresponding horizontal plane intensity diagrams shown in Figure 10. If the directivity represented by the intensity diagrams can be taken as relative measure of the average stray-to-signal ratio, we find that the magnetic loop should have 50 per cent as much strays as the elevated antenna, should have 50 per cent as much strays as the elevated antenna,

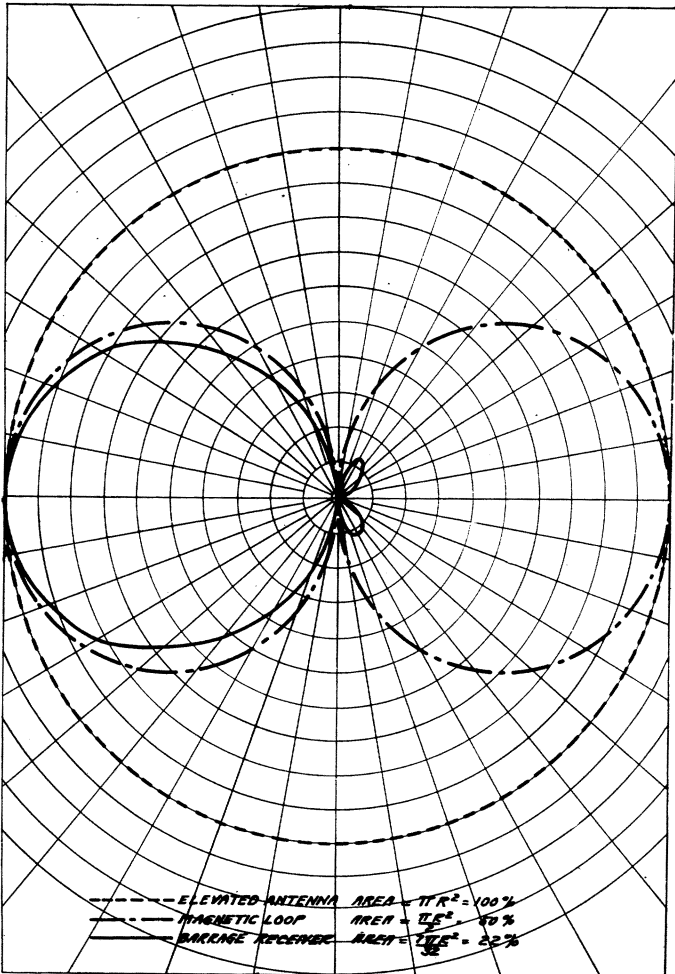


FIGURE 10—Directional Characteristics of Various Receivers

the differential horizontal antenna (Sayville, Long Island), probably about the same as the magnetic loop, and the barrage receiver 22 per cent. Statistics of reception indicate that these figures are reasonably in agreement with facts, when the strays are evenly distributed. When the strays are directive the improvement is much greater.

A rather surprising characteristic was discovered by the use of the barrage receiver. It was expected that this receiver could be used to neutralize signals from all directions except the direction close to the signal to be received. As a matter of fact it was found that interference could be neutralized, originating in the same direction as the signal. This was first discovered in the New Brunswick installation. Signals from San Diego, California, right in line with the transmitting station could be received without great reduction in intensity, while the set was adjusted so as to neutralize the transmitting station. The explanation for this is the fact that in the case of the nearby station, the wave front is curved and the radiation diverging, whereas in the case of the far-away station the radiation is parallel. The receiving antenna covers a space of four miles (6.4 km.), and in this space there is sufficient divergence of the radiation from the nearby station so that an adjustment can be made whereby the diverging and parallel radiation have different effect upon the receiving set. The phenomenon is comparable to the focussing of a field glass on nearby and distant objects. In this case we have a radio field glass of four miles (6.4 km.) in diameter; and, for such dimensions, the focussing effect is sufficient, even at considerable distances, to produce an effective discrimination.

While the barrage receiver was worked out primarily to avoid interference in transoceanic communication, it may be found useful also for the purposes for which the bridge receiver was developed, that is, simultaneous sending and receiving from small shore stations or ship stations. In such cases, it has the advantage over the bridge receiver that it can be used not only to neutralize the transmitting station to which it belongs, but can neutralize interference from any other ship or shore station. By the use of a double set of phase rotators, the barrage receiver may be used to neutralize two stations in different directions simultaneously, and this principle may be carried still further if desired. It is thus hoped that this development will open up new possibilities in dealing with a problem which is perhaps the most important in the immediate future, that is, to meet the

demands on the radio technique for a rapidly increasing number of systems of communication.

January 25, 1919.

**SUMMARY:** A system of simultaneous reception and transmission for radio telephony is described, together with the reasons for its use. It involves transferring the received speech (from a separate receiving antenna at some distance from the transmitting antenna) to the subscriber's line, and transferring speech originating at the subscriber's station to the radiophone transmitter.

Another type of duplex radio communication is considered, this being based on nearby receiving and transmitting antennas so arranged with their associated apparatus that the receiver and transmitter are in conjugate branches of a Wheatstone bridge. The wiring of the bridge receiver is given and the apparatus shown.

A so-called "barrage receiver" is then described. This is a highly directional combination of aperiodic antennas, with unilateral directional characteristic. When two aperiodic antennas are used, the phase difference of the received currents produced in them depends on the direction of the incoming signals. By phase shifting devices and differential coupling to a common receiver, the signals from any given direction can be balanced out. The wiring and apparatus and its functioning are described.