Radio Extension Links to the Telephone System

By R. A. HEISING

TO the general public, the word *radio* means broadcasting, and a *radio set* means a radio receiver for listening thereto. The average man never has any direct contact with a radio transmitter, nor with the radio telegraph which preceded the radio telephone and so utilizes the all inclusive word "radio" for that one part of it which he sees, buys, and uses.

The radio engineer is not quite in that class. There is, however, much in radio with which he is unacquainted. The radio field has become so broad and extensive that it is physically impossble for anyone to keep abreast of the whole art. Since the application of radio to telephone links is a specialized field, undoubtedly much of its history and technical developments is known only sketchily or not at all to many engineers. This paper, therefore, is planned to cover this field briefly, show its general development, and describe in principle a number of devices developed for use therein, most of which are seldom if ever used in the field of broadcasting.

The radio telephone was not one of those devices that an inventor springs upon an unexpecting world. On the contrary it was expected, and was the object of search and investigation for years before a practical form appeared. Because the wire telephone followed the wire telegraph, technical men expected the radio telephone to follow the radio telegraph as soon as the latter had been practically demonstrated. Telephone men developed an interest in it as soon as it was suggested. Telephony over large bodies of water, over difficult terrain, and to moving conveyances was difficult or impossible for wire telephony, and the telephone man was intrigued by the possibility of providing his circuits without the use of conducting wires.

During the first few years of this century, several radio telephone systems were technically demonstrated but were found impractical. In 1912 an important step occurred. The audion, invented by DeForest, was brought to the attention of the American Telephone and Telegraph Company. It appeared to have possibilities making it superior to the mechanical and the arc repeaters for wire telephone lines. A telephone repeater, or amplifier, was a main object of search at that time by telephone men. The audion became the subject of study in the Research Department of the American Telephone and

Telegraph Company and Western Electric Company immediately, and within a year and a half went through some rapid transformations. A high vacuum and increased electron emission were provided by H. D. Arnold and A. M. Nicolson, while a practical circuital theory was provided by H. J. Van der Bijl. The internal arrangement was engineered and a socket and base developed. This improved vacuum tube was put into use on the commercial telephone lines in the latter half of 1913 as a telephone amplifier and was the first commercial use of the high vacuum tube. This vacuum tube amplifier contributed to the establishment of the original transcontinental wire telephone line which carried its first messages in July 1914.

The improved vacuum tube, during its period of development, appeared to have possibilities as a generator of sustained oscillations and suggested to telephone engineers that it might be much more useful in radio than it had been up to that time. With this in mind the A. T. & T. Company decided to start work in that direction and as one result a number of new engineers, including the writer, were employed and began work in the Research Department of the Western Electric Company in the middle of 1914. Developments on the radio telephone moved rapidly. Early in 1915 plans were made and active work was started for field trials. A transmitting station was established at Montauk, L. I., and a receiver located on Hotel DuPont in Wilmington, Delaware. On April 4, 1915, speech was transmitted from Montauk to Wilmington, a distance of 220 miles. Connections were made with telephone lines at both ends to show its possibilities as a link in a telephone circuit.

There followed tests to Jekyl Island, off the coast of Georgia, about 800 miles, and then work was started for a transoceanic test. To transmit across the ocean required more power and a larger antenna. In order to avoid the antenna expense, arrangements were made with the Navy Department to use the Arlington antenna for transmitting, and to use Naval radio stations at San Francisco, San Diego, Panama and Honolulu for receiving locations. Observers with radio receivers were dispatched to these four receiving locations while a fifth expedition was sent to Paris where, in spite of the war, the French Government kindly allowed listening on the Eiffel Tower antenna. At Arlington the Western Electric Research Department (now part of Bell Telephone Laboratories, Inc.) installed a vacuum tube transmitter, and proceeded to make one-way tests. In August 1915 speech was understood at Panama, and in September a one-way demonstration was made across the continent, receiving at San Francisco. Within a few days speech was heard in Honolulu and then in Paris. The tests showed that transoceanic telephony was possible and indicated some of the difficulties that had to be overcome.

The radio transmitter in these tests deserves a few words because of its novelty and because in one respect it has never been equaled. The carrier was modulated at a relatively low level and then amplified. The final stage of amplification contained 550 tubes in parallel which in number appears to be an all time record. Each tube was capable of delivering only 15 or 20 watts peak h.f. power which would give a power rating on a telephone basis of about $2\frac{1}{2}$ kw.

With these tests completed, transoceanic telephony withdrew into the laboratory for almost eight years while further intensive work was carried out. The second step in public occurred in January 1923

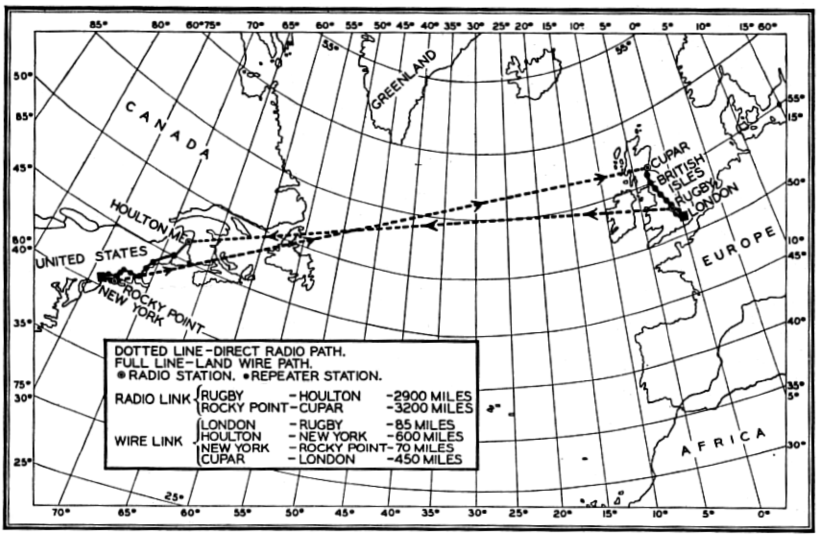


Fig. 1—The first transoceanic radio telephone circuit opened for commercial use January 7, 1927.

when a second transoceanic test was made. A 200 kw. single sideband transmitter had been constructed and installed at Rocky Point, Long Island, while engineers with receiving equipment journeyed to London. A demonstration was given to government engineers and to newspaper reporters over there to show that practical transoceanic telephony was possible and to interest them in constructing a return circuit. The British government was interested and with our assistance took up the matter of providing a transmitter and receiver for their end. Three years were required for this third step and in February 1926 the first two-way radio telephone conversations were held between the United States and England. Commercial service opened in January 1927. See Fig. 1.

With the first transoceanic circuit established, further circuits followed rapidly. For a number of years prior to 1927 investigations had shown that short waves could travel enormous distances with very much less attenuation than the long waves. Telephone engineers conducted a series of long distance tests which laid the foundation for developing circuits on these short waves with much less power. As a result a short wave transoceanic telephone circuit, the first of its kind, was opened on June 6, 1928, between the United States and England. The Germans followed by establishing a circuit to Buenos Aires in December of that year. The Dutch established one to Bandoeng in January of the following year, 1929. Then another circuit was opened up between the United States and London in June of 1929. The circuit from Madrid to Buenos Aires was established that same year, and there followed very rapidly circuits from London to various British Colonies, a circuit from New York to Bermuda, and one from San Francisco to Honolulu, so that as of Jan. 1, 1939 the world was covered by a multitude of circuits as indicated in Fig. 2.* However, the radio circuits of greatest interest to us are those circuits extending from this continent to other continents. These appear in Fig. 2. There are several channels to London, one to Paris (temporarily suspended), one to Rome, one to Australia (temporarily suspended), one to Berlin, one to Switzerland, two channels to Honolulu and a number of circuits to South and Central American countries, circuits to Manila, Bandoeng, Tokyo and Shanghai. There is a circuit from Montreal to London operated by the Canadian Marconi Company and British Post Office. The facilities are now such that from almost any telephone in the United States it is physically possible to talk to almost any telephone in the rest of the world, although due to censorship some of the circuits are not actually in use.

Another use for radio as a link in telephone service is for providing service where wire circuits would be unusually expensive and difficult to maintain. Such a circuit indicated in Fig. 2 runs from Seattle to Juneau, Alaska. It is operated by the Signal Corps and connects with the general telephone system at Seattle. Another circuit is shown in Fig. 3 which runs from Green Harbor to Provincetown, Massachusetts, a distance of 24 miles across Cape Cod Bay. This circuit supplements the wire lines which reach Provincetown by a roundabout path by land around the south side of the Bay. The radio link provides a very desirable alternate route to points on the Cape and has been useful in a number of emergencies in maintaining

* Explanation.—On account of unsettled conditions, has not been brought up-to-date.

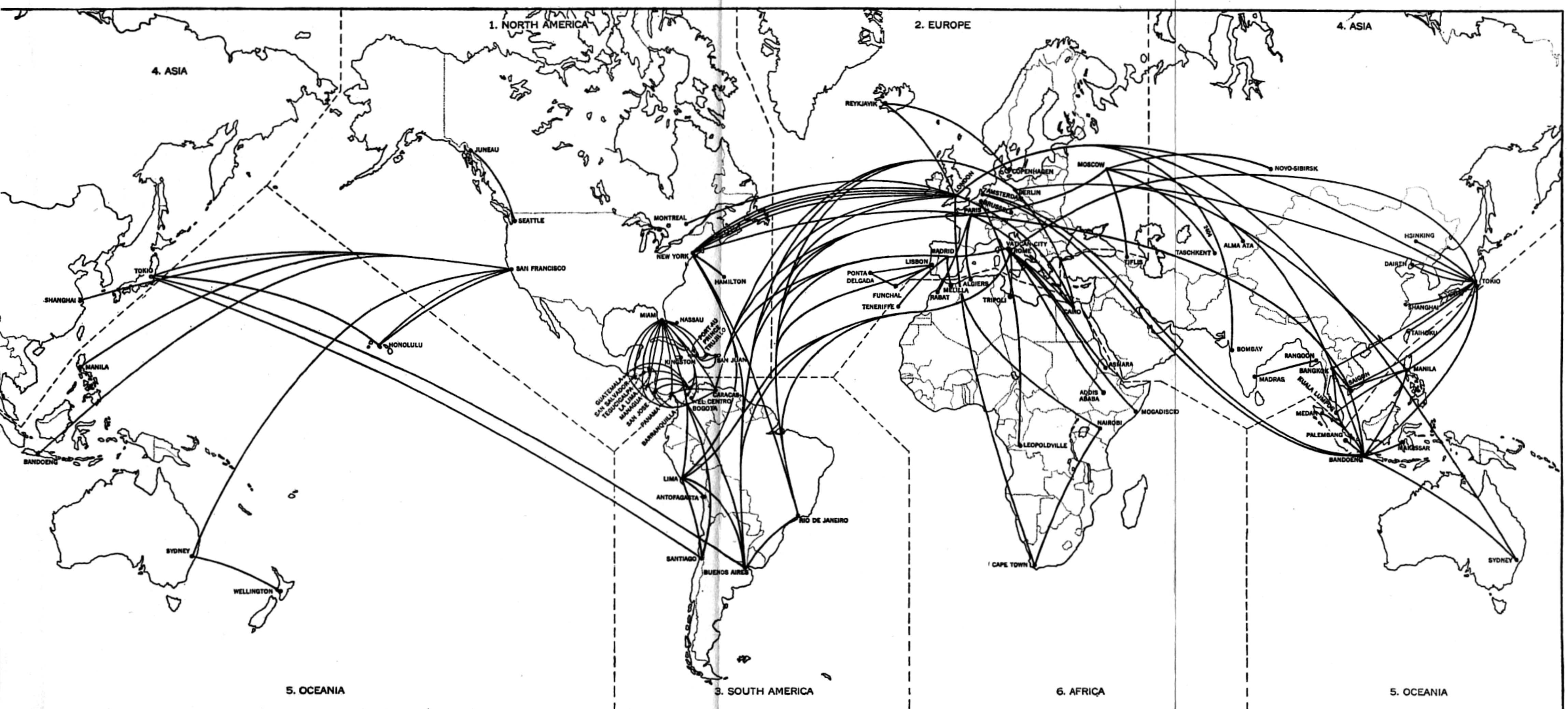


Fig. 2—Transoceanic radio telephone circuits in operation January 1, 1939.

service. During the hurricane of 1938 it provided the only route to Cape Cod for a time. The Provincetown radio link is different from any of the transoceanic links mentioned previously in that it operates in a third region of the radio spectrum known as the ultra-short-wave region while the transoceanic circuits are in the short-wave and long-wave regions. This circuit operates on 63 and 65 megacycles, 4.75 and 4.61 meters, respectively.

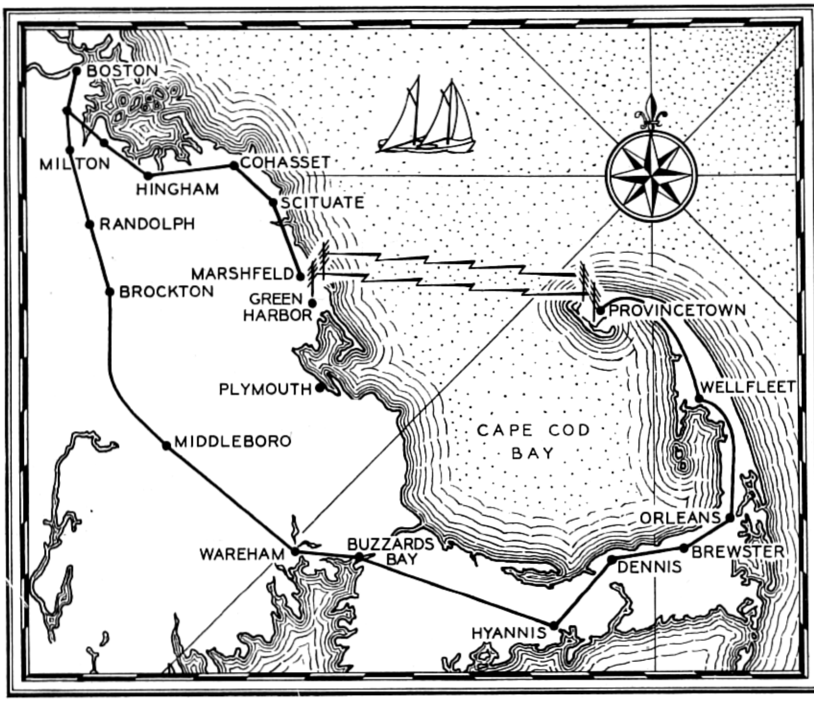


Fig. 3—Radio telephone circuit from Provincetown to Green Harbor, Massachusetts, connecting with the telephone line to Boston. Land wire route between Provincetown and Boston is also shown.

Transoceanic and other point-to-point services were not the only services envisaged by radio engineers prior to the era of broadcasting. Service to ships was considered an important use for radio. The first commercial telephone service to ships was the service established with transatlantic liners in December of 1929. Most of the larger transoceanic liners are now equipped for radio telephone communication with both shores. A few years after this service was established, a ship radio telephone service of a more local character was initiated to serve fishing fleets off the New England coast. The radio station for this service was established near Boston. The necessary equipment for boats was also developed. The fishing boats by means of this service can keep in touch with the fish markets and can take advantage of rises in prices. They also find it convenient for communicating with each other when schools of fish are found and that has also been a help in their operations. There have been a number of occasions also in which it has resulted in the saving of lives at sea, as the radio was used to notify the shore station in case of accident and the shore station called other vessels and sent them to the rescue. This service to fishing vessels was then extended to other coastwise vessels, yachts, tugs, etc., so that there has gradually developed an extensive radio service of this type on both of our coasts. Radio stations are located not only in Boston now but as indicated in Fig. 4 there are stations at New York, Ocean Gate, N. J., Wilmington, Del., Norfolk, Charleston, S. C., Miami, New Orleans, Galveston, Los Angeles (San Pedro), San Francisco and Seattle. Stations are under construction at Tampa, Fla., Astoria and Portland, Oregon. Service is now given to more than 2,000 vessels, there being 200 tugs, 1,100 yachts, 100 steamships, 400 fishing vessels and numerous others, police boats, pilot boats, barges, launches, etc. The largest number of vessels so equipped for communication with shore are grouped around New York and San Pedro, there being about 600 in each of these areas.

In this type of service each shore transmitter and each shore receiver is assigned a frequency. Any ship may provide itself with frequency control crystal elements for communicating with as many of the shore stations as it desires. Coastwise vessels in traveling along the coast may thus keep in touch with their nearest shore station. In New York there are two such circuits provided with transmitters located on Staten Island, and there are receivers located at four places around the harbor for each of the circuits so that the low-powered ship transmitters may reach the nearest receiver while the higher-powered shore transmitters reach the ship receivers directly.

On the United States side of the Great Lakes, connecting telephone companies operate coastal harbor radio telephone stations at Lorain, Ohio, Duluth, Port Washington, Wis., Lake Bluff, Ill. and Mackinac Island.

The use of radio in the telephone system brings forth a number of problems. First of all, to provide a radio circuit for a telephone conversation there are required two radio transmitters and two radio receivers. The transmitters and receivers must be so located and so designed and operated that one person at one end of the circuit may speak to a second person at the other end and the second one to the

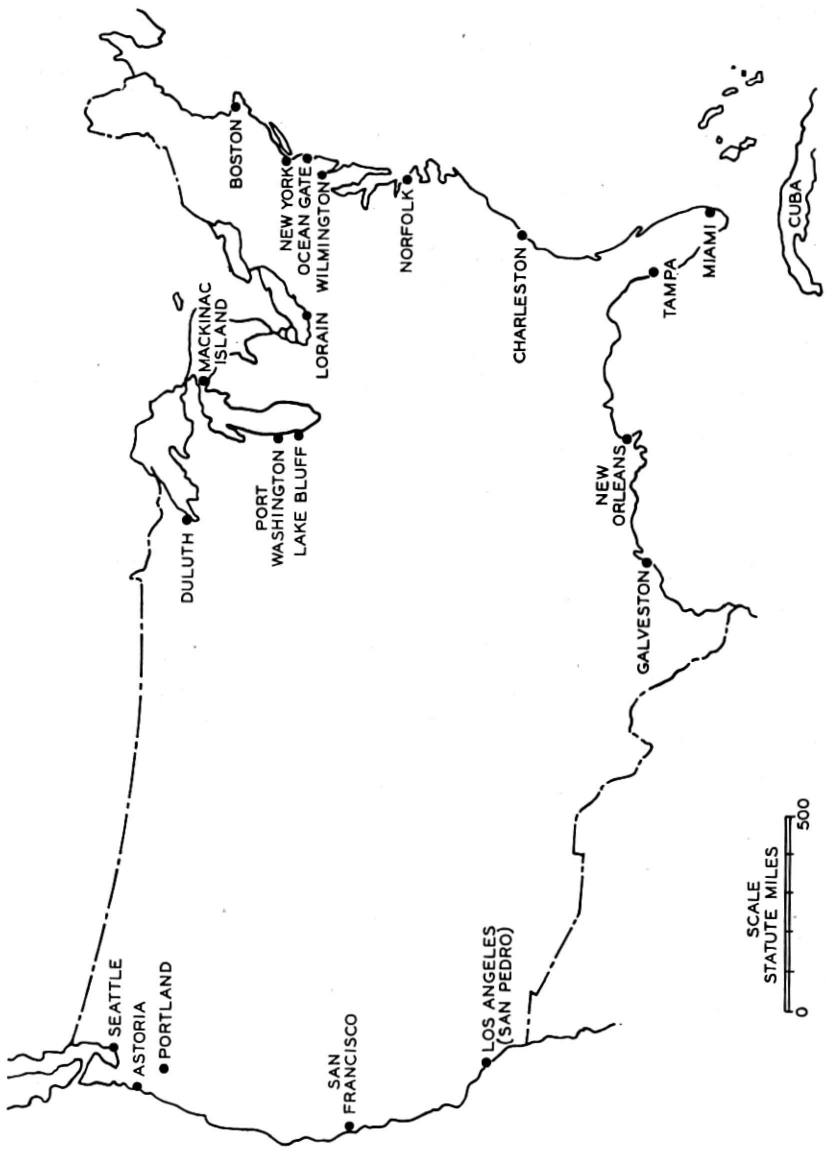


Fig. 4—Coastwise boat radio service, and other radio links.

first even though either or both of the radio equipments be entirely outside of the manual control of the speakers and be many miles away. The problems involved have given rise to the development of many pieces of apparatus which are seldom used in the broadcasting field. It is the intention, therefore, in this paper to review some of these devices and tell briefly why they are used and what they do.

To begin with, attention is called to three diagrams in Fig. 5. These three diagrams indicate three of the many ways in which a transmitter

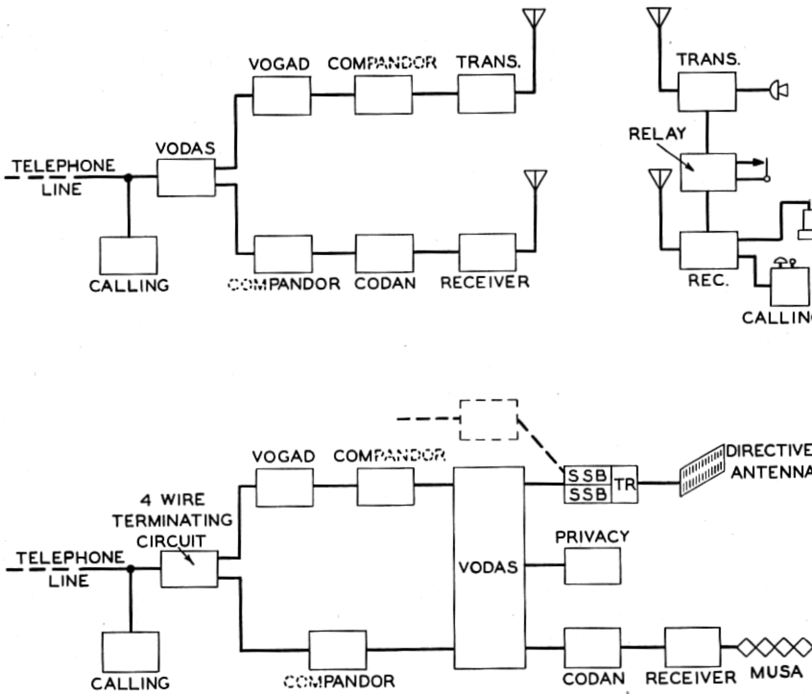


Fig. 5—Three arrangements of radio terminal apparatus are shown herein.

and a receiver might be connected with associated apparatus for one end of a radio link. Two of the diagrams indicate connection to a telephone line which may extend more than 3,000 miles to a subscriber. The third circuit indicates an arrangement which is customary on small boats, sometimes in aircraft, and other places where a partially trained operator is available and is the one using the device.

It is to be observed first of all that in two of these diagrams the input to the transmitter and the output of the receiver are connected to the same telephone line. This necessary connection leads to difficulties. Signals from a subscriber on the telephone line operate the radio transmitter. Some of the radiated energy from the transmitter impinges on the receiver. If the receiver should be tuned to the same wave-length the signals will then get back onto the telephone line and some will again go to the transmitter, producing by this circular path a singing circuit. A circuit so constructed will be entirely useless due to the singing produced. Now it appears possible to use a hybrid coil to connect a balancing circuit to the telephone line, with conjugate connections to the transmitter and to the receiver so that the incoming signals from the receiver will not go to the transmitter. Such a hybrid circuit will work provided it can be balanced and maintained in balance. However, anyone who has tried balancing such circuits knows that it is generally not practicable to provide a balanced circuit suitable for all wire line connections and for the variable gains in the radio link. Additional means must therefore be used. Now, of course, it is possible to operate the incoming radio circuit and, therefore, the receiver on a different frequency as is usually done, in which case the signals from the local transmitter will be tuned out. However, if a similar system is used at the other end of the radio link the signals from the near end transmitter will come in on the far end receiver, will again go out on the far end transmitter, will come back into the near end receiver whence they get back into the near end transmitter, thereby making a loop circuit again which will produce singing even though the round trip path of such a circuit may be 6,000 miles. It is therefore found necessary, when connecting with telephone lines, to provide a system which will at all times keep the incoming energy of the receiver from going out on one's own transmitter.

To accomplish the foregoing is the function of the "Vodas" [1] as indicated on the diagram, a device which connects the telephone line to either the transmitter or the receiver but not to both simultaneously. It must, however, connect them at proper and suitable times so that a two-way conversation can take place. A simple system comes immediately to mind to accomplish this purpose. It is that of a voice-operated relay which throws the telephone line from the receiver to the transmitter whenever the speaker on that end speaks, with the relay making the reverse connection when he stops speaking. Such a simple circuit has been used in some cases but has been found not to be adequate for general use. To begin with, the line is not switched until part of what the speaker has said has arrived to actuate the relay. Some clipping, therefore, occurs. To make things worse many words begin with sounds of small energy like f's and s's, which may not be sufficient to actuate the relay. The relay will then not operate until the vowel sound following arrives and when the relay does operate the entire preceding consonant is clipped off. The clipping is sometimes disconcerting and may impair the intelligibility of the transmitted speech. If the relay is made sensitive enough to operate on the f's and s's another difficulty arises. Relatively low values of room noise, noise induced on wire lines, or the speaker breathing into the microphone may produce enough energy to actuate the relay during listening periods, thus interrupting the conversation. In other words, if the relay is sensitive only to the loud sounds clipping will occur, while if sensitive to the weaker sounds it may be actuated by noise. These difficulties are surmounted by using the more complex circuit termed the "Vodas" as indicated in Fig. 6.

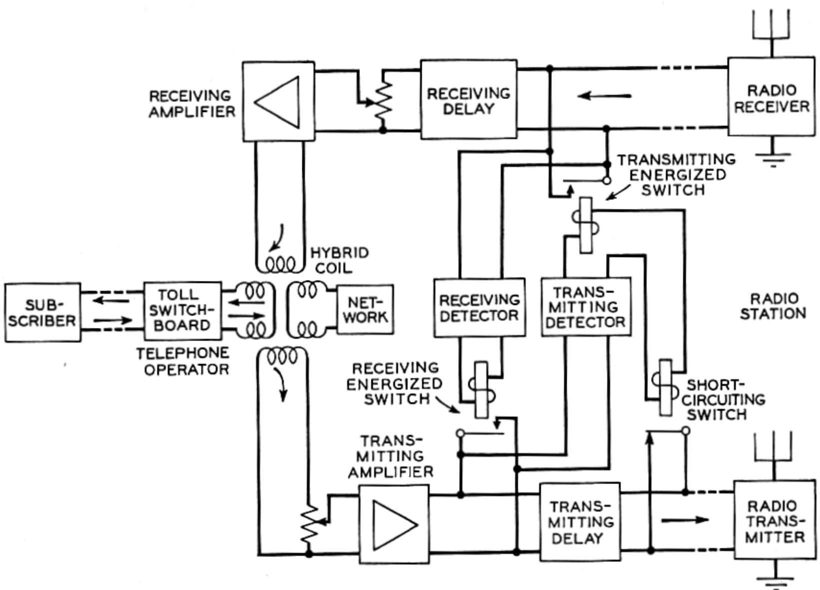


Fig. 6—Vodas (voice operated device anti-singing).

In this diagram the transmitter is located on the bottom branch in which there is interposed a transmitting delay circuit. The incoming speech after passing through the transmitting amplifier operates relays by means of the transmitting detector. The relay is so adjusted as to be operated by the louder sounds in the voice but not by noise. While it is operating upon the vowel sound following a consonant, the consonant may be on its way through the delay circuit so that the relay which normally shuts off signals to the transmitter will actually clear the path to the transmitter in time for the first sounds of a word in most cases. The utilization of the delay circuit can therefore practically eliminate the clipping and allow of relays being adjusted so as not to be operated by small noises from the telephone line.

This circuit also includes arrangements to prevent other difficulties. It will be observed there are two sets of relays, one operated by the transmitting branch rectifier and one by a receiving branch rectifier. These are so arranged that when speech signals operate the transmitting branch rectifier, the receiving line is short-circuited to prevent any signals, such as noise, from the radio receiver reaching the talker or from going out on the transmitting branch to interfere with the transmitted speech. When no talking is occurring at this end of the circuit signals coming in on the radio receiver operate a receiving relay which short-circuits the transmitter circuit so that the received speech will not be retransmitted by the transmitter and so set up a singing condition. This particular diagram indicates the hybrid coil and balancing network which are used to assist in operation but not to provide the main means for preventing the received speech from reaching the transmitter.

This circuit as indicated is about as simple as a satisfactory circuit can be made. Figure 7 indicates a more complex circuit which has a number of advantages, among which is that of connecting in privacy equipment. This circuit allows of using one piece of privacy equipment which is used in the transmitter branch for outgoing signals and is switched to the receiver branch for incoming signals.

Returning now to Fig. 5, attention is called to another device in the first diagram labeled "Vogad."[2] This word comes from the initial letters of the words "voice operated gain adjusting device."[2] This is a type of device which is very useful in telephone practice but is seldom, if ever, used with a broadcasting transmitter. Every telephone user is cognizant of the fact that different people with whom he speaks over the telephone use different intensities of voice; also different lengths of telephone line introduce different amounts of attenuation. If the incoming telephone signals are to operate the radio transmitter to its full modulation capacity some means must be provided to equalize these signals of various levels. It is therefore desirable to have a device which will maintain the output level nearly constant regardless of the variation in the input level due to different speakers and different lengths of telephone lines. This operation is provided by the Vogad indicated in Fig. 8. The channel across the top is the direct path of the speech signals. Within the dotted lines marked "vario repeater" are some elements including the amplifier whose gain is varied to make up for variation in intensities at the input. It is not sufficient to construct an amplifier which will give a large gain

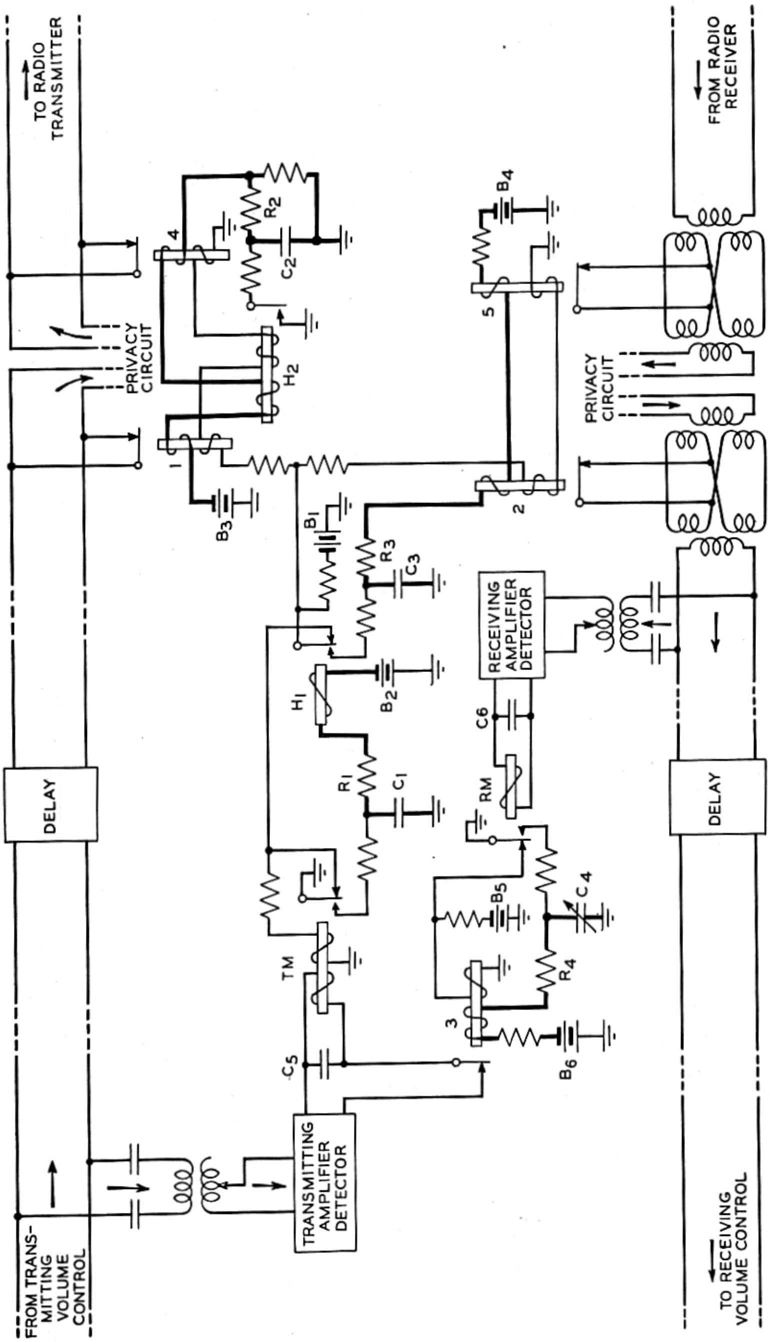


Fig. 7—Improved vodas circuit.

with a small input and small gain with a large input as the use of as simple a circuit as this will cause the amplifier to adjust itself for maximum gain when no input signal is coming in and in that case any noise on the line may be amplified sufficiently to be troublesome. Also, with such an amplifier the gain will become larger whenever the speaker stops or hesitates and will momentarily overload the transmitter with the first syllable on resumption which may result in dis-

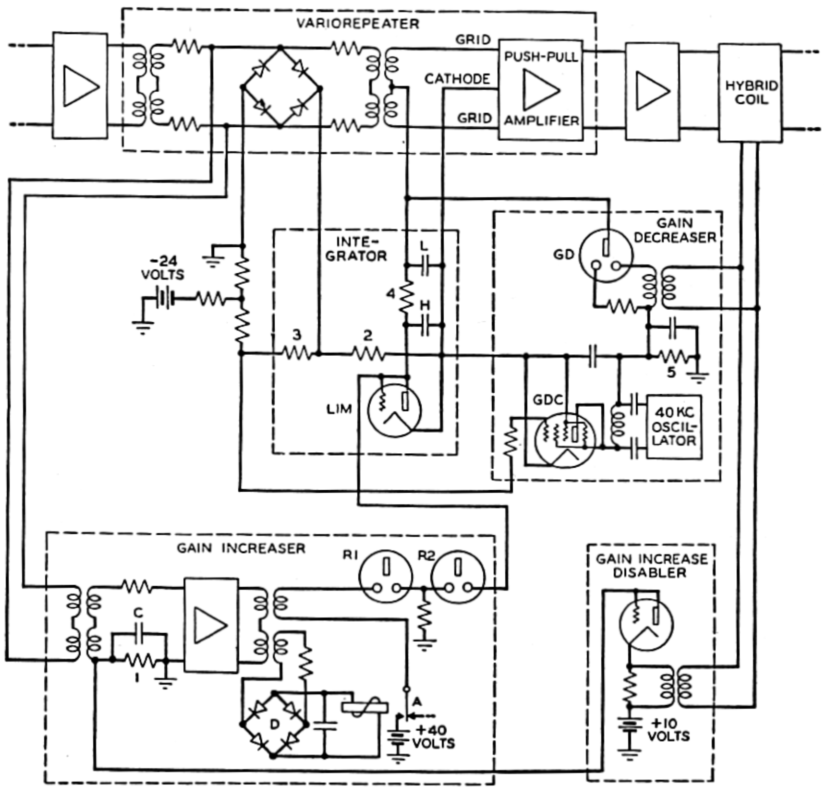


Fig. 8—Vogad (voice operated gain adjusting device).

tortion of considerable consequence. It is therefore desired that this circuit have a maximum gain which will not make noise troublesome and also be so constructed that the gain during any conversation will remain constant even during hesitation and listening periods, and in which the gain will increase only when speech signals become weaker or the gain decrease when speech signals becoming stronger. To accomplish this one element of the circuit marked "Gain Increaser" receives energy from the input and operates through the gas tubes

R1 and R2 causing the gain integrator to increase the gain of the main amplifier when the speech input levels decrease. However, this increase in gain must continue only until sufficient speech volume is going out to modulate the transmitter in an approximately satisfactory manner. At this instant another part of the circuit called the "Gain Increaser Disabler" operated by the output signal comes into play and disables the gain increaser. If the input signal and, therefore, the output signal become louder, then a fourth element, called the "Gain Decreaser," comes into play and begins to reduce the gain of the amplifier. The combination of these control circuits with the main amplifier therefore causes the volume of output signal to be reasonably constant with wide variations in the volume of the input signal and at the same time to hold the gain substantially constant as long as speech signals of the same volume are coming or while no speech signals are coming.

Returning to Fig. 5, note a situation which may be troublesome. Anyone who has operated the earliest broadcast receivers with automatic gain control will remember that when the incoming signal became weak or disappeared the gain of the receiver climbed to such a point as to produce disconcerting noise in the loud speaker. The receivers in all of the systems indicated in this figure contain automatic volume control and if the transmitter from the remote station stops momentarily or if the signals fade out this automatic volume control boosts the gain to such an extent that noise is delivered by the receiver to the telephone line. Such noise may be sufficient to operate the Vodas and in doing so will seize control of the circuit and not allow the signals from the subscriber at this end to reach the transmitter. This would lock up the circuit and put an end to the conversation.

Such a contingency is avoided by the use of the device indicated in the block marked "Codan."[3] The word Codan comes from the initials of the words "carrier operated device anti-noise." The Codan is a device which is operated by the carrier picked up by the receiver and connects the receiver to the telephone line only while a carrier is present. Under these conditions the volume control will go up and down as the carrier goes down and up but if the carrier disappears the Codan disconnects the receiver so that noise will not operate the Vodas and prevent the speech from the subscriber at the near end from being transmitted.

Specifically, circuits operating with ships at sea must have the Codan or its equivalent because the ships usually employ a system in which the carrier is cut off when the ship stops speaking so that the disappearance of the carrier at the receiving station on shore is the period during which the shore subscriber is expected to talk. The noise at this time in the receiver on shore must not actuate the Vodas or the transmitting branch will be interrupted. A suitable rectifier with a relay can, under certain conditions, be a satisfactory Codan but not in all cases. There is always a certain amount of static, strays and so forth, reaching an antenna and if the relay is adjusted to operate on a very weak carrier the strays and the static may also operate the relay. Now, of course, it is possible to adjust the relay so it will not operate on the noise occurring at a particular time but will operate on a carrier which is slightly stronger. If that adjustment is made during the day on short waves when the noise is low, when night comes the noise level rises and the noise may then be able to operate the relay. It would be necessary with a simple Codan of this type to have the operator continually adjust and readjust the Codan for different parts of the day and night.

However, it is impracticable for an operator to be continuously on watch and continuously and satisfactorily adjust the sensitivity of such a relay, with the consequence that a satisfactory Codan necessarily involves automatic adjustment as provided in the circuit of Fig. 9. In this diagram the part above the middle dividing line is the receiver while the part below is the Codan. The Codan here consists of two parts. It consists of a part which selects the carrier by a crystal filter for operating the relay, and instead of a spring to hold back the armature an electrical arrangement is provided whereby the noise coming through the second part of the circuit will produce current in the relay in the opposite direction. The noise is picked out by another crystal filter Y4 which selects all the energy in the two sideband positions minus the carrier position. This noise is amplified and rectified so that whenever the noise is high it will require a large carrier coming through filter Y3 to operate the Codan relay S2 and when the noise is low through the noise branch a smaller carrier coming through the carrier branch can operate the Codan relay. This Codan therefore automatically adjusts itself to the noise level in the ether so that the carrier can connect the receiver to the telephone line whenever the carrier appears.

Since the development of a successful Codan it has been found practical to dispense with the Vodas at terminals that connect with radio stations which radiate their carrier during transmitting periods only. This is brought about by using the Codan to operate the relay that switches from transmitting to receiving. Since the Codan is operated by the incoming carrier and not by outgoing voice signals,

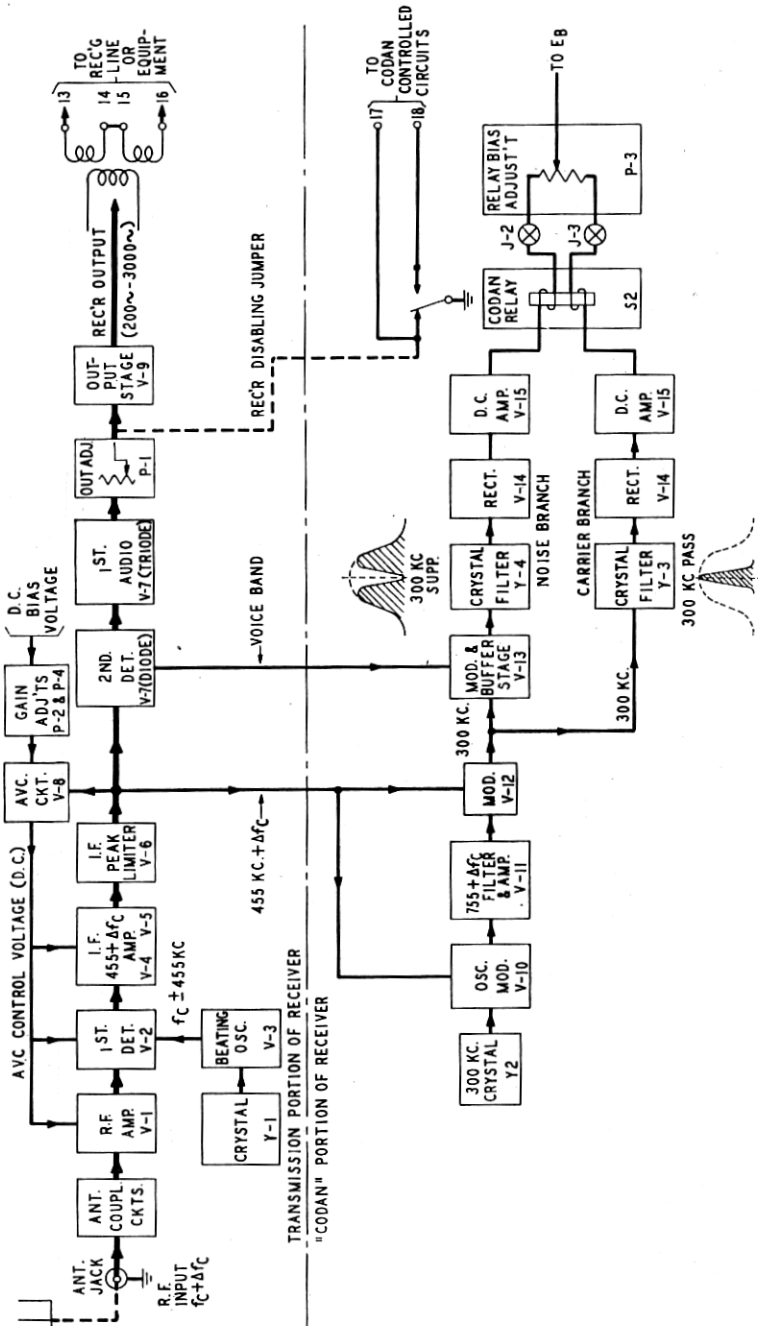


Fig. 9—Codan (carrier operated device anti-noise).

the delay circuits of the Vodas are unnecessary. This arrangement is finding increased application in ship-shore terminals.

Referring again to Fig. 5, note two squares in the first diagram labeled "Compandor." [4] Each of these squares has part of the name dotted to indicate that the two circuits are different but together form the entire Compandor. The Compandor is another device to assist in making signals more intelligible in the presence of noise at the receiver. It accomplishes this by the peculiar method of distorting the signal going out and then restoring it at the receiver. The reason for such a device and its mode of operation are as follows. Ordinary speech contains loud as well as weak signals. Most of the consonants and some of the vowels do not contain much energy. They therefore

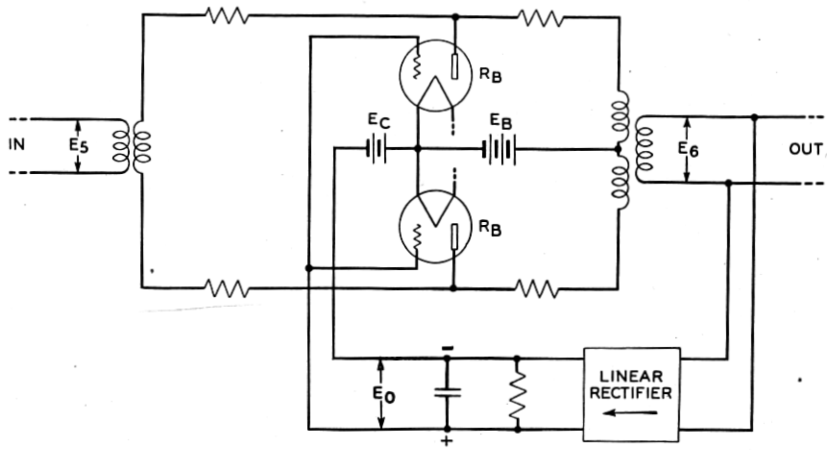


Fig. 10—Compressor part of the compandor.

will not modulate the transmitter fully and are the ones whose reception will be interfered with by noise at the receiver. The Compandor reduces this effect by making the weak parts of the transmitted signal larger than normal.

The part of the Compandor in the transmitter branch distorts the speech signal by reducing the energy variations between the loud and weak sounds a certain amount. It does not wipe out all variation as it is necessary to leave a certain variation which is made use of at the receiver to restore the original variation. The circuit used at the transmitter end is given in Fig. 10. It is called the Compressor. A speech signal comes in on the left-hand side and goes out on the right. Between the input and output circuits are connected two vacuum tubes. Although superficially this circuit looks as though these tubes are amplifiers, actually they are connected to absorb energy. The operation therefore involves absorbing part of the energy in the louder signals and a lesser amount from the weaker signals so that the output contains speech which has been distorted in such a fashion that the variations in energy may be only one-tenth as much as they originally were. These two absorbing vacuum tubes are controlled by potential built up across a circuit containing capacitance and resistance. This circuit has a potential E_0 produced on it by a linear rectifier which secures its energy from the output circuit. The strong signals appearing in the output produce a larger voltage on the resistance-condenser combination, thereby causing the grids of the two vacuum tubes to be more positive than with weak signals or no signals, and the two tubes, then acting as conductive resistances, reduce the intensity of the loud signals. The resistance-condenser combination is so proportioned that the charge on the condenser rises and falls with syllabic frequency. It must not have such a short time constant as to wipe out individual cycles. It is to operate upon groups of cycles only. With this Compressor between the telephone line and the transmitter, and the amplifiers properly adjusted, the transmitter can still be fully modulated with the louder sounds in the voice but it will be modulated very much more than it would normally be by the weaker sounds in the voice.

At the receiving end the signal delivered by the receiver and transmitted towards the telephone line will be the same distorted signal which modulated the transmitter. Such a distorted signal, although scarcely discernible from the original, is not in all situations the desirable one to put upon a telephone line, so there are reasons for restoring this distorted signal to its original form. This distorted signal contains the weaker parts of speech amplified many times with respect to what would occur without the Compandor and therefore these weaker parts of speech will be many times above the noise which would have interfered with reception under ordinary conditions. This distorted speech now goes into the part of the Compandor in the receiving branch which is called the "Expandor," as shown in Fig. 11. The Expandor contains many elements similar to those in the Compressor but they are arranged in a slightly different form. Two vacuum tubes instead of absorbing energy are now used as amplifiers. The signal comes in on the left and goes out on the right but the output is not a true amplified picture of the input because as the signal goes through the amplifier the amplification of the two tubes is varied so as to restore the original signal. To do this use is made of the remaining amplitude variations within the signal to operate a linear rectifier and put a variable voltage E_x upon similar condenser and resistance, and by virtue of connections to vary the amplification of the two amplifier tubes. The louder signals therefore put more positive bias on the grids of the amplifiers than the weaker ones and the amplifier tubes will amplify the stronger tones more than the weaker. There is thus delivered to the output the original signal but with very much improved signal-to-noise ratios.

In the use of the Compandor on circuits having noise it has been found possible to produce signal-to-noise improvements as high as 30 db. Average improvements are 15 to 20 db. The improvement depends upon the amount of noise present.

Returning again to Fig. 5, there are certain elements labeled "Calling."[3] The particular configuration indicated with calling devices attached to the telephone line in the first diagram and to a receiver

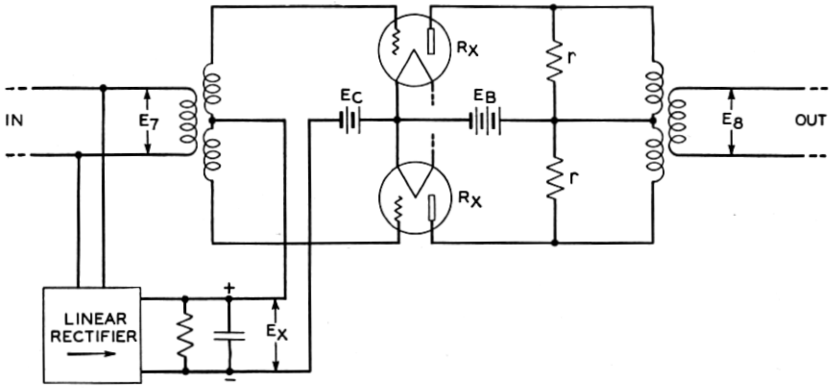


Fig. 11—Expandor part of the compandor.

in the second diagram are the particular calling arrangements used for communicating with boats at sea. The fishing boats, such as mentioned previously, and private yachts, do not find it expedient to have an operator listening at all times for calls nor do they like to have a loud speaker operating continuously delivering all and sundry communications to the people on a boat. It is desirable that means be provided so that the boat may be called by having a calling mechanism available. The system is indicated in Fig. 12. In this system the receiver on the boat must be operated continuously and must be connected to the selector and bell circuit so that whenever the correct calling signal comes in the bell will ring. At the shore station the calling is accomplished by sending out certain combinations of 600 cycles and 1500 cycles as indicated in this figure, the various combinations being chosen by the telephone dial which actuates a relay switching one or the other audio frequency onto the transmitter.

A certain combination which consists of certain sequences of the 600 and 1500-cycle tones is assigned to each boat. The 600 and 1500-cycle tones selected by band-pass filters are rectified and actuate a polar relay which then delivers to the part marked "selector" signals corresponding to those made by the telephone dial. The selector is a standard train dispatcher selector which can be set for various combinations of signals and when the correct combination arrives it will close a switch and ring the bell.

For calling the shore operator from the ship, the Codan mentioned previously connects the receiver to the line and also operates a relay to light the shore operator's switchboard light whenever a boat operator starts his transmitter and puts on his carrier.

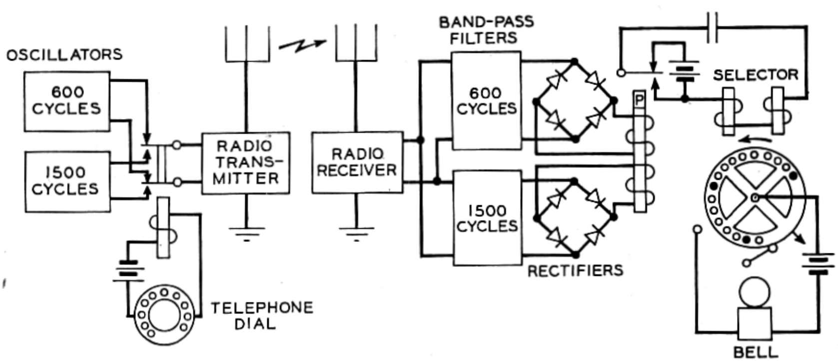


Fig. 12—Calling system for boats.

These two methods of calling in the two directions are not the only ones which are used on radio links. For most transoceanic and service to the large liners, prearranged schedules or continuous watch allow of calling by voice. In the Green Harbor-Provincetown circuit of Fig. 3 and some transoceanic circuits calling is accomplished by transmitting 1000 cycles interrupted 20 times a second which is a standard means of ringing over telephone lines.

Referring again to Fig. 5, note the third diagram and the element marked "SSBTR" [5] which means single sideband transmitter. Single sideband transmission has been used on transoceanic radio telephone circuits since the first circuit was opened. It is not used in broadcasting, at least in this country, although it has been proposed a number of times. Single sideband communication was first used on wire line carrier circuits with their inception in 1918. It was utilized when the long-wave radio circuit was tested experimentally in 1923 and opened in 1927. Single sideband has since been applied on short wave circuits to London and to Honolulu.

Single sideband has the theoretical advantage of 9 db in signal-to-noise ratio over double sideband with carrier transmission; 6 db is secured from the utilization of all of the energy in one sideband and 3 db comes from reduced noise in the reduced band width of the receiver. Tests have shown that the 9 db signal-to-noise improvement is secured in practice.

The application of single sideband to the short-wave circuits encountered a number of difficulties. One of the bigger difficulties was that of resupplying the eliminated carrier. In order that speech received over single sideband circuits be truly normal and be recognizable as the voice of the talker, the carrier must be resupplied within 20 cycles. If it is supplied more than 20 cycles out of position the speech will be intelligible in varying degrees but it is impossible to recognize the voice even of one's best friend. To resupply the carrier within 20 cycles when the radio frequency is 20 MC means that the transmitter and the beating oscillator at the receiver individually should not vary more than 10 cycles, and 10 cycles out of 20 MC is one part in 2 million. The frequency of either oscillator must therefore remain constant to better than one part in 2 million if voices are to be recognized. It is of course possible to build oscillators which are more stable than this. However, such oscillators at present appear to be in the laboratory rather than the commercial class and so it has been found desirable to adopt a different means for maintaining this frequency of the resupplied carrier at the right value. This is accomplished by transmitting a small part of the original carrier and then at the receiver use this small or vestigial carrier as it is known to actuate a mechanism which will supply a local frequency exactly in synchronism with it. The resupplied carrier can therefore be maintained well within one part in 2 million, in fact it can be maintained within one cycle in 20 megacycles.

In producing a single sideband other difficulties are encountered. In the present state of the art it is difficult to eliminate one sideband and leave the other, except at relatively low frequencies. In the long-wave transoceanic circuits which operate on 60 to 70 kc the elimination occurs at 30 kc and a second modulation shifts the remaining sideband to the desired position. This gives good selection of the desired sideband and provides flexibility in the final positioning of the sideband.

In operating at high frequencies, which may be as high as 22 MC, it has been found desirable to reach the desired point not with two steps in modulation but with three steps. This is indicated in Fig. 13.

Signals come in on input circuit A to modulator 1A which modulates 125 kc from which crystal filter A selects the upper sideband. This upper sideband then goes into modulator 2 where it modulates 2500 kc. The sideband in this case will be located more than 125 kc away from the carrier and can be selected by a relatively inexpensive filter which now delivers the single sideband in position 2625.1 to 2631 kc to modulator 3. In modulator 3 this sideband modulates a suitable

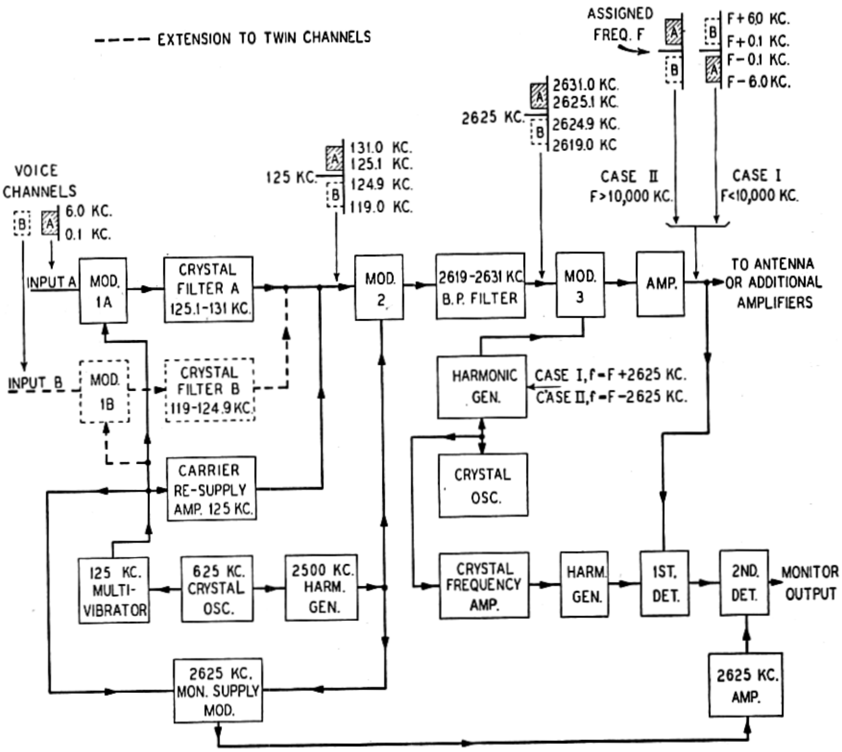


Fig. 13—Single sideband transmitter circuit.

frequency which may be anywhere from 6 MC to 20 MC which is secured from a suitable source such as the harmonic output of a crystal oscillator. The output of this third modulation places the single sideband in a desired position in the ether whereupon it passes through an amplifier to an antenna and is radiated. This desired position in the ether may be either above or below the final carrier frequency as may be found desirable, depending upon the frequency range in which operation is to occur at that particular hour.

Following the success in applying single sideband to one of the short-wave channels consideration has been given to utilizing the position of the vacated sideband or the contiguous position for a second channel. The resultant method is called "twin channel single sideband." Referring to the diagram in the upper right-hand corner of Fig. 13, Channel *A* is the single sideband which has just been discussed while the second single sideband is now placed in *B* position so as to give two separate conversations with the same transmitter. This immediately brings to mind the question, "Is the advantage of single side band lost by using the two sideband positions for two separate channels?" Odd as it may seem it is only slightly affected. If those two sideband positions are used for a single channel the frequencies in the two sidebands appear simultaneously, and in corresponding positions. The transmitter must handle both simultaneously and the receiver must be broad enough to receive both bands. However, when two separate conversations are placed in the two separate sideband positions similar frequencies do not appear simultaneously in both bands except at such remotely occasional times that their mutual interference is small or not noticeable, and at the same time the receiver for each channel is tuned for only one sideband, thereby keeping down the noise. By using the two positions for two separate channels it is possible to get on a statistical basis two single sideband circuits each 8 db better in signal-to-noise ratio than would be obtained using the same two sideband positions for one channel alone. It produces a remarkable increase in efficiency of use of a circuit.

Now it also happens that addition of the second channel requires a surprisingly small amount of apparatus. Looking at this same figure, Channel *B* is indicated on the left providing input *B* to modulator 1*B*. This modulator modulates the same frequency as modulator 1*A* but crystal filter *B* selects the lower sideband in this case, which sideband is now delivered to modulator 2 along with that from filter *A*. These two parts are all the apparatus necessary to add to this transmitter to convert it from one channel to two channels. It is thus to be observed that by suitable application of single sideband to the short-wave channels it has been possible to multiply their number by two and increase each one 8 db in signal-to-noise ratio. This twin channel single sideband has been applied to two of the three short-wave transoceanic circuits, to the San Francisco-Honolulu circuit, and undoubtedly will be applied to other circuits in the future.

Referring again to Fig. 5, there will be seen an element marked "Directive Antenna." Directive antennas have been used very little in broadcasting. They are coming into greater use with short-wave broadcasting and with efforts to produce less interference between stations in the United States operating on similar wave-lengths, but their use has been much smaller than their use in radio links of the telephone system. Directive antennas are of great importance in telephone links for the reason that in operating over great distance, where weak signals must be received all or most of the time, much power may be saved if directive antennas at the transmitter are used

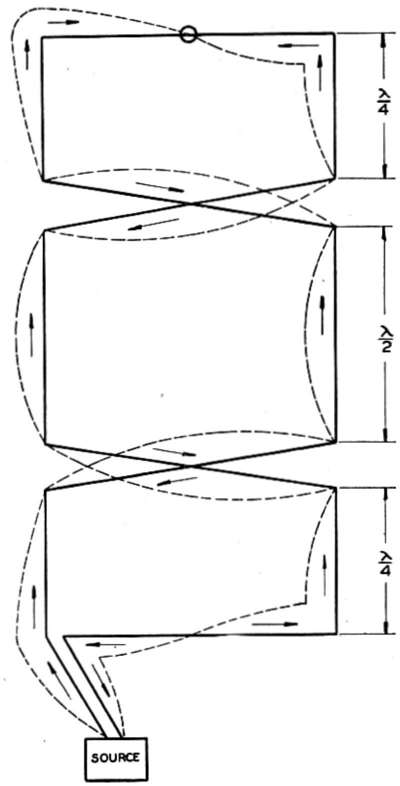


Fig. 14—Element of the Sterba directive antenna.

to send as much energy as possible in the desired direction, and used at the receiver to exclude as much noise from undesired directions as can be done.

In connection with the directive antennas used in the telephone system, quite a variety have been developed. Figure 14 indicates the principle of what is known as the Sterba [6] antenna, invented by the late Mr. E. J. Sterba. This is an elemental section, the complete antenna being built up of a number of elements of this kind. The element consists of a conductor, whose length is an integral number of half wave-lengths, bent in such a way that the currents in all of the vertical elements will be in phase while in the horizontal elements they will largely balance out. The vertical elements are all placed in the same plane and the horizontal elements depart from that plane only enough for crossing without short-circuiting. With this arrangement the energy radiated in a direction perpendicular to the paper will be a maximum. It will be a minimum in the plane of the paper in side or vertical directions. Any suitable number of these elements may be arranged in the same plane and connected together so as to increase the energy in the desired direction. Inasmuch as the length of the wire and the configuration into which it is bent are associated with the frequency, an antenna constructed for one frequency is not usable at another. This is true in any antenna where standing waves exist.

In the antennas of this type which have been used on our short-wave circuits for operating across the Atlantic, as many as 8 elements were connected in parallel in the same plane so as to radiate in the desired direction producing a sharp directivity pattern. At the same time another set of 8 elements were located one-half wave-length away parallel to the first as indicated in Fig. 15 so as to eliminate the radiation in one of the two directions perpendicular to the screen. This causes all the energy to be radiated in the desired direction. For operating one radio transmitter on a transoceanic circuit it is necessary to have three or four antennas for each transmitter, one for each wave-length. These antennas were strung between towers. Figure 16 shows the antennas as used formerly at Lawrenceville, New Jersey. One antenna occupied two inter-tower spacings. The direction of transmission is perpendicular to the line of the towers.

At the receiving end directive antennas are also used. An elemental picture is shown in Fig. 17 of the receiving antenna devised for this purpose by Mr. E. Bruce.[7] The third diagram shows the shape into which a long conductor is bent and the arrows show the instantaneous directions of current flow at a moment of maximum. It is observed here also that in all the vertical elements the currents flow in the same direction while in the horizontal elements enough flows in the two directions so the effect is neutralized. This antenna will therefore also receive or transmit in the directions perpendicular to the plane of the conductor and not in directions within the plane. This type of antenna can also be constructed with a reflector behind it to reduce the direction of transmission or reception to a single direction.

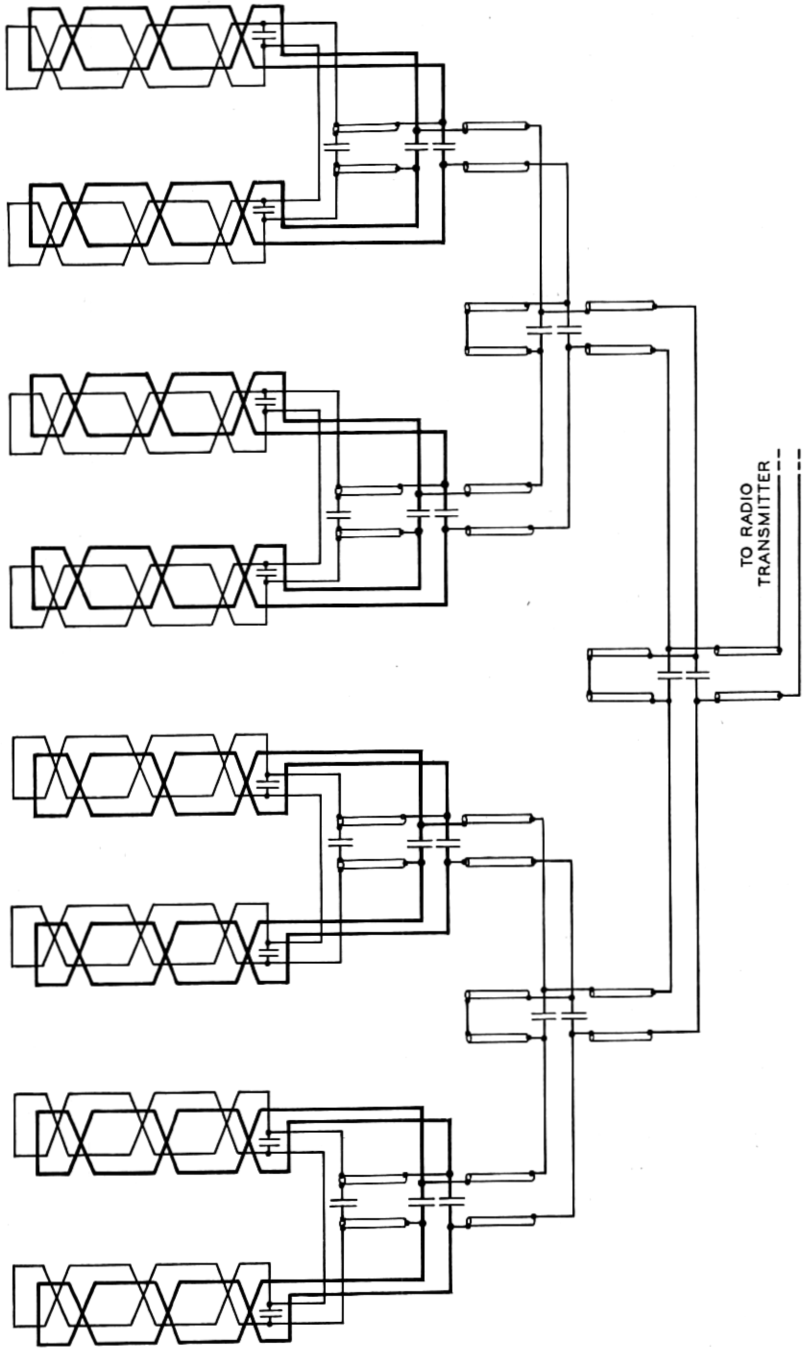


Fig. 15—A complete Sterba antenna with reflectors for one wave-length.

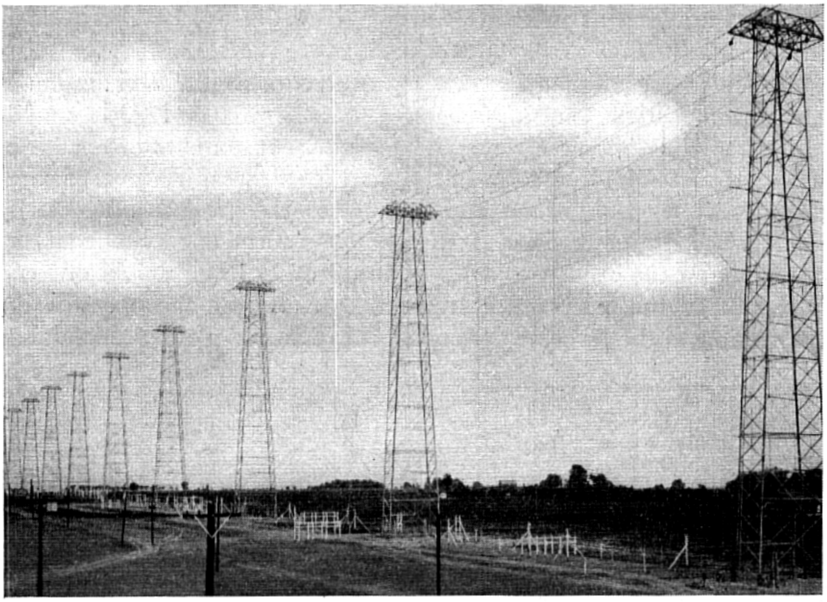


Fig. 16—Towers at Lawrenceville, New Jersey, used to support a number of Sterba antennas for transoceanic communication. These antennas have since been superseded by rhombic antennas.

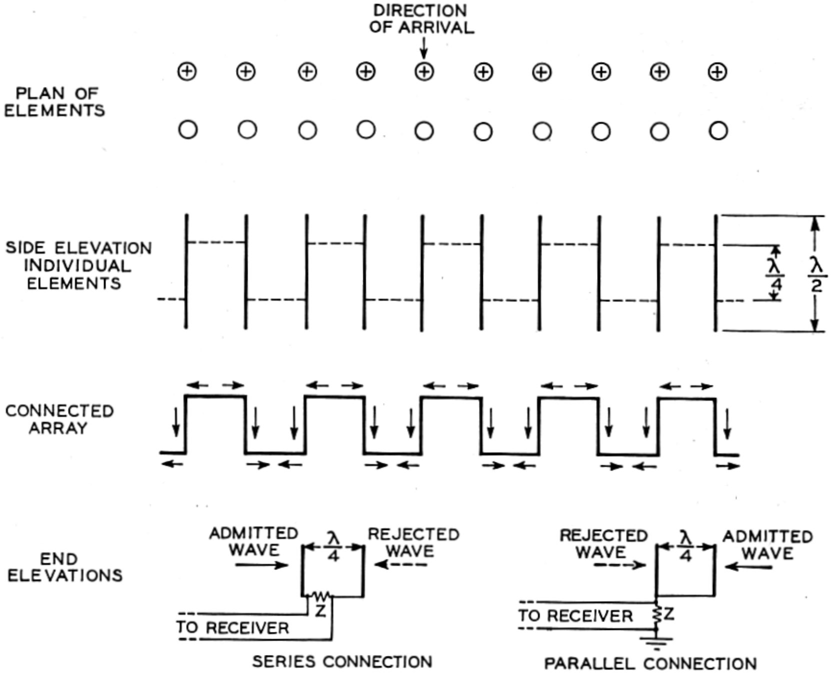


Fig. 17—Bruce antenna array.

Such an antenna as used at Netcong, New Jersey, for reception is shown in Fig. 18.

In the course of time further improvements in directive antennas have been made. One improvement is indicated in Fig. 19 and is known as the "rhombic antenna" [8] because it consists of a wire or wires supported by four poles in the shape of a rhombus elevated some distance above the ground and parallel to the ground. As usually used two contiguous sides of the rhombus form one branch of the antenna and the other two sides form the other branch. At one end is connected the receiver (or transmitter). At the end opposite the connection to the receiver are connected resistances of suitable value.

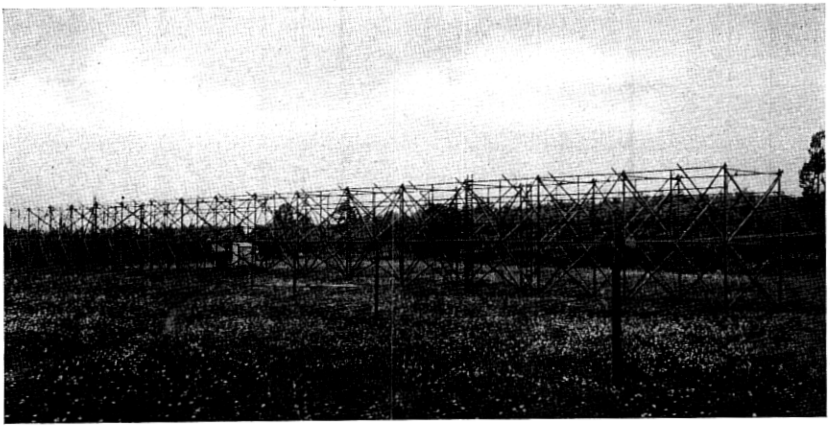


Fig. 18—Bruce receiving antenna at Netcong, New Jersey, used for transoceanic communication. This type of antenna has been superseded by the rhombic type at Netcong.

This antenna differs radically from the previous ones and most other directive antennas in one respect and that is it does not usually operate with a standing wave thereon. The purpose of the resistors is to absorb all the energy reaching such resistors. This antenna when arranged as in Fig. 19 receives from the right. The energy strikes the wires and is thence transmitted to the receivers. Energy coming from the left-hand side travels away from the receivers and when it strikes the resistors is absorbed. If the resistors are not used and the two terminals are either connected together or kept insulated, energy reaching this end will be reflected, in which case this antenna will operate with a standing wave thereon and will receive or transmit from either the right or the left. Inasmuch as this antenna as preferably used is unidirectional and does not operate with a standing wave, a single antenna may be used for a number of wave-lengths without readjustment.

When the rhombic antenna is used for a number of frequencies without change in size or form, the directivity is different for each frequency. The maximum directivity for the higher frequencies will be a lower angle than for the lower frequencies. This works in very well for long distance operation since the angles at which the high and low frequencies come in tend to agree with this characteristic of the antenna.

The rhombic antenna has come into extensive use for transoceanic short-wave links during the last few years. Due to its multi-wave-

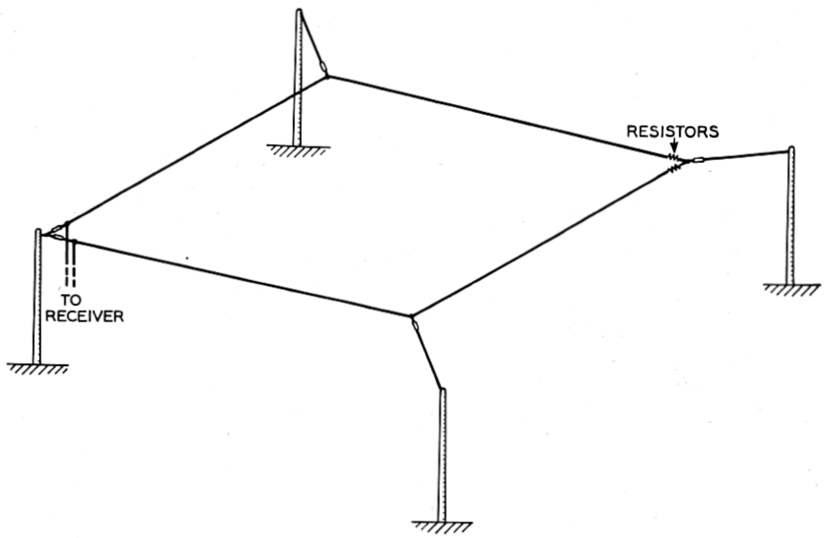


Fig. 19—Rhombic antenna invented by E. Bruce.

length characteristics it is replacing the other types of antennas described previously. The initial cost is much less than the type supported on steel towers, the land required is less, and the upkeep is also less.

In Fig. 20 is shown a photograph of another type of directive antenna. Two antennas are indicated, one for transmitting and one for receiving. These antennas are known as "pine tree" [9] antennas because of the connections of the radiators to a transmission line passing up from below. This particular antenna is for ultra-short-wave operation around 60 MC and is one end of the Provincetown-Green Harbor circuit. Each antenna contains 8 radiators in a plane

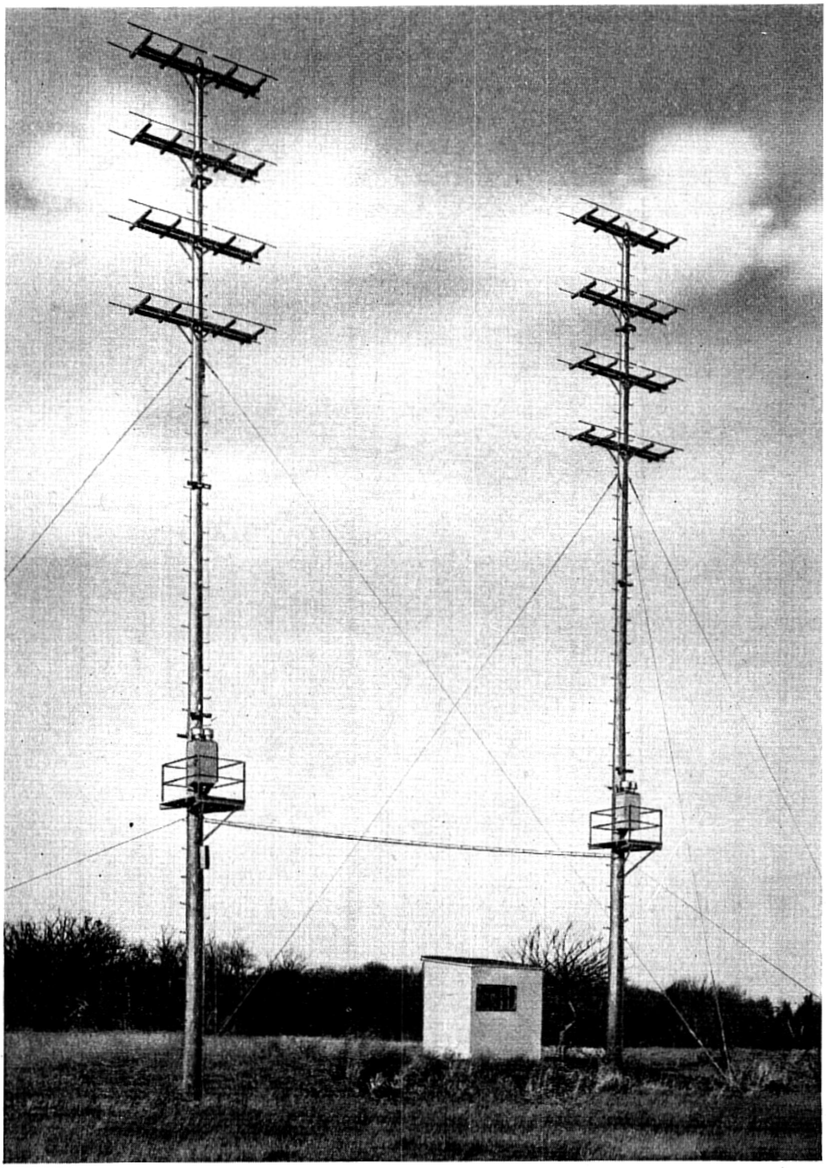


Fig. 20—Pine tree antennas used on Provincetown-Green Harbor ultra-short-wave circuit.

and 8 reflectors in a parallel plane. This type lends itself very well to construction for ultra-short-wave operation. The directivity of any antenna is a function of its breadth measured in wave-lengths and when the wave-length is short it is more economical and easier to construct the antenna with the larger dimensions up and down the pole or at right angles to the pole than to stretch it along the ground.

Figure 21 indicates one of the first directive antennas to be used. This is known as the "Beverage" [10] antenna and is used on long-wave telephone circuits which operate between 60 and 70 kc. Such an antenna is located at Houlton, Maine, for receiving from England. The antenna structure appearing in this diagram may be several miles in length. It receives best from the upper right-hand direction, as indicated by the arrow. The incoming wave produces currents in the antenna which experience gradual build-up along the line to the receiving end where they operate the receiver and deliver the signal to the telephone line. This type of antenna has a horizontal directional pattern as indicated in the figure. Its maximum direction as used is northeast, as that is the direction signals arrive from England. It also happens that more static and strays reach this part of the country from the southwest than from other directions and with the antenna so oriented there is what is sometimes called a "blind eye" faced in the southwest direction so as to receive a minimum of interference from that direction.

Some of the difficulties involved in transoceanic short-wave reception may be explained by reference to Fig. 22; this shows a diagram of the earth and the ionized region of the atmosphere called the "ionosphere." Signals from the transmitting station in England may reach the receiving station in the United States by more than one path. One path indicated has two reflections from the ionosphere and the other has three reflections. Careful measurements on this diagram indicate that these two paths are not equal in length, with the result that signals received in the United States from across the ocean coming over the two paths may be out of phase. Not only may there be two paths but sometimes there are three, four or more so that the interference caused by signals coming over the several paths can give rise to bad fading and distortion. The lower diagram in this figure shows the vertical directive pattern of an ordinary directive antenna. It shows this directive pattern to be large enough to receive simultaneously both incoming signal components from the two paths. If it is desired to eliminate the undesirable effects produced by the two signals coming in out of phase, one should be eliminated. This can be done provided an antenna is constructed having a sharp directive

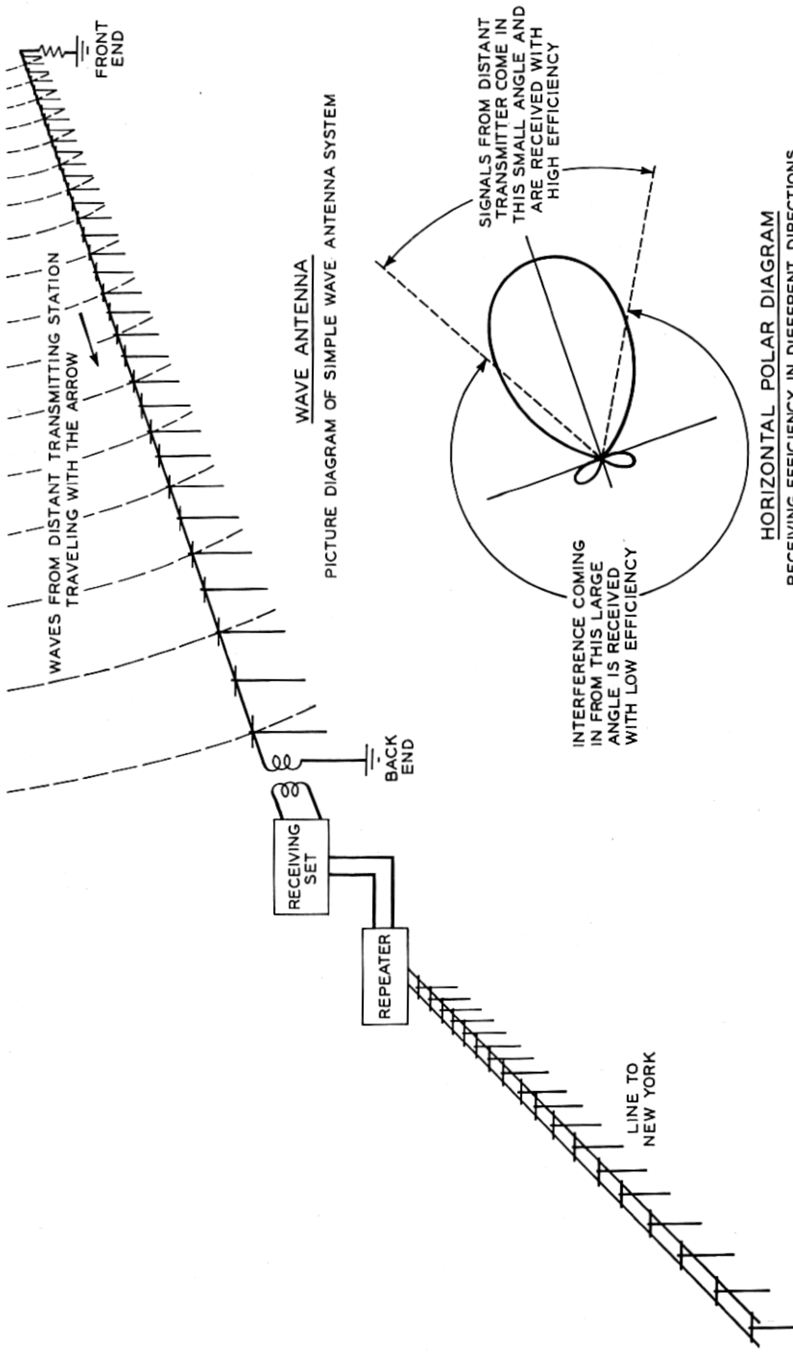
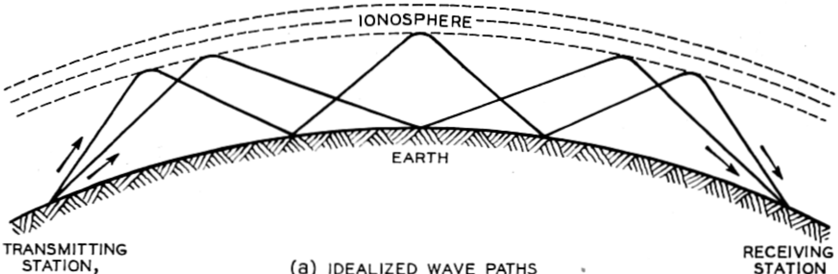


Fig. 21—Beverage antenna.

pattern as indicated in the same sketch and such a directive pattern is produced by an antenna system called the "Musa."[11] The name "Musa" comes from the initials of the words "multiple unit steerable antenna." The Musa is one of the latest developments in directive antennas and possesses not only the important characteristic of a very sharp directivity pattern but also is steerable so it may be altered to receive a desired component, and if such desired component changes its angle of arrival alteration may be made to accommodate such change.



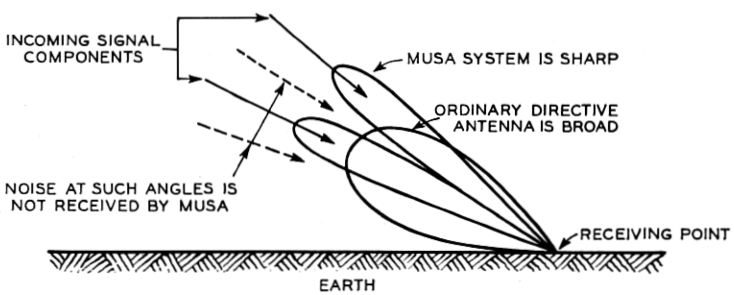


Fig. 22—Paths of short waves over long distances as determined by the ionosphere.

Figure 23 indicates the elements of the Musa. It consists of a row of rhombic antennas lined up in the direction from which signals are expected. Each rhombic antenna is connected by a transmission line to a phase shifter and the outputs of the phase shifters are connected to a receiver. These phase shifters may be so adjusted as to cause any desirable phase additions from the separate antennas. By changing the adjustments on the respective phase shifters the direction of reception may be altered. In this diagram a row of antennas is shown as connected through phase shifters to receiving branch *A* with the phase shifters adjusted to produce a directive pattern as indicated in the neighboring diagram marked branch *A* and drawn dotted. Into branch *A* will therefore come the signals which arrive from one trans-

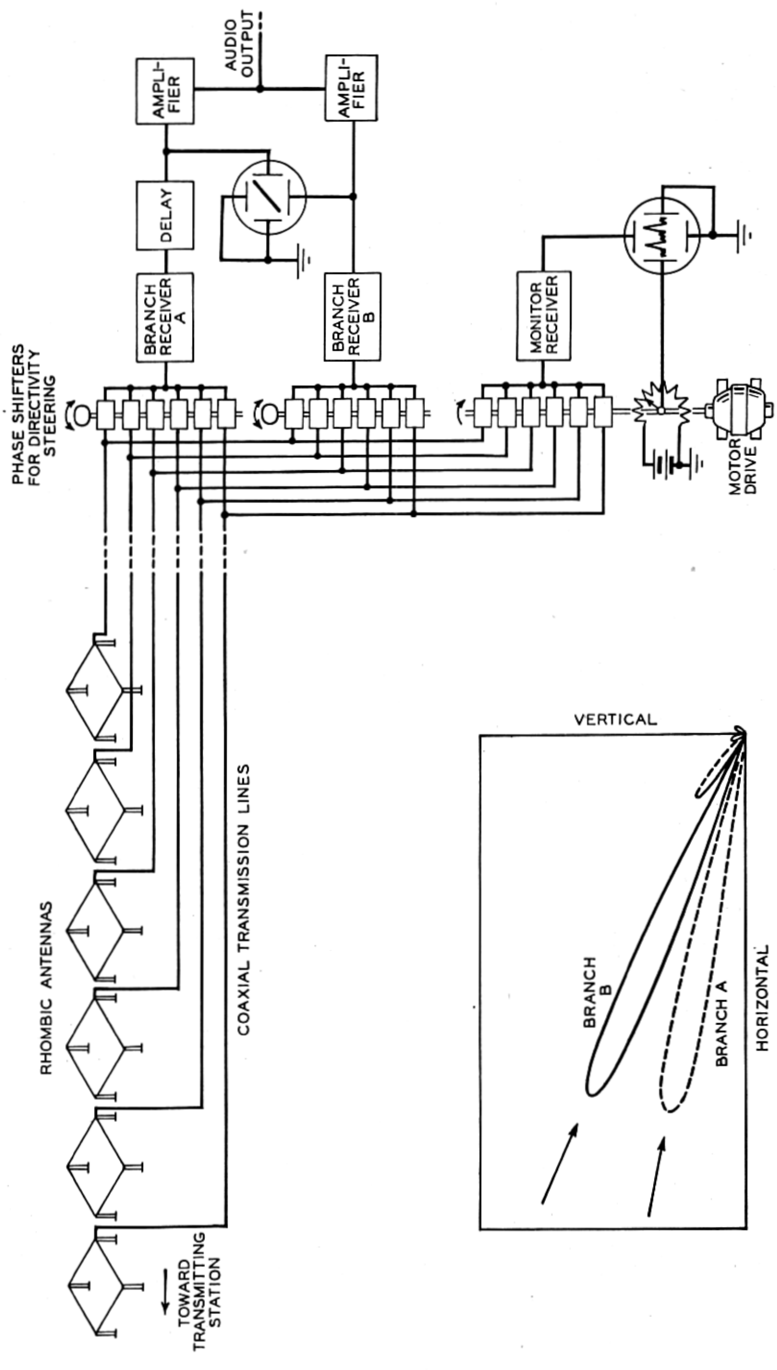


Fig. 23—Schematic of musa (multiple unit steerable antenna).

oceanic path at the lower angle. Beneath this row of phase shifters is indicated a second set connected in parallel with the first set. The second set is adjusted somewhat differently so that the receiver in branch *B* will receive signals over the path with the higher angle as indicated by the solid line directive pattern in the neighboring diagram. The two separate signals may therefore be separately received. Since, however, they do not arrive at identical times they cannot be added without producing distortion. By interposing a delay in the output branch of the one arriving earlier, which in this case is branch *A*, they may be added directly into a single audio output. In this case if one branch fades the other will continue to receive the signal, and while both are receiving a better signal-to-noise ratio obtains.

A cathode ray oscillograph is connected on the outputs of these receivers as indicated in the diagram so as to indicate when the delay is satisfactory for adding the two signals in phase.

As mentioned previously the direction from which a signal comes may change from time to time. In this case a fixed adjustment of the phase shifters may allow the signal to disappear. The operator needs to be ready to change the phase shifters when necessary but it is also desirable that he change them in the desired direction without interfering with the conversation arriving over the circuit, which means he should be able to adjust them without using cut-and-try methods of adjustment. To accomplish this a third set of phase shifters is provided which are continually driven in rotation by a motor so that as they rotate they cause the direction of the signal received by a monitoring receiver to shift its angle of reception over the entire angle range at which signals might arrive. The output of this receiver is connected to two plates of a cathode ray oscillograph while to the other two plates are connected potentials from a rheostat on the phase shifter drive shaft so that the potential will be indicative of the position of the phase shifter. If the phase shifter continually rotates the varying signals will cause the varying deflection in the vertical direction and so draw a pattern as indicated in Fig. 23, which will show immediately by suitable calibration the angle between the two different signals. The operator may thereby adjust his phase shifters by calibration and without cut-and-try tuning.

Inasmuch as the rhombic antenna does not operate with standing waves and may be used for a variety of frequencies it may be used simultaneously for this variety of frequencies. The transmission lines from the rhombic antennas to the phase shifters also operate without standing waves so they likewise may operate simultaneously at a variety of frequencies. It is thus possible by connecting other phase shifters and other receivers to utilize a single row of rhombic antennas to receive simultaneously a number of radio signals on different frequencies. Each one of these receivers with phase shifters will provide its own directivity pattern and may be adjusted independently of the others.

A Musa system has been constructed for transoceanic reception on short waves at Manahawken, New Jersey, and is now in operation. In this system 16 rhombic antennas are placed in a row approximately a mile and a half long.

The radio terminals for all services have not attained standardized final forms but are in a slow state of flux as better circuits and methods for handling existing problems are devised. The circuits and devices indicated in the figures in principle or in detail are not the only ones that have been tried or used, but represent steps that at one time or another were considered to be advancements suitable to be put into use while the attentions of the development engineers were directed toward more pressing problems. These various devices have augmented the reliability of radio circuits enormously. Distances covered have been enlarged. To accomplish similar results by power increase alone would have in most cases rendered it uneconomic to construct and operate the radio systems. In each case peculiarities either in speech, in radio circuits, or in static and noise characteristics are taken advantage of in making a design to aid the signal and reduce the effect of noise. It is believed that the limit has not been reached but that further improvements and other devices will in due time give increased reliability.

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