# The Electrical Plant of Transocean Radio Telegraphy

BY E. F. W. ALEXANDERSON, A. E. REOCH and C. H. TAYLOR
Fellow, A. I. E. E. Associate, A. I. E. E.
All of the Radio Corporation of America

***Review of the Subject.***—*A description of the expansion of the Transocean Communication System of the Radio Corporation of America from a few isolated plants to a unified group of electrical plants all controlled for communication purposes from a central traffic in New York City, with a summary of the technical conditions covering the design of the Radio Central Station and of the technical conditions to be met in operating efficiently a modern radio communication system.*

---

At the beginning of 1920 the United States Government removed the war restriction on commercial radio service, and the Navy Department restored to the Radio Corporation of America those stations which were built and equipped in 1914 by the Marconi Wireless Telegraph Company of America for transocean service.

In addition to the agreements previously entered into with countries in Europe for transocean radio service, the Corporation faced the situation arising out of the Great War, in which practically every European country demanded direct radio commiunca-tion with the United States.

The need for the provision of modern facilities for carrying on radio communication with those countries with which agreements had already been made, was imperative, and hardly less imperative was the need for the expansion of our facilities to meet the new situation.

The radio equipment in all of the installations restored to the Corporation was of obsolete type and based on the use of damped waves, except in the case of the New Brunswick station. At that station the Navy Department had instructed the General Electric Company to install high-frequency alternator equipment and to modify the antenna circuit to meet the requirements of their system. Accordingly, an alternator equipment was installed which was able to supply to the antenna circuit 200 kilowatts at the high frequency to which the antenna circuit is tuned. The antenna at this station had been erected as an inverted L, approximately a mile long and 550 feet wide. This was changed to the multiple-tuned type by adding five tuned down leads, equally spaced along the length of the antenna, and connecting them through a balanced distribution system to the ground and counterpoise wires. This installation has been described by technical papers read in 1920 and 1921.

Operation of the system of the Radio Corporation started with two transmitting stations — at New Brunswick, New Jersey, and at Marion, Massachusetts. Each of these transmitting stations had its corresponding receiving station at Belmar, New Jersey, and at Chatham, Massachusetts, respectively. New Brunswick was used for communication with England, and Marion for communication with Norway. The telegraphic operation of the English circuit was centered in Belmar, and the operation of the Norwegian circuit was centered in Chatham. Messages to England or Norway were telegraphed to Belmar and Chatham respectively, where they were copied and transmitted over the radio circuit via New Brunswick and Marion. Similarly, messages from England and Norway were received in Belmar or Chatham, were copied by hand, and re-telegraphed to New York. This process involved several relays of telegraph operators with the consequent high expense and possible delays and errors.

With the present system of operation, the Radio Corporation has six transmitters on the Atlantic coast, two in Tuckerton, one in New Brunswick, one in Marion, and two in the Radio Central station on Long Island. All these transmitters are controlled directly from the traffic office in New York City.

Only one receiving station is needed for all incoming messages. This receiving station is located at Riverhead, Long Island. It has a single antenna of a new and special type, which will be described later. This antenna intercepts the waves from all European transmitting stations. The receiving apparatus, also of a new type, separates this conglomeration of ether waves which come in over the receiving antenna, into separate messages which are automatically relayed over telephone wires so that all messages are received and copied in the same traffic office in New York.

The transmitting station on Long Island — known as "Radio Central" — and the receiving station at Riverhead, Long Island, represent the modern system of the Radio Corporation. The stations at New Brunswick, Marion, and Tuckerton, are adaptations of the modern transmitting apparatus developed by the General Electric Company and antennas built before the war. The characteristic features of the transmitting system are: The high-frequency alternator, the multiple-tuned antenna, the speed or wave-length regulator, and the magnetic amplifier.

In the Riverhead receiving station the method of centralization has been carried to its logical conclusion by concentration of all radio apparatus in the one station, and concentration of all reception in New York. The advantage of such concentration is obvious. New receiving circuits for communication with any new station in Europe can be added at a negligible cost by installing a new set of receiving apparatus on some of the shelves provided for that purpose in the Riverhead receiving station.

The Radio Central transmitting station has been

*Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 25-29, 1923.*

planned in such a way that the cost of additional transmitting units will be a minimum. The choice of the site of the Radio Central transmitting station was carefully considered, looking forward to a growth of international radio communication which would require as much as twelve transmitters in this new station. Two of these twelve transmitters are already completed.

The principal considerations in selecting the site for the Radio Central station were:

1. The site must be within a reasonable distance from New York — the center of traffic.

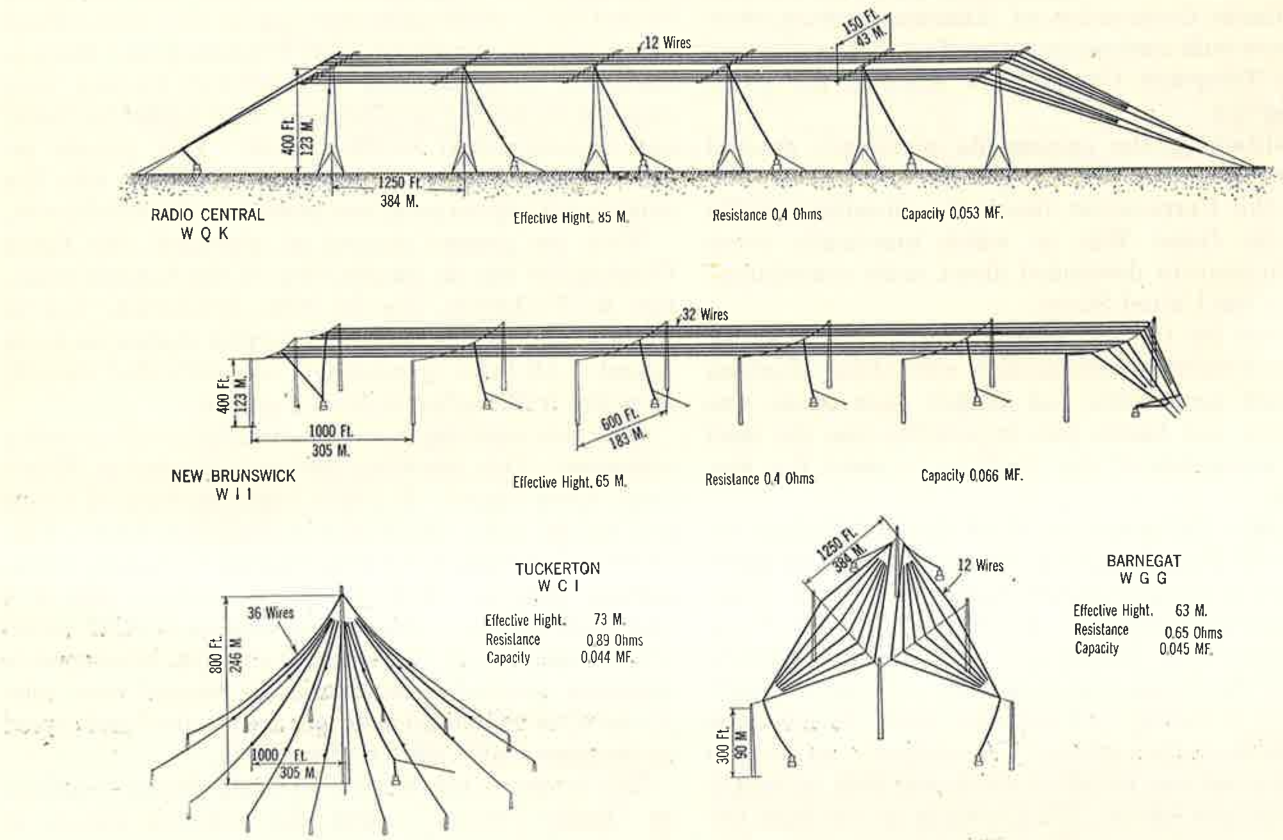



Fig. 1

2. A large tract of land of a desirable nature must be available, at a moderate cost.

3. A good power supply must be within easy reach.

4. There must be direct and reliable wire line communication with New York City.

The site selected on Long Island fulfilled these requirements in an ideal way, but another desideratum which, in the past, had been the deciding factor in selecting sites for transmitting stations, was not fulfilled in the Long Island location — a natural low ground resistance. The Long Island ground consists of quartz sand of extraordinarily high resistance. The decision, therefore, regarding the selection of this site was a grave responsibility for the engineers of the Radio Corporation. It meant a radical departure from the generally accepted theories. It implied that practical operation rather than technical considerations was to be the controlling factor. The engineers thus undertook to remedy by new developments in the technique what nature had failed to provide — a good ground. Much progress had already been made to reduce ground resistance by multiple tuning and ground equalizers, but this experience had been gained in stations like New Brunswick, Marion, and Tuckerton, where the natural ground resistance was low. However, we had sufficient faith in the further possibilities of development of improved grounding methods to take the responsibility for starting the construction of the new station while investigation was going on to find a solution for the grounding problem. The development work of the new ground system required as much time as the completion of the rest of the station, but by the time the station was ready to go into service the ground system was also ready and proved to be succesful beyond the most sanguine expectations.

The Radio Central transmitting station of the Radio Corporation of America is the first of our stations that has been planned and designed from the beginning to meet modern requirements, the other stations having been made to conform to modern practise by modification of equipment installed in earlier times. The Radio Central type of station is being duplicated in Poland and Sweden. This station has been frequently described and while its 400 ft. steel towers with 150 ft. cross arms are quite well known, little has been published regarding the technical performance of the plant.

## Radiation

The transmission value of the transmitting station is expressed by the product of the effective height — usually given in meters — and the charging current of the antenna circuit — given in amperes. In deciding upon the value of meter amperes that would be required at our Long Island station, we took advantage of the experience gained from work done with the signals transmitted from the Nauen station in Germany and the Carnarvon station in England. As a result of the preliminary work in this connection, a figure of 50,000 meter amperes was decided upon and the antenna circuit was designed to give this value with full power on one transmitting unit.

As this figure of 50,000 meter amperes is made up of two factors, effective height of and current in the antenna circuit, the values assigned to each of these factors must be so chosen that the cost of the antenna, cost of power equipment, and cost of operation and maintenance, will result in the most economical investment. In order to determine the most economical height of antenna, it was necessary to check carefully, the varying effects of capacity, effective height, wave length, voltage and current. The result of these investigations showed that if the first cost of the transmitting station be plotted against the height of the towers for a given value of meter amperes at a given wave length, a curve is obtained showing a distinct minimum. This minimum is not sharp but shows that there is a minimum cost of station for the given meter ampere value over a small range in the height of the towers.

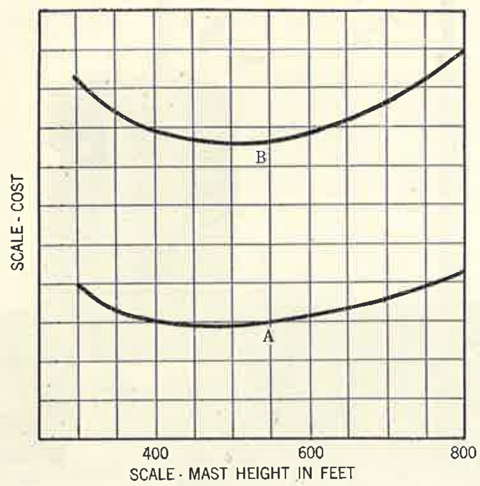



Fig. 2

Design Data: Radio central type antenna; wave length 16,000 M.; Voltage maximum 120,000 M.; meter ampere value: Curve A-50,000, Curve B-100,000.

Fig. 1 gives for comparison the principal dimensions, effective height, and resistance of the four types of antenna used in the Atlantic shore stations of the Radio Corporation. The effective heights are determined by measurements of radiation.

Fig. 2 shows the calculated cost for antenna structures at different heights for two typical stations of 50,000 and 100,000 meter amperes radiation.

The antenna voltage limitations which had been experienced at our older stations necessitated an investigation of the insulators that should be used in connection with these antennas. This work has been described recently in a paper read by Mr. W. W. Brown on March 7th, last, before the Institute of Radio Engineers, and this shows that by careful design and arrangement of parts, we have been able to raise the working voltage of our antennas from around 60,000 to 150,000. In a recent test of the insulators actually installed and operating at our Radio Central station at a voltage of approximately 120,000, it was found that the voltage distribution over the double insulator unit, by means of which the wires are suspended from the bridge arm of the towers, is roughly 45 per cent and 55 per cent, the insulator nearer the tower having the smaller proportion of the voltage.

## Power

The power to operate the station is generated in the Long Island Lighting Company's plant at Northport, L. I., and carried by a three-phase network at 22,000 volts, a distance of 30 miles to the radio station. At the radio station, the power is transformed to 2300, two phase, to drive the induction type motors connected through step-up gears to the high-frequency alternators.

## Antenna

The suspension of the antenna wires followed current transmission line practise. The wires run the full length of the antenna; standard transmission line clamps are fastened to the wire at each tower suspension point. These are shackled to the insulators suspended from the tower bridge arm. As the working voltage at which this antenna would operate, was higher than that used at our other transocean stations, the design of this circuit was carefully considered with respect to corona losses. The operation of this antenna at 135,000 volts showed that the corona limit was not reached on any portion of the circuit, although there is not a very great reserve where the inner wires unshielded by the suspension insulators, pass across the face of the steel tower.

The antenna consists of 12 parallel wires 5/16 in. diameter 7500 feet long and spaced on an average about 14 feet apart forming an approximately horizontal plane about 150 feet wide. The wires are stretched from dead end structures close to the building to the first tower cross arm then from cross arm to cross arm in a straight line to the sixth tower, then again to a dead end structure at the ground level at the far end.

The self supporting type of tower was selected for use with this antenna. It is equipped with a bridge arm, its length 150 ft. over-all—fixed to the top of the tower. The insulators carrying the antenna wires are suspended from the lower face of this bridge.

Many reasons entered into the decision to use this type of tower, three of which may be mentioned here. One consideration was, the average height of the antenna wires. With a group of similar antenna wires, equally loaded, suspended on a springstay between two towers, the height above ground of the point of suspension of a wire decreases as the distance between this point and the nearest tower is increased. With a similar group of wires suspended from the bridge arm of a tower, there is no similar variation.

Another engineering consideration was the variation in antenna constants caused by high winds. The suspension of the group of antenna wires from a spring-stay slung between the tops of two masts or towers, has been used at our New Brunswick, Marion, and similar stations. It has been found that whenever there is a high wind blowing across the antenna wires, the spring stay assumes a new position varying with the strength and direction of the wind. With gusty winds of high velocity, this change of position is continuously occurring. There is, in addition, the variation in the position of the antenna wires due to the cross wind on the wire span between the spring stays. The result of these changes in position of the wires is that the constants of the antenna circuit change, and detune the antenna from the alternator which is operated at an accurately regulated wave length. The resulting fluctuations in radiation have been so great at times as to seriously impair the commercial effectiveness of this station. Now, with a fixed point of suspension, such as the tower bridge arm, the only variations in position of the wires, are those due to the wind on the wire span between the towers. Those due to the variation in the position of the spring stay are not present.

The antenna circuits at all of our stations are equipped with variometers to correct for these changes and our experience is that the variations are less severe with Radio Central type of antenna than with that of New Brunswick.

As Long Island is well within that zone of the United States in which sleet and glare formation must be expected on all structures exposed to the weather during the winter months, provision has been made to melt such ice as may form around the antenna wires. The heating current for sleet melting, is supplied from the power house, at 60-cycles, through special transformers and reactances. The antenna wires are connected together at the far end of the circuit. By opening switches at the power house end of this circuit, the wires can be disconnected from the radio frequency feeder circuit and the 60 cycle power circuit can be connected. If the several downleads were connected directly to the antenna wires throughout their length the path of the heating current would be short-circuited. Two satisfactory methods have been used to avoid such short circuit. One method consists in dividing the wires into four groups and connecting only the wires belonging to one group at each of the four intermediate points. At both ends, all wires are connected. The other method consists of making the connection of each wire through a specially designed condenser.

The inductors used at each downlead of the multiple tuned antennas are installed without any protection from the weather. This type of installation has proved satisfactory except at some locations close to the sea where the spray from the sea water deposits salt on the insulators.

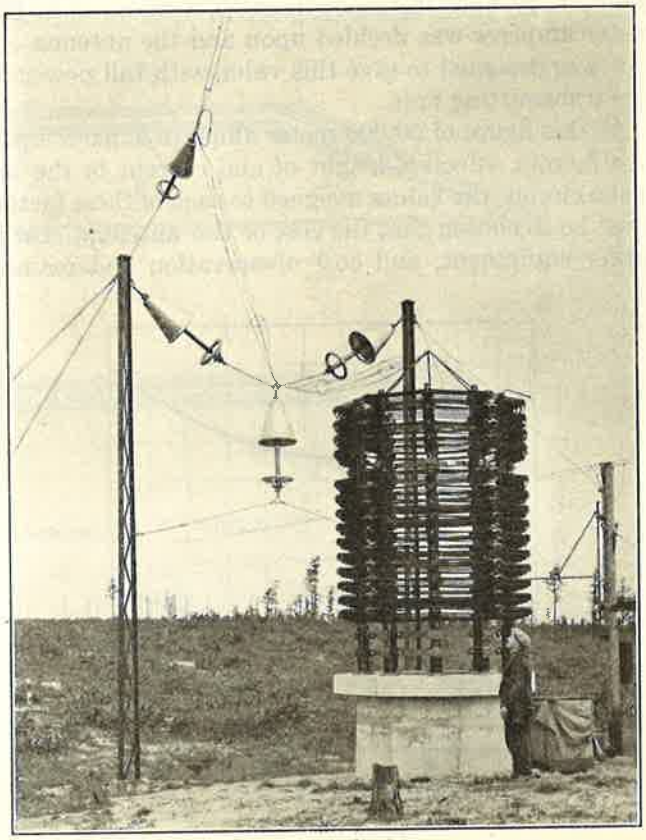


Fig. 3

The standard outdoor coil is shown in Fig. 3. Fig. 4 shows coils housed in frame structures lined with copper.

At stations where more than one antenna circuit is installed, attention must be given to the disposition of the several antennas and of their individual feed circuits in order to minimize their mutual interaction. In enlarging or remodelling an existing station, it is not always expedient to attempt to bring all antenna circuits to the close proximity of the power house. This is particularly true of a station where the original antenna circuit is of umbrella design and where a second antenna circuit is to be installed, which can be operated simultaneously with the first and on a long wave length differing from that of the first by only a few per cent. Such a situation confronted us at our Tuckerton station. The space immediately surrounding the power house was occupied by the umbrella antenna, which was in continuous commercial use. The new antenna could be erected on some vacant land just beyond the boundary of the space occupied by the umbrella antenna provided this antenna circuit could be fed with power at radio frequency from the power plant. The study of a transmission line that would be suitable for supplying to this antenna from the power plant, 200 kw., at frequencies of around 18,000 per sec. with little loss on the line, disclosed that this was quite practical. The antenna has been erected, this high-frequency line has been installed and the circuit has been operated very satisfactorily now for over a year. The power delivered to the antenna circuit is 92 per cent of the power supplied to the line.

The success of this type of antenna feed circuit will have a profound effect upon the design of stations operating two or more antenna circuits simultaneously.

### Grounding System

The first decision to be made in the development of the ground system was whether it should be of the buried wire type, or the type known as "counterpoise" or "earth screen." The New Brunswick station has a ground system combining counterpoise and buried

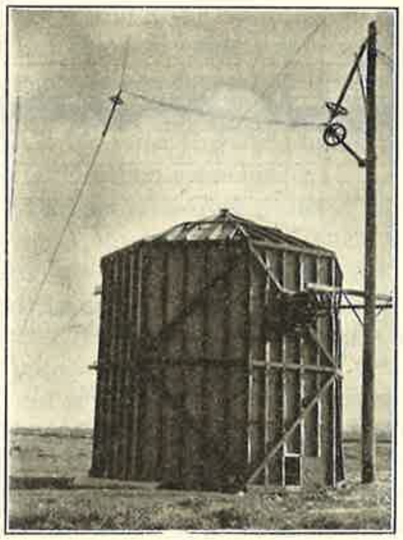


Fig. 4

wires. Experience had shown that while the counterpoise type might be ideal, from a theoretical point of view, it would be undesirable from the point of view of practical maintenance.

A counterpoise consists of a network of wires mounted on poles. These wires carry fairly high potential and the failure of any one wire will cause interruption of service until the fault is located and repaired. The overhead system of wires is also undesirable because it is an obstruction, making the maintenance of the overhead antenna wiring difficult and expensive. Theoretical considerations indicated that a buried wire system would be as effective as an insulated counterpoise provided that its dimensions and design were carefully planned with reference to the character of the soil.

To determine the basic factors for the design of a buried ground system, measurements were made of wave propagation on wires of different lengths buried in the Long Island soil. As a result it was found that the velocity of wave propagation on a wire in this soil is about one-tenth of the velocity of wires suspended in the air. It was found, furthermore, that the resistance of the wire is a function of the wavelength. With increasing length of the wire, the conductivity increases as a linear function up to a length of one-quarter wavelength, where it reaches a maximum, after which it becomes a periodic function of the wavelength and the length of the wire. The results of these measurements showed that the maximum length of wire which could be used effectively must be something less than one-quarter wavelength of the wave propagation in the buried wire.

Measurements of wave propagation in the buried wires indicated that while lengths as great as 1200 feet could be used economically in the Long Island soil, it was furthermore determined, through calculations of the electric field distribution around the antenna, that 76 per cent of the electric lines of force radiating from the antenna would be collected by these ground wires if they were made 1000 feet long. One thousand feet on each side of the center line of the antenna was therefore considered sufficient; the result is that the Long Island antenna, in effect, stands on a plate of copper 2000 feet wide and 3 miles long, and therefore the functioning of this antenna is made independent of the resistance of the soil.

The combined antenna and ground system offers a total equivalent resistance to the antenna currents of only 40 hundredths of an ohm, made up as follows:

| | |
|---|---|
| Radiation resistance....... | 0.05 ohms at 16,500 meters |
| Ground resistance......... | 0.10 ohms |
| Tuning coil resistance...... | 0.15 ohms |
| Conductor resistance....... | 0.05 ohms |
| Insulator and other losses... | 0.05 ohms |
| Total.... ........... | 0.40 ohms |

The unit is operated with 200 kw. in the antenna, and the antenna current is 700 amperes, resulting in a radiation of 60,000 meter amperes.

A special plow was constructed by which the wires could be laid cheaply. The plow carried a coil of wire. It had a blade which introduced the wire in the ground at a depth of twenty inches. The plow was drawn by two Ford tractors.

The ground network consists of wires each 2000 feet long buried in the ground a depth of 15 to 20 inches in lines at right angles to the line of the antenna with the center point of the ground wire under the center line of the antenna. The ground wires are spaced 10 feet apart and as the antenna is 7500 feet long there are therefore 750 such wires making the total length of buried wire approximately 1,500,000 feet. The ground wires are connected to a heavy underground bus which runs in the ground under the center line of the antenna. There is also an aerial bus feeder which is connected to the buried bus through inductive reactances in such a manner as to make all paths to ground of equal reactance, resulting in equal distribution of the antenna current to all sections of the ground system.

### Constancy of Wavelengths

A factor of great importance is that of maintaining the frequency or wavelength radiated absolutely constant for reasons that will be referred to later. In radio stations using high-frequency generators of the alternator type the speed of the alternator determines the frequency of the waves radiated. In many other forms of transmitters the frequency is affected by the

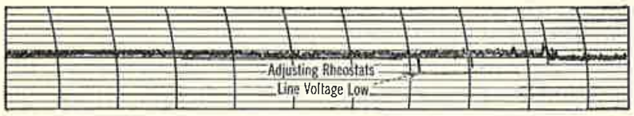



Fig. 5
New Brunswick, N. J.

antenna constants if not actually controlled by the antenna, with the result that as the antenna wires are blown about by wind; and ground and insulators are affected by dry, wet or frosty weather; changes in frequency will constantly occur. In the case of the alternator the problem resolves itself into maintaining the driving motor at constant speed regardless of voltage or frequency fluctuations in the power supply or the telegraph load fluctuations to which it is subjected by the alternator. This is accomplished by a system of relays operated in synchronism with the telegraph key by means of which the voltage applied to the motor terminals and the resistance in series with the wound rotor is varied so that the motor torque

Fig. 6
Radio Central, Long Island.

is always just equal to the load to which it is applied. Tendency to change speed on account of the telegraph load is thereby eliminated. Speed fluctuations due to changes in the power supply are not so easily disposed of however. A portion of the generator output is utilized to energize a tuned circuit of low resistance adjusted to have a natural period slightly different from the frequency at which the generator is maintained so that if the alternator frequency varies only a few hundreths of one per cent in one direction, there will be a large increase in the current in this resonant circuit, or if the variation is in the other direction, there will be a correspondingly large decrease. A portion of the current in this resonant circuit is rectified and we are thus provided with a direct current which varies up or down practically instantaneously with the slightest change in the alternator frequency. This direct current is made to control the voltage supplied to the motor terminals reducing the voltage to counterbalance a tendency towards increase in speed and vice versa. In order that there may be a visual indication of what is going on, a recording ammeter is inserted in the rectified current circuit; a fine straight line on the ammeter chart indicates a constant frequency, a thick line indicates small and continuous variations of frequency and so forth. Under usual conditions of operation, irregularities of the ammeter chart line can be included within two parallel lines 1/8 in. apart representing maximum frequency variations not exceeding one in 5000 or 4 cycles per second, or 3 meters when operating at 20,000 cycles and 15,000 meters.

Fig. 5 is a section of speed control ammeter chart from the New Brunswick station; the irregularities in this chart are due to various adjustments being made while in operation.

Fig. 6 is a section from a Speed Control Ammeter chart for one of the transmitters at the Radio Central Station.

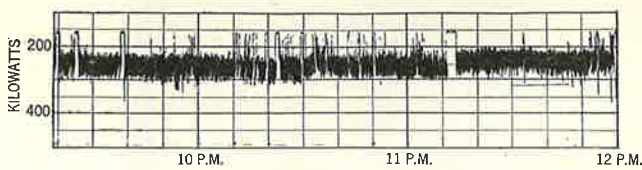



Fig. 7

Fig. 7 is the corresponding section of the wattmeter chart of the same transmitter.

### Receiving System

The centralized receiving system is located at Riverhead, Long Island. The antenna is of a new type which gives uni-directional reception. This system is so oriented as to receive signals from the over-ocean transmitter and annul signals from all other directions, including the powerful home transmitter nearby.

The antenna consists of two copper wires strung on ordinary poles like a telephone line, and extending over a distance of nine miles, (15,000 meters). This antenna feeds a number of separate receiving circuits of different wave lengths without the slightest mutual interference or weakening of the signals.

Important as it is, from the point of view of centralization, to be able to receive an indefinite number of signals from the same antenna, the greatest importance in the use of this new receiving system is its remarkable properties of suppressing atmospheric disturbances or the so-called "static" which hitherto has been the bane of radio communication. The attainment of these results is not an accident; it is the result of development work covering a number of years. The "wave antenna" as now used in Riverhead, is the practical answer to the receiving problem of today. The principle of directive reception has almost unlimited possibilities, and, by economic laws, the receiving system should be developed along these lines until its cost begins to equal the transmitting system. Then will the total cost of a complete circuit, transmitter and receiver, reach its ultimate minimum. However, this economic balance is far from reached as yet. The principles of reception by long antennas were laid down in two papers presented to the A. I. E. E. in 1919, one by Weagant describing a system of balanced long loops, and the other by Alexanderson describing a system of open wires balanced against each other.

In this development the controlling idea is a mental picture which we now have of the nature of the disturbance which we wish to suppress. We call it "static" because it was assumed, in the past, that it was of the nature of static electricity. The hypothesis which is the basis of our modern work is, however, different. We imagine the ether as a disturbed ocean with waves of every length rolling in from all directions. These waves are of the same nature as the signal waves. Those disturbing waves which are of different wave length from our signals, can be shut out by the same means as we use for shutting out other signals; that is, by tuning. But the disturbing waves which have the same wave length as our signal and are in all respects of the same nature, pass through our tuning system like the signal. We must therefore find some basis for discrimination other than wave length.

If we can construct a receiver which is sensitive only to waves coming from one direction, then we can shut out waves from all other directions, even if they have the same wave length. This idea started us on the work of directive reception. Theoretically, there is no limit to the improvement attainable in this direction. We might build a receiving antenna focussed on one transmitting station in Europe, but such receiving antenna would cover a very large area.

A complete theoretical analysis of the wave antenna has been given in a recent paper read this year before the A. I. E. E. by Messrs. Beverage, Rice and Kellogg. For those who wish only to understand the characteristics of our modern receiving system, in order to make use of it, the following popular explanation may be of some guidance.

Imagine the antenna to be a long, narrow lake, and that the wind is the incoming signal, and further that a cork, floating on the waves of water that beat against the shore is the detector. If the observer stands at one end of the lake, he will observe waves beating against his shore only when the wind blows lengthwise to the lake and from the end opposite to this location. When, on the other hand, the wind blows from his end of the lake, the beating waves appear at the opposite end, while his shore is calm. This, at least, would be the case if the lake has smooth sand beaches on which the waves could spend their energy without reflection. But, if the lake ends have steep rocky shores, the water waves will be reflected back and forth and thereby make the surface of the whole lake rough. The waves, which indicate the "signal wind," would thus appear at both ends of the lake, regardless of the longitudinal direction of the wind. This reflection must be avoided. The wave antenna is therefore made with ends corresponding to the sandy beach. The antenna terminates in a resistance which is carefully adjusted to absorb all wave energy and reflect none. The practical advantages of the use of the wave antenna are the elimination of about 90 per cent of the extraneous disturbances known as static.

A valuable practical feature of the form in which the wave antenna has been developed is the method of reflecting the signal so that the "surge resistance" which absorbs the static can be located in the receiving building. This is accomplished by erecting a two-wire line and making the same two wires function both as an antenna and as a transmission line for radio frequency waves. The two wires in parallel act as the antenna. At the far end of the line they are connected together through the primary winding of a special transformer. One end of the secondary of this transformer is connected to the middle point of the primary winding; the other end in connected to ground. The secondary winding feeds the current back into the two wires in series as a transmission line and a second transformer at the front end of the line couples the transmission line to the receiving set. The midpoint of the transformer winding connected to the lines is grounded through the "surge resistance." By this connection, the windings on the two halves of the transformer are opposed for currents flowing over the two wires in parallel, that is, for the antenna effect, and produce no effect upon the receiver.

The resultant reception characteristic curve shows that reception residuals of static of a few per cent may occur in certain directions in the back area of the diagram. The residuals are practically negligible in most cases, but when there is very strong interference or strong sharply directional static in their general direction, an appreciable improvement may be obtained by balancing the residuals to absolute zero for some particular direction in the back area. This is illustrated by Fig. 8.

The final balancing of static and interference is accomplished by the use of an artificial line. This line is fed by currents coming from only the same direction as the undesirable residuals. The phase of these currents may be made anything desired with respect to the phase of the residuals in the secondary of the transformer to which the surge resistance is connected. By making the intensity of the voltage on the artificial line the same as the residual voltage intensity, and by making the phase displacement 180 degrees, the residual currents are readily balanced for any particular direction in the back area.

With this antenna system, extremely satisfactory multiplex reception is being carried out at Riverhead.

Six sets of receiving equipment are normally coupled to this one antenna system, and the signals on six transoceanic circuits are separated by tuning, and copied simultaneously, each independent of the electrical operation of the other sets.

For this purpose, the antenna output transformer is built with several secondaries and the artificial lines are made up to accommodate a number of receiver sets. Many precautions are necessary in the design and arrangement of the receiving equipment to eliminate cross talk and "beat note" interference between the different sets. With this end in view, the equipment for reception of long waves has been completely remodelled.

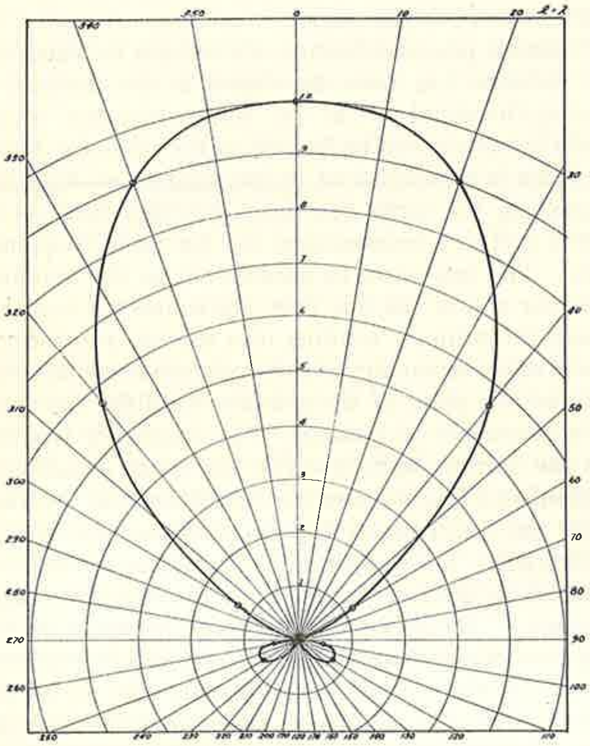


Fig. 8—Directive Curve of Wave Antenna

In the first place, all of the different elements in each receiving set must be thoroughly shielded. The tuning inductances are all balanced pairs of coils placed in an inner shielding of copper to eliminate the losses in the iron casing of the outer shield. In spite of the shielding, cross talk and beat note interference occurred until suitable chokes and filters were placed in both the positive filament and positive plate leads of all coupling tubes, amplifiers, detectors, and oscillators.

The receiving apparatus is arranged in line, with the antenna input panel at one end and the audio frequency output panel at the other end. The intervening units are placed in correct sequence so that the signal currents pass in progressive order along the line through all the various units from input to output panel without looping back over this same path.

The elements of a set are mounted on a sub-panel which is placed in an iron box, the front door of which may be opened. All adjustments of tuning and filament control which are likely to be made frequently on a set tuned to a fixed wave length can readily be made without opening the front door of the iron boxes because such control handles are mounted on the outer doors in such a manner as to engage with the controls on the sub-panel when the iron door is closed.

These receivers are set up on racks holding three sets per rack. Each set is arranged as a complete unit on a shelf and the shelves are arranged in three tiers on the racks. The Riverhead station is equipped with three racks making space for the accommodation of nine receiving sets.

Fig. 9 gives the general view of the receiving equipment.

The signals received from the wave antenna are strong; so usually a total of four stages of amplification is sufficient to bring the intensity of normal European signals up to a strength that is rather uncomfortable to the ear.

Since all the local long wave stations, except Marion, are either behind or in the case of Rocky Point, at right angles, to the direction from which the European signals come, directive reception alone lowers the intensity of the local stations so much that tuning can easily eliminate their interference. Interference as strong for instance, as that from Marion, can be eliminated when the wavelength differs by not less than 3 per cent. For interference of considerably less intensity than that from Marion, as for instance, that from stations in Europe, or from a local station, reduced by directive reception, a 2 per cent difference in wavelength is sufficient.

Fig. 9

For wavelength difference of 2 per cent and less the constancy of frequency of the transmitting station becomes of very great importance. Extremely good frequency regulation at the transmitting station will allow the use of filter circuits by means of which interference on wavelengths differing less than 2 per cent from that of the desired signal can be eliminated.

The receiving station at Riverhead, L. I., is about 70 miles east of New York and the next phase of the problem was the automatic transfer of the radio signals to the central control office in New York City in order to eliminate the double handling of traffic, the slowing up of the circuit, and the other delays inseparable from the older system. The requirements of this circuit were studied and then the American Tel. & Tel. Co. was requested to provide a suitable tone circuit from Riverhead to our Broad Street office, New York City. For a period of several months experiments were conducted over this temporary line, during which it was demonstrated that it was feasible to send these tone signals over a 70-mile circuit without detriment to the readability of the signals. Continuous commercial operation over a single tone circuit was started about July 1st, 1921. Subsequently additional tone circuits were built for the commercial operation and control of Riverhead station in this manner.

### Central Operating Room

The operating room at the city offices is the place where the written message is converted to the dot and dash of the Morse code. The continental code is used in radio as in all other international telegraphic communication. During the last few years a great change has taken place in the transmission of the message. Whereas formerly the manually operated telegraph key was used almost universally for speeds of transmission of 40 words per minute or less, this has been entirely displaced by the machine transmitter. The advantages of machine transmission over hand transmission are (1) that the operator is required to work a typewriter keyboard only and need not necessarily be a skilled telegraphist, (2) that one operator can transmit messages in this manner at rates up to 100 words per minute, whereas the best that can be done by hand is 35 or 40 words per minute, (3) that all characters are perfectly formed and do not vary with the different operators, and (4) the machine is tireless and has no lost time. The telegraphic manipulation is actually accomplished by first punching the message on a paper tape and subsequently passing the punched paper tape through the mechanical transmitter which is an automatically operated telegraph key.

The transmitter sends telegraph impulses over the control wires between the city office and the transmitting station and operates the relay system at that station.

In order that a check can be kept on the performance of the automatic transmitter, the control wires, and the relay system of the transmitting station, a radio receiving set is provided at the city office which makes audible or visible to the operator the actual signal being transmitted into the ether. This receiver is a very simple piece of apparatus, since the reception of the signal from the nearby high power transmitter is not at all difficult, although of course, as there are so many transmitters operating in one locality with only small wavelength separation, very efficient tuning equipment must be provided.

The reception of a message at the city office requires a reversal of the above process. The signal as received at the receiving station is in the form of audio frequency current, the frequency of which is variable as desired, these signal currents are transferred to the city office by telephone wires. At the city office it is necessary to further amplify the currents before they are introduced into the telephone or the recorder. It is possible to use aural reception at speeds up to 35 or 40 words per minute. Better speeds can be secured at times by a combination of aural and recorder reception. At speeds over 40 words per minute tape reception must be used exclusively. It is possible for some tape readers to copy as fast as 60 words per minute but generally for speeds over 40 words per minute; the work is divided up among an increased number of operators; 40 to 70 words per minute two operators; 70 to 100 words per minute three operators, and so forth. The development of the tape recorder used for transoceanic radio reception was ably described in a paper presented to the Inst. of Radio Engineers by J. Weinberger in 1921.

The electrical equipment of the operating room of a city office, handling a large number of circuits, requires careful planning. In the city office of the Radio Corporation of America at 64 Broad Street, New York City, there are at present in continuous operation,

6 transoceanic receivers
6 local Monitor receivers
6 automatic transmitters

and over 30 land wires. To these will soon be added a number of new services.

Power supplies of different types are provided for the various electrical and mechanical devices and measures have been taken to prevent inductive interference effects between instruments.

### Wavelength Distribution

The economical wavelength for communication over a certain distance can be selected by the practical rule that the economic range of a station for reliable communication is about 500 to 1000 times the wavelength. If too short a wave is selected the signals will be weak in daytime and strong but variable at night. This variation is most noticeable during the period when darkness exists over the area between the communicating stations. In some parts of the world it is possible to use short waves to advantage because the absorption is comparatively lower than on long waves and variations are unimportant but generally speaking for distances over 3000 miles the reliability of wavelengths of over 11,000 meters is so much greater than that of shorter waves. Long waves have therefore been universally adopted for long distance communication.

It can now be readily seen that since the ability to receive distinct signals depends on the separation of different frequencies there is a definite limit to the number of "channels" of communication between stations that can be set up.

If the wavelengths between 11,000 and 22,000 meters are divided into 2 per cent bands there are 35 "channels." If into 1 per cent bands, there are 70 "channels." Except to such extent as directional reception will permit the number of one way channels open for such, long distance communication is limited to the number of these bands.

If we suppose our plans to be based on the use of 1 per cent bands, it is evidently necessary first that each transmitter shall cause no radiation outside of the 1 per cent band allotted to it and furthermore shall maintain its actual radiation frequency exactly on the center of such band; and second that each receiver shall be capable of separation of currents from those differing only 1 per cent in frequency. The above requirements imposed upon the transmitter have already been proved practicable. But the realization of the full possibilities of radio communication requires that all transmitters of antiquated type which take undue space in the ether be replaced.

There are, however, other difficulties that cannot be so easily overcome. For instance while it is quite possible for the receiving station to separate currents of frequencies differing 1 per cent if the voltages induced at the station at the different frequencies are equal, it is not an easy matter to separate the currents when the voltage induced in one case is 1000 times the voltage induced in the other. This is the situation where in the case of a transatlantic circuit the receiving station in America receives from Europe on 15,000 meters and the transmitting station in America sends to Europe at the same time on 15,150 meters. In such cases, as described above, it is necessary to increase the separation between frequencies to 3 per cent and in order that such large separation may not be too numerous a rule has been established by precedence and informal agreement, that all the transmitters in one locality shall transmit on wavelengths close together. We have such a case in the concentration of American transmitters between 16,000 and 17,500 meters. In this band of wavelengths there are operating at present the following stations:

15,900 Meters Tuckerton No. 1 Transmitter
16,300 Meters Kahuku No. 1 Transmitter
16,465 Meters Radio Central No. 1 Transmitter
16,700 Meters Tuckerton No. 2 Transmitter
16,975 Meters Kahuku No. 2 Transmitter
16,975 Meters Annapolis Compensating Wave Arc
17,145 Meters Annapolis Signalling Wave Arc
17,500 Meters Radio Central No. 2 Transmitter

It is planned to operate transmitters in Sweden, Poland and Argentine in the near future on wavelengths 18,000 meters to 19,000.

The French Government station at Lyon operates at 15,500 meters and there are a number of additional European and American Transmitters operating between that wavelength and 11,000 meters, while other Government and Commercial stations in France are at present operating at wavelengths from 19,000 to 22,000 meters.

The congestion of the ether is therefore not a mere matter of looking into the future, but a real present day problem. The necessity for traffic regulation is at least enough to prevent reckless driving so to speak, is just as apparent as the undesirability of hidebound regulations until such time as the limit of possible improvements in technique have been more definitely determined.

Such is the present situation in the long distance radio ether. The congestion is due to the necessity for the use of the longer waves for long distance work and the fact that all high-power stations are broadcast

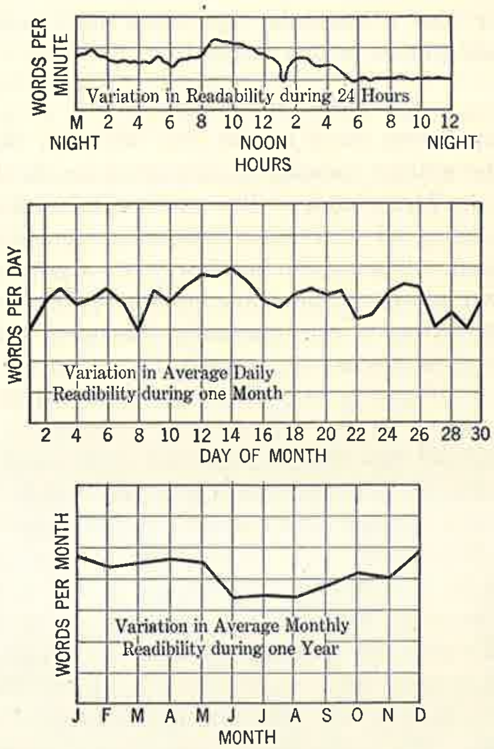



Fig. 10

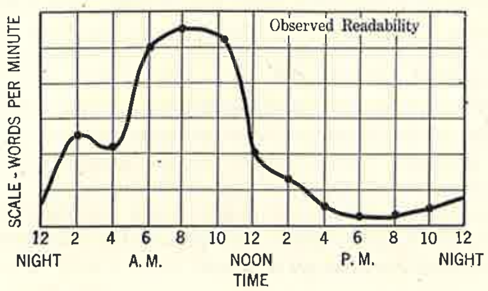
stations; much improvement is possible in existing practise but radically new methods of operation must also be considered, such for example as directional radiation on shorter waves. With the realization of such possibilities the situation will take on a new aspect.

## Project of New Communications

Sufficient statistics are now available by means of which the technical and financial possibilities of new circuits of communication can be accurately predetermined.

Fig. 10 shows the daily, monthly and yearly reception curves for a typical transatlantic circuit. The ordinates of these curves show the capacity of the circuit at the different times of the day and year respectively. By the capacity of the circuit we mean the practically possible speed of reception in five-letter code words per minute. The capacity of the circuit is a function of the strength of the signal and the intensity of the disturbance. The intensity of the signal is measured in absolute units of microvolts per meter.

Experience has shown that under any given condition of atmospheric disturbance, there is a direct proportionality between the strength of the signal measured in microvolts per meter and the traffic capacity of the circuit measured in words per minute. The proportionality defined above is almost exact between the



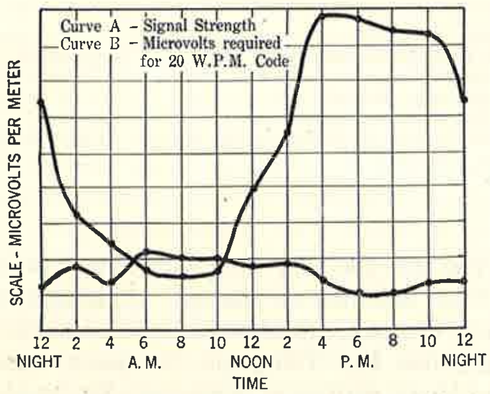




Fig. 11—Typical Daily Variation of Signal and Disturbances on Vertical Antenna During Summer Months at Belmar, N. J.

limits of oral reception ranging from 5 to 40 words per minute and it can be considered as substantially correct up to the highest speeds that are used. This simple relation between strength of signal and words per minute has given us a practical method of measuring the intensity of atmospheric disturbances.

As an actual standard method of measurement an artificial signal is introduced into the receiving system and regulated so that the capacity of the receiver is 20 words per minute. The number of microvolts per meter which must be introduced to permit reception at 20 words per minute is thus a direct measure of the intensity of disturbance.

Fig. 11 shows a typical daily curve of variation of signal strength and disturbance, measured on a simple vertical antenna.

If a transmitting station is to be designed for a new geographic location, measurements of disturbances are taken in that location. The results of these measurements, which may be taken over a large part of a year, show what strength of signal will be needed during the different months of the year to carry a desired traffic. Fig. 12 shows a typical chart of this kind. Comparison between this chart and the known typical yearly chart for a transatlantic circuit gives a direct indication of the capacity of the new circuit in terms of the circuit in operation. The chart for the projected circuit shows the capacity of a 50,000-meter ampere and of a 100,000-meter ampere transmitting station.

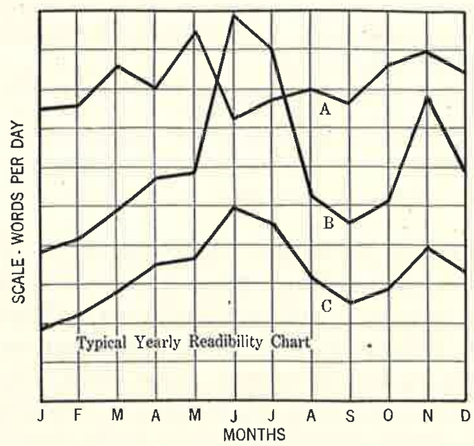



Fig. 12

Curve A — Typical East-West circuit.
Curve B — Typical North-South circuit. Calculated for 100,000 M.A.
Curve C — Typical North-South circuit. Calculated for 50,000 M. A.

Thus it can be stated that guess work has been eliminated from the development of radio communication, and that sound foundations, both technically and financially, can be laid for all future expansions of our system.