

A Magazine Devoted Exclusively to the Radio Amateur

The Wave Antenna for 200-Meter Reception

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For a year now QST has been endeavoring to secure reliable information on the so-called Beverage Wire or wave antenna, which for special purposes is the best arrangement known today. With the approach of our Transatlantic Tests the matter became of even greater moment and we appealed to the Engineering Department of the Radio Corporation of America. They had never done any practical work with it on amateur wave-lengths but very courteously arranged for a series of special tests at their Belmar station, where engineers were sent and numerous lengthy tests conducted on this special subject. The following article, written especially for the A.R.R.L. and QST, is the result. It is absolutely a classic in the literature of amateur radio, and we are very proud of it. We acknowledge our gratitude to the Radio Corporation and its engineers for their very kind co-operation.

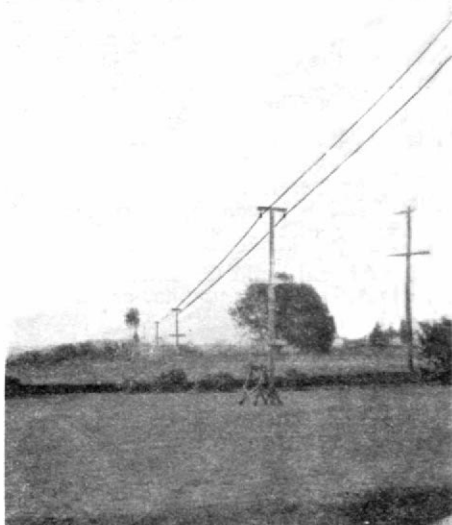
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THE Wave Antenna is a new type of unidirectional antenna which has been developed by the author and Messrs. Chester Rice and E. W. Kellogg of the General Electric Co., and is covered by patents and applications. This antenna has been in existence for some time, but was first brought to the attention of the amateurs by Mr. Paul F. Godley, who described it in his report on the reception of American amateurs at Ardrossan, Scotland. The full theory of this antenna is scheduled to appear in an A.I.E.E. paper for the Pittsburgh convention in November, so this paper will be confined to very elementary theory and practical considerations.

Theory

If a wire is suspended in space, it has a certain capacity and inductance per unit length which bear a definite relation to each other. This relation may be expressed as $1/\sqrt{LC}=V$, where V is a constant. This constant is the velocity of light. For example, if L and C are expressed as the capacity and inductance per meter, then $V=3 \times 10^8$ meters, which is the velocity of light in meters per second. If a larger wire is used, or if two or more wires are used instead of one, in the ideal case the inductance decreases in the same ratio as the capacity increases, so that $L \times C$ is always a constant. This means that, for the ideal wire, the currents induced in that wire will always travel along it at the velocity of light, independent of the size or number of wires.

A practically-constructed wire must be supported at several points and must run



One of the "Beverage Wires" erected at Belmar for these tests.

horizontally within a few feet of the earth. The effect of the supporting insulators and the proximity of the earth is to

increase the capacity in a greater ratio than the inductance decreases, so the velocity of the currents on a practical wire is always somewhat less than the velocity of light. On short wave-lengths, however, the velocity approaches very close to the velocity of light, generally between the limits of 85% and 98% of the velocity of light for 200 meters, depending upon the size and number of wires.

In order to make the antenna unidirectional, it is necessary to stop the reflections at the end farthest from the receiver end. This is accomplished very simply by placing a non-inductive resistance between the antenna and ground at the far end. If this resistance is made equal to the "Surge Impedance" of the wire, it absorbs all of the energy and prevents any of it from being reflected back to

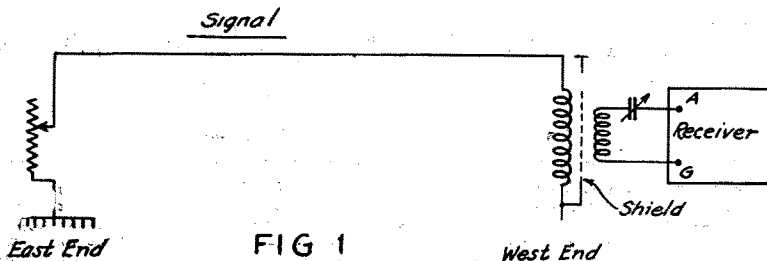


FIG 1

In Figure 1 is shown the simplest form of Wave Antenna. It consists simply of a wire, at least one wave-length long, stretched in the direction of the transmitting station. For explanation purposes, it may be assumed that the transmitting station is east of the receiving station, and that the receiver is placed at the west end of the antenna, as shown. The travelling wave from the transmitting station moves from east towards the west at the velocity of light. As the wave moves along the antenna, it induces currents in the wire which travel in both directions. The current which travels east moves against the motion of the wave and builds down to practically zero if the antenna is one wave-length long. The currents which travel west, however, travel along the wire with practically the velocity of light, and, therefore, move along with the wave in space. The current increments all add up in phase at the west end, producing a strong signal, as shown by curve A in Figure 2. In like manner, static or interference originating in the west will build up to a maximum at the east end of the antenna, as shown by curve B in Figure 2.

If the east end of the antenna were open or grounded through zero resistance, all of the energy represented by curve B would be reflected and would travel back over the antenna to the west end, where part of the energy would pass to earth through the receiver and part would be reflected again, depending upon the impedance of the receiver winding. The horizontal plane intensity diagram would be bi-directional, as shown in Figure 3. The reception from the west is not as good as from the east because some of the energy is lost due to attenuation in the wire as the reflected wave travels back from east to west.

the receiver. The intensity characteristic becomes unidirectional, as shown in Figure 4.

The value of the surge impedance depends upon the size, number, and height of the wires above ground, but is independent of the length of the wire. For practical construction with one or two No. 12 copper wires, the surge impedance lies between the values of 200 and 400 ohms. The surge impedance is theoretically equal to $R = \sqrt{L/C}$, where L and C are the inductance and capacity per unit length.

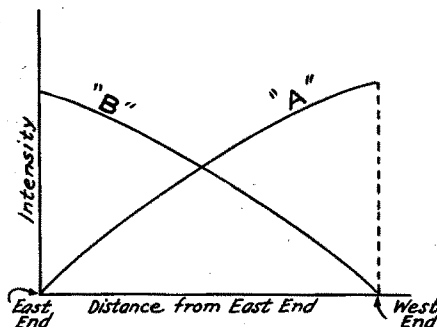


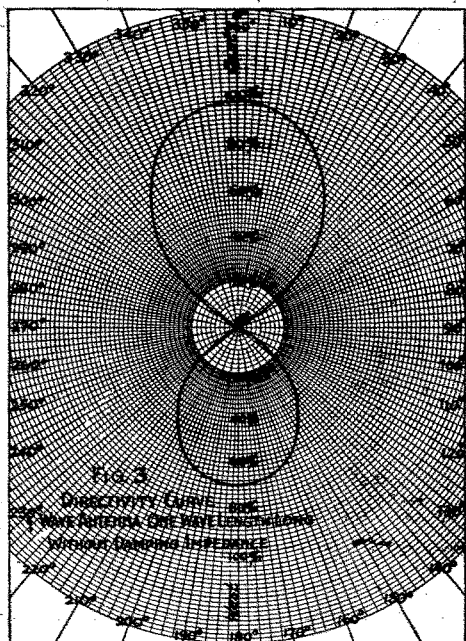
FIG. 2

Godley used the simple form of wave antenna, as shown in Figure 1. However, this is not the most practical form as it is necessary to go to the far end to make adjustments of the damping resistance.

Feed-Back Antennae

If two parallel wires are used, the wave antenna becomes very flexible and the receiver may be placed at either end with local control of the damping. In Figure 5, for reception from the east, the receiver

at the west end is replaced by the primary P of a transformer T_1 . The primary is coupled to the secondary S as closely as possible, and feeds the energy over the two wires as a transmission line. A second transformer T_2 at the east end feeds the energy from the transmission line into the receiving set. The energy fed over the transmission line circulates around the line

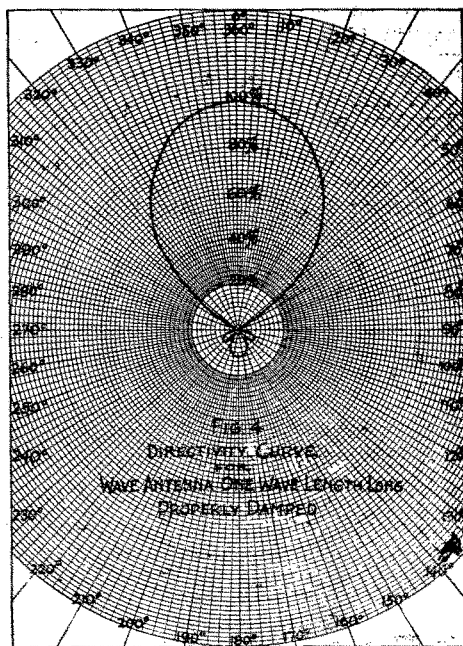


as in an ordinary metallic-circuit telephone line, and, therefore, the currents pass through both halves of the primary of T_1 in the same direction, inducing voltages in the secondary which feeds into the receiving set. On the other hand, currents coming over the wires as an antenna, that is, from the west, are equal and in phase on both wires, and upon passing to ground through the two halves of the primary of the output transformer T_2 , they pass through the winding in opposite directions and neutralize. With this circuit, the energy reaching the receiver is the same as it would be if the receiver were placed at the west end, excepting for the transmission line losses, which ordinarily are 20 to 25% with proper design. With this feed-back system, the operator can make adjustments of the surge resistance without leaving the station, and can listen to the signals while he is making the adjustments.

Figure 6 is equivalent electrically to Figure 5, but in this case the transformer T_2 has been replaced by a simpler circuit. By grounding one wire and leaving the other wire open, the energy is reflected on

each wire, but the reflected currents on the transmission line are 180 degrees out of phase on the two wires, and, therefore, a difference of potential exists across the terminals of the primary of transformer T_1 , exactly the same as when the reflection transformer T_2 of Figure 5 was used. If the ground resistance at the reflecting end is zero, the reflection of energy with the connections of Figure 6 would be 100% efficient, and the only loss would be the transmission line losses. The open-ground reflection connection is preferable to a transformer, on short wave-lengths particularly.

It is possible to damp a two-wire antenna from either end. In the case of Figure 6, the signal from the east built up to a maximum at the west end, and was then reflected up to the east end, where the receiver and damping circuit were placed. In the case shown in Figure 7, the receiver is placed at the west end as in the case of the simple antenna of Figure 1. Instead of placing the damping circuit at the east end, however, it is placed across the transmission line at the west end where the receiver is. This damping circuit is practical-



ly just as effective as it would be if actually placed at the far end. This circuit also has the advantage that the desired signals do not pass over the transmission line, and the transmission line losses are avoided.

In order for the damping circuit to be effective, it is necessary that the two wires of the antenna be joined through an in-

ductance which is of high impedance compared with the impedance of the damping circuit. The best way to accomplish this result is to use a coil with a mid-point tap, as shown at *N* in Figure 4. With respect to the transmission line, the two halves of this coil are adding, so the inductance across the line is high. With respect to the receiver, however, the two halves of the coil are opposing, so that the impedance in series with the output transformer amounts only to the leakage reactance of the coil *N*, which can be made very small. A satis-

eliminate. This is made possible by making the damping-circuit reactance, either slightly capacitive or slightly inductive, instead of purely resistive. In some cases it may be desirable to reflect a small amount of energy to neutralize undesirable signals from the back end. This is readily accomplished by adjusting the resistance and capacity of the damping circuit. The capacity and inductance in this damping circuit are usually found to practically neutralize each other for the best adjustment; that is, they should tune approxi-

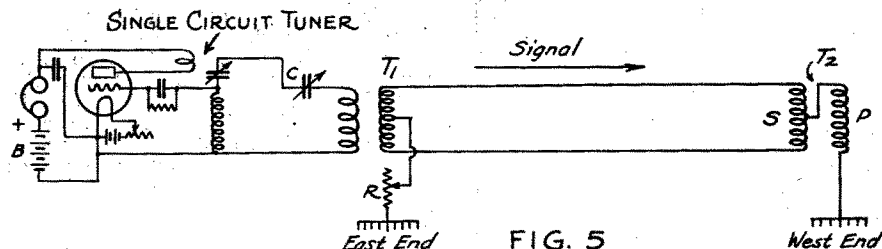


FIG. 5

factory coil for *N* for 200 meters was a 24-turn coil seven inches in diameter, with a tap at 12 turns for feeding the output transformer *T*. This coil was about 0.3 millihenries across the line, or 1900 ohms at 300 meters, and nearly 3000 ohms at 200 meters, which was high enough to have no appreciable influence on the damping circuit, and yet had low enough leakage reactance to allow the signals to pass to the receiver without noticeable weakening.

mately throughout the band of wavelengths it is desired to receive. If the wave-length being received is varied over wide limits, it is necessary to readjust the damping circuit condenser for best results, although the adjustment is usually quite broad. The resistance does not need readjustment except in special cases.

For a range of 180 to 360 meters, the damping circuit consists of an inductance of about 0.08 millihenries, a variable con-

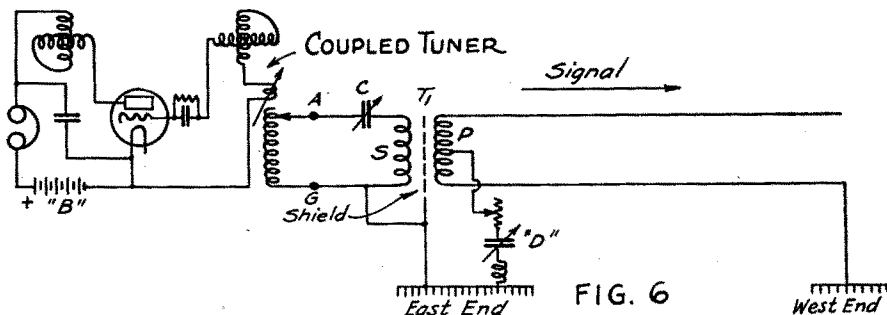


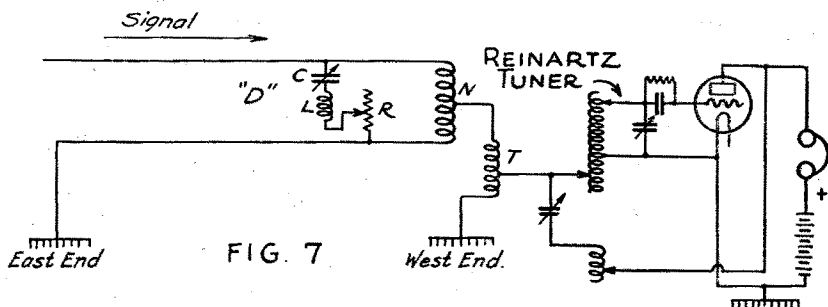
FIG. 6

Damping Circuits

In Figures 6 and 7, damping circuits "D" are shown which consist of resistance, inductance, and capacity, in series. Due to distortion on the antenna, to back-wave effects, to interfering signals or static coming from such a direction as to be received on one of the little "ears" on the back of the antenna, as shown in Figure 4, etc., it often happens that there are appreciable residuals which it is desirable to

denser of 0.0015 mfd. maximum capacity, and a non-inductive resistance variable in steps of one ohm from 0 to 500 ohms. A General Radio decade box is ideal for this purpose. However, ordinary resistance wire potentiometers, inductively wound, have been used with entire success in damping circuits. It is necessary to select a potentiometer with sufficiently low inductance to tune well below the shortest wave it is desired to receive; then the induct-

ance of the potentiometer is taken into account when calculating the value of inductance to be used in series with the resistance and capacity. In this manner the inductance of the potentiometer used for the variable resistance may be tuned out, and the damping circuit may be made pure resistance for any one particular wave-length.



When the damping circuit is placed across the transmission line as shown in Figure 7, the value of the damping resistance may vary considerably with wave-length, becoming lower for short wave-lengths, due to the increase in attenuation at short wave-lengths partially damping the antenna. In other words, the transmission line acts as a resistance in series with the damping circuit, and the transmission line resistance becomes appreciable at short wave-lengths.

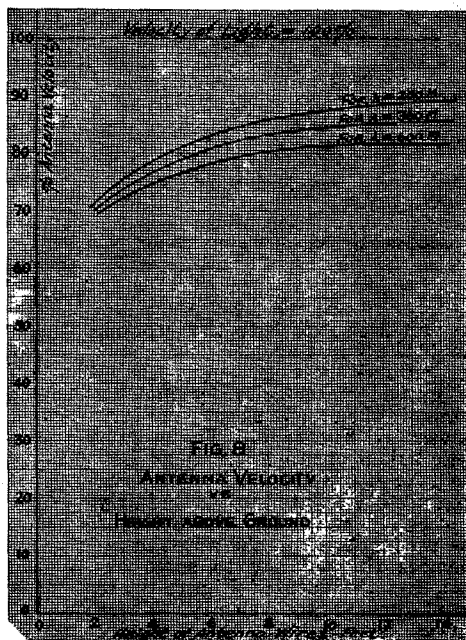
Antenna Design

It is obvious from the theory of the wave antenna just given that it must either point towards the desired signals or that it must point directly away from the desired signals. In case the antenna is pointed away from the signal, then the maximum signal occurs at the far end and must be brought up over the transmission line to the receiver, as shown in Figure 6. In case the antenna is pointed towards the signal, it is necessary to put the damping circuit on the transmission line, as shown in Figure 7. It is possible to use a single antenna for reception from either direction by switching arrangements to change to either the connection of Figure 6 or that of Figure 7 at will. It is preferable on short wave-lengths to point the antenna towards the signal, using the connections of Figure 7, but the feed-back of Figure 6 gives practically the same results, excepting that the signals are not quite as loud due to the transmission line losses.

It is necessary to run the wave antenna in as straight a line as possible and not nearer than 200 feet to other parallel wires, such as telephone and power wires, as the influence of these wires is liable to distort the directive characteristic of the antenna.

Other wire lines may be crossed at right angles without undesirable effects. In cases where it is not feasible to run the wave antenna in line with the desired signals, it is possible to get good reception with the antenna somewhat off line by sacrificing signal intensity. By referring to Figure 4 it is seen that for the average antenna one wave length long it is possible

to be 45 degrees off line before the signal drops to half intensity. Beyond 45 degrees the signal falls off very rapidly. Twenty degrees off line, the signal intensity has fallen off only 10%, so very good reception may be obtained. If the antenna is two



wave-lengths long, it is more directive, and it is not possible to receive well if it is more than 25 or 30 degrees off line.

The antennae are constructed of copper or other non-magnetic material, although

Mr. Cutler of 7IY reported in the October QST that he has obtained good results on a galvanized iron wire. The size of the wire is usually between No. 10 and No. 14 B.&S., although it is possible to get fair results even with No. 18 bell wire. The usual construction is to put up two wires

end is so far behind in phase that it not only does not add to the increments from points close to the receiver, but may actually subtract. The maximum length that it is feasible to use is that length at which the current in the wire lags 90 degrees behind the wave in space. This length is given by the formula:

$$L = \frac{\lambda}{4 \left(\frac{100}{C} - 1 \right)}$$

where

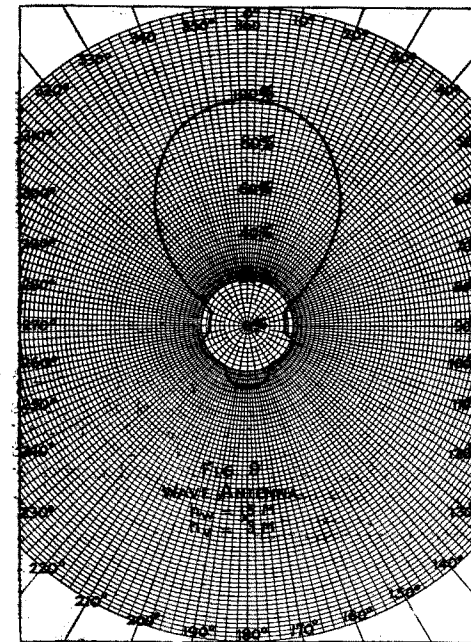
λ = wave-length in meters.

C = signal velocity on antenna expressed in per-cent velocity of light.

For example, from Figure 8 we find that the velocity of the currents in the two wires suspended at a height of 10 feet is about 88% of the velocity of light for 200 meters, so the maximum usable length is:

$$L = \frac{200}{4 \left(\frac{100}{88} - 1 \right)} = \frac{200}{.544} = 367 \text{ meters.}$$

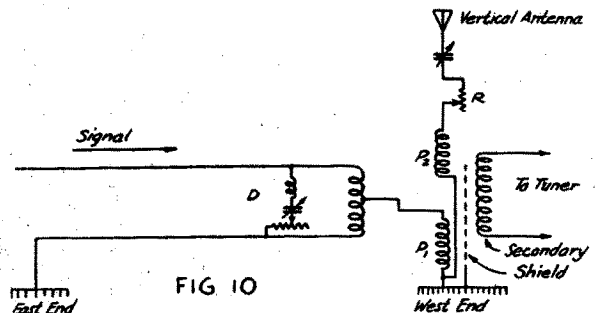
Therefore it is not feasible to use a two-wire antenna suspended at a height of 10 feet more than two wave-lengths long for 200 meters. By increasing the height, the velocity will increase, and longer wires may be used. Figure 8 shows that the velocity increases slowly with height above 10 feet, so the wires must be much higher to be of material advantage. Making the wires too high introduces a difficulty on short waves which does not occur on long waves, and that is the "end" or vertical-antenna effect. The effective height of a 200 meter wave antenna is about 5% to 10% of its horizontal length, depending upon the nature of the earth beneath the antenna, etc. If an antenna is 200 meters long, therefore, its effective height will be between 10 and 20 meters. If the antenna



on a cross arm about two to three feet long. The wires are suspended by porcelain cleats, or in more permanent construction standard telephone pins and high grade insulators are used.

The height of the wires above ground has a marked influence on the velocity of the currents along the wires when the wires are close to the ground, but if the wires are ten feet above the ground there is very little to be gained in velocity by making them higher, as shown in the curves of Figure 8. These data were taken on an antenna at Belmar, N. J., by Mr. H. O. Peterson. This antenna extended over fairly conducting soil. The character of the soil underneath the antenna influences the velocity to some extent, but the data of Figure 8 are about the average velocity. These curves show that the velocity becomes lower at longer wave-lengths.

If the velocity is too slow, then the currents in the wire lag in phase behind the wave in space, and a point is soon reached when the current in the wire from the far



is on supports 10 feet high, the vertical or end effect may be equivalent to an effective height of nearly 3 meters, distorting the directive curve. In Figure 9 is shown

the directive curve of a wave antenna of 15 meters effective height with a vertical or end effect of 3 meters superimposed upon it. It will be noted that the end effect may mount up to very serious proportions if the antenna is made too high. It is, however, possible to balance this end effect by means of a separate vertical antenna, as shown in Figure 10. P_1 is the standard primary, while P_2 is a second primary coil of about the same number of turns, which is wound over P_1 but in the opposite direction. How-

the Westinghouse RC or the General Electric AR-1300 tuner. For 200 meters, it is usually better to use a separate condenser C outside of the tuner condenser, as shown in Figure 5, but for longer wave-lengths this series condenser may be omitted.

When the circuit of Figure 7 was used, the transformer described above was used with success but better results were obtained by cutting the primary turns down to 15 turns instead of 20 turns. This transformer is shown in Figure 1, but may be used with the connections of Figure 7. A tinfoil shield is used between primary and secondary, and is grounded as shown. In all of these transformers the coupling between primary and secondary should be as close as possible.

In Figure 7 an auto-transformer T is shown. The total turns are 15, and the receiver is tapped off at 5 turns. The diameter of the turns is 7 inches, but smaller diameters have been used by increasing the number of turns to make the same inductance. This auto transformer connection has been adapted to a Reinartz tuner with excellent results by Mr. Bourne at 2BML.

Determination of Surge Resistance and Velocity

The velocity and surge resistance were easily determined by oscillator tests. An oscillator was coupled to the antenna, as

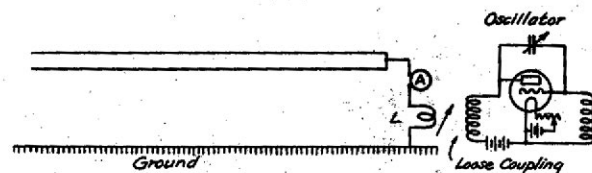


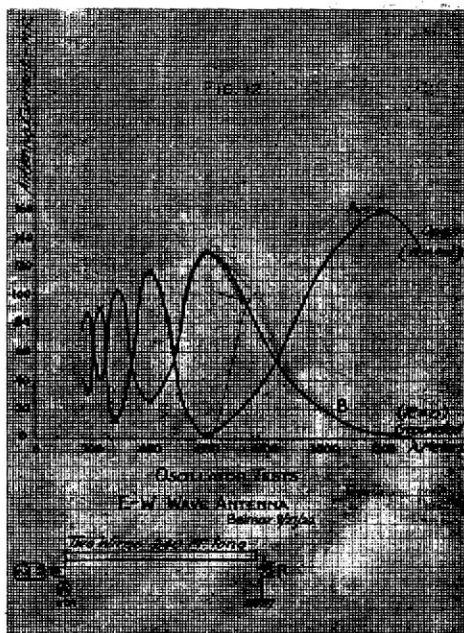
FIG 11

ever, in practice, the end effects seem to be very much smaller than predicted theoretically, so as a general rule if the antenna is not over 10 feet high the end effects are so small that it is not worth the trouble to balance them. From the above considerations, it is evident that 10 feet is a good average height for short wave antennae.

Design of Transformers

With the feed-back circuit of Figure 6 only one transformer is necessary. The output transformer T_1 was made up on a 7-inch cardboard tube. The primary P was 20 turns of No. 24 B.&S. D.C.C. copper wire, with a tap at ten turns or the exact center. Over the primary was placed a shield consisting of a piece of tinfoil insulated from both windings by paper. This shield was grounded to cut out capacity currents between primary and secondary. It is important that the tinfoil be not quite a complete turn around the primary; the ends must not touch or it will act as a short-circuited turn and introduces high losses. The secondary consisted of five turns of No. 18 bell wire wound over the tinfoil shield. The center of the secondary winding was lined up carefully over the center of the primary winding; otherwise the transformer would not be balanced. With the circuit of Figure 6, the transformer balance was tested by opening both wires at the west or reflection end. When the transformer T_1 was properly balanced, the receiver was quiet, indicating that the two halves of the primary were perfectly symmetrical with respect to the secondary.

Transformer T_1 of Figure 6 was designed to work with a coupled receiver. The secondary of the output transformer was connected in series with the primary of the receiver and was tuned by the series condenser C . This same transformer can also be used with a single-circuit tuner like



shown in Figure 11. In the antenna circuit was included a coupling coil *L* consisting of only two turns! The far end of the antenna was left open for the first test, and a resonance curve of the antenna was taken. The curve is plotted as Curve A in Figure 12. Then both wires of the antenna were grounded at the far end and the resonance curve taken again. This curve is plotted as Curve B in Figure 12. In order to find the velocity, it is necessary to calculate what the resonance points would be if the velocity of the currents on the wires was equal to the velocity of light.

The length of the antenna was carefully measured. In the case of this particular antenna at Belmar, the length was 240 meters. Assuming that the velocity of the currents on the antenna is equal to the velocity of light, the first resonance point with the far end of the antenna open will be the quarter-wave oscillation as in an ordinary antenna. The wave-length will be $4 \times 240 = 960$ meters. The next resonance point will be the three-quarter wave oscillation, or $4/3 \times 240 = 320$ meters. The next will be the 5/4 oscillation, or $4/5 \times 240 = 192$ meters, etc., for all odd multiples of the quarter wave oscillation. In like manner, with the far end of the antenna grounded the antenna will oscillate at all even multiples of the quarter wave oscillation. These calculated values are recorded in the table below. In the next column, the observed values taken from Figure 12 are recorded. By dividing the calculated value by the observed value, we get the actual velocity at that particular wave-length in terms of per-cent of velocity of light.

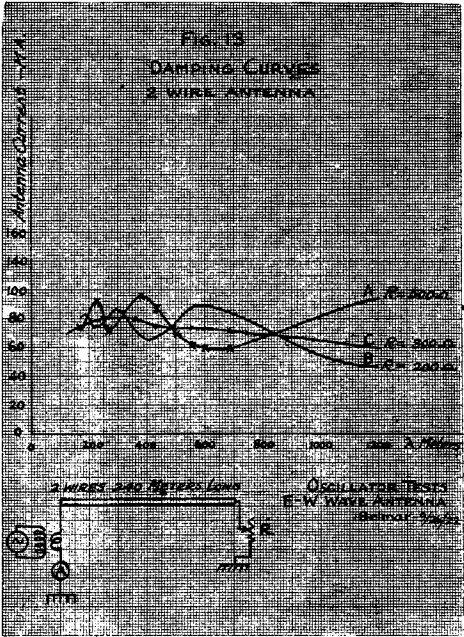
Calculation of Velocity of Currents on Antenna

Length=240 meters, 2 No. 10 wires, 3 meters high.

Mode of Oscillation	Wave-length Calculated	Wave-length Observed	Velocity on Wires Velocity of Light
1/4	960	1200	80%
2/4	480	590	81%
3/4	320	390	82%
4/4	240	280	85%
5/4	192	220	87%
6/4	160	180	89%

To determine the surge resistance, a non-inductive resistance was placed between antenna and ground at the far end, and the resonance curve taken again. Figure 13 shows the results of this test on the Belmar antenna. Curve A, with 500 ohms at the far end, shows broad but unmistakable resonance points at open oscillation wave-lengths. On the other hand Curve B, with 200 ohms at the far end, shows grounded resonance points. Curve C, with 300 ohms at the far end, shows no resonance points, indicating that the antenna is quite aperiodic. Therefore the

surge resistance for this particular antenna is approximately 300 ohms. The downward bend of Curve C below 200 meters is not due to the antenna but is due to the oscillator output falling off when the coupling condenser approached zero.



When one of the wires was grounded at the far end and the other wire was left open, and the damping resistance was placed across the wires at the station end, as shown in Figure 7, a smooth curve, similar to Curve C of Figure 13, was obtained when the non-inductive resistance was 500 ohms. In this case, however, there were slight irregularities in the curve which do not appear in Curve C of Figure 13.

Figure 14 shows the resonance and damping curves taken on a single-wire antenna by Mr. R. B. Bourne at 2BML-2EH. This wire was 195 meters long, and was suspended from trees at a height varying from 15 to 20 feet. It is interesting to note that Mr. Bourne's antenna has a velocity of approximately 93% of the velocity of light at 200 meters and, therefore, shows that a single wire may be used up to a length of over three wave-lengths or approximately 2000 feet. Such an antenna should show very directional properties, but lacks the flexibility and ease of adjustment of the two-wire antenna.

Performance

Two 200-meter wave antennae were erected at Belmar, one running west from the station, and the other running south.

These antennae were arranged with switching such that the connections of Figure 6 or Figure 7 could be selected at will on either antenna. That is, the west antenna could be used for reception from either the east or the west, and the south antenna could be used for reception from either north or south. For comparative purposes a flat-topped single-wire antenna 40 feet high was erected. The effective height of this vertical antenna was estimated as approximately 8 meters. The signals on the wave antennae were about 50% stronger than on the vertical, giving an effective height for the wave antennae of 12 meters. This figure corresponds to about $5\frac{1}{2}\%$ of the horizontal length of the wave antennae.

Listening tests on these antennae showed marked directive properties, as expected. Listening south, most of the stations heard were in the 3rd and 4th districts, but careful adjustments were necessary to eliminate 2nd district stations to the north. With the antenna directive towards the

was excellent, great numbers of 3rd, 8th, 5th, and 9th district C.W. stations being heard without interference from 1st and 2nd district stations. With the antenna directed east, only local 2's, Long Island 2's, and a few 1's were heard. There was considerable static reduction at times on the eastward reception, as the static was often heavy in the south or west.

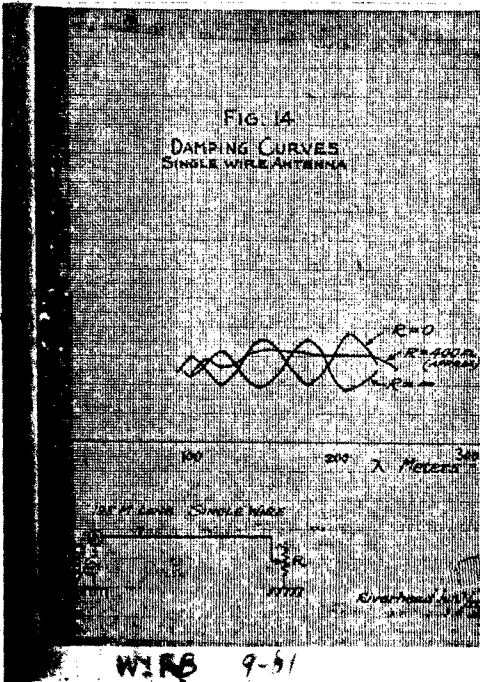
On the 360-meter broadcast station wavelength, very good results were experienced in eliminating interference, particularly when using the antenna for west reception, and cutting out New York and Schenectady interference. Station WOC at Davenport, Iowa, was received particularly well on the wave antenna at times when reception was impossible on the vertical antenna due to local interference.

Even on 600 meters, these wave antennae showed very good directivity, particularly for reception from ships at sea.

Mr. Bourne's antenna at Riverhead, L. I., runs in a direction about ten degrees north of west. He reports his results as follows: "Signals from the south and southwest come in with about 25% to 50% increase in signal strength over a vertical antenna 60 feet high. Signals from New England are, in general, very weak, and in some cases cannot be heard at all when using the wave antenna. No interference from ships, or shore stations using commercial wave-lengths has been noticed. WSA, at Easthampton, about 20 miles away, at times has a very strong harmonic on about 225 meters, which interferes seriously with 200 meter reception when the ordinary antenna is used, but due to the fact that this station is southeast, no interference is experienced when using the wave antenna. Radiophones on 360 meters come in with about the same intensity as with the vertical antenna, but often the signal-static ratio is much improved with the wave antenna, and, as with 200 meter reception, interference from WSA and WBC (East Moriches, 10 miles away) is entirely done away with."

The amount of static reduction experienced with the 200-meter wave antenna at Belmar depended entirely upon the distribution of the static at different times. On several occasions very marked improvement was noted in the signal-static ratio when receiving from the east and north, and sometimes when receiving from the west, but it was rarely observed to make any marked improvement when receiving from the south.

The author wishes to acknowledge the valuable assistance received from Messrs. H. O. Peterson, R. B. Bourne, and A. B. Moulton, in the collection of these data on the 200-meter wave antennae.



north, the best reception was from the 1st and 2nd districts, although several 8th district stations were heard. The east-west antenna worked better than the north-south antenna, probably because the ground resistance at both ends was less than an ohm, whereas the ground resistance at the far end of the north-south antenna was very high, nearly 300 ohms, making it difficult to operate the damping circuit effectively. The reception from the west