July 28, 1931. R. H. RANGER 1,816,614

WAVE ANTENNA

Filed Feb. 9, 1923 2 Sheets-Sheet 1

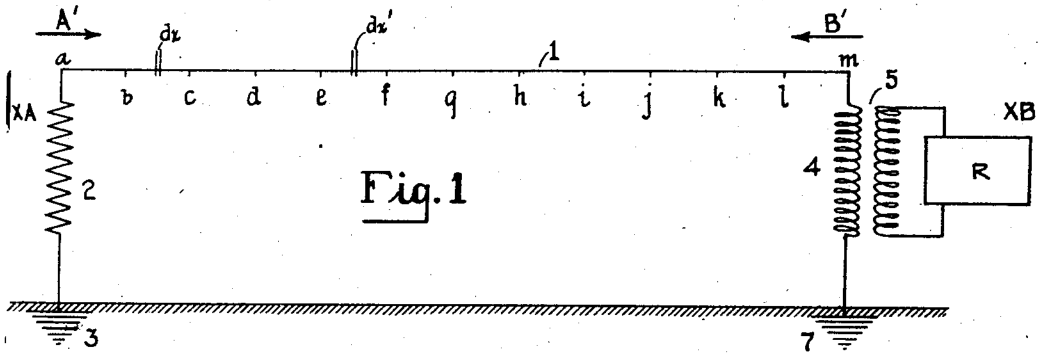

Fig. 1

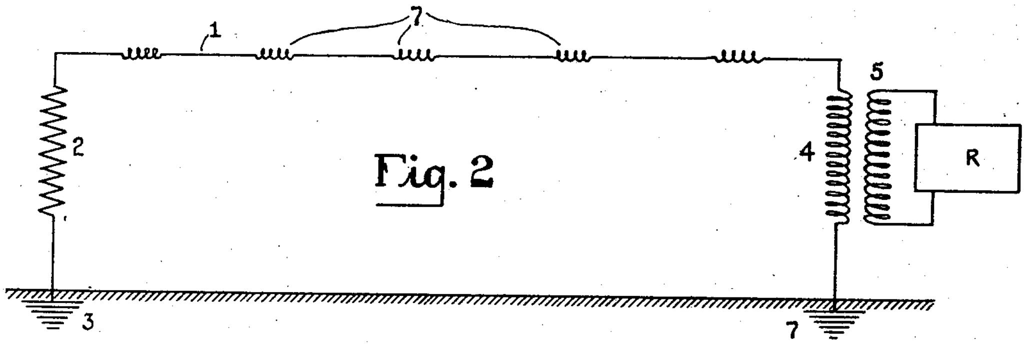

Fig. 2

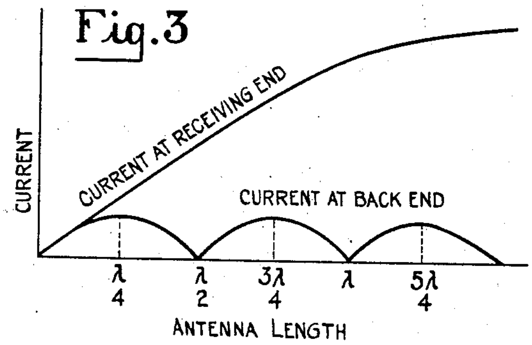

Fig. 3

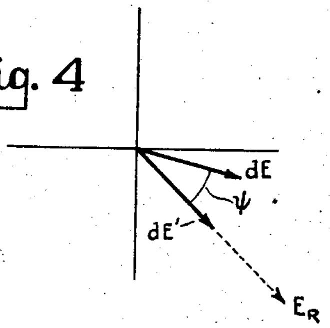

Fig. 4

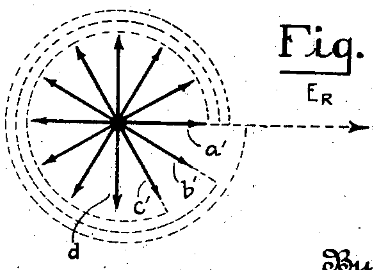

Fig. 5

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July 28, 1931. R. H. RANGER **1,816,614**

WAVE ANTENNA

Filed Feb. 9, 1923 2 Sheets-Sheet 2

Fig. 6

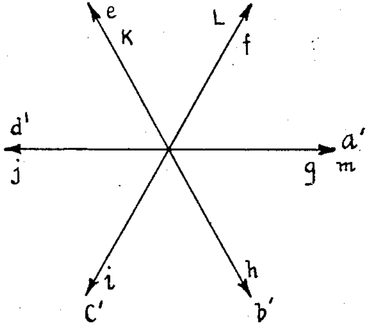


Fig. 7

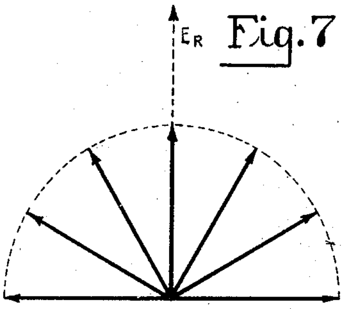


Fig. 8

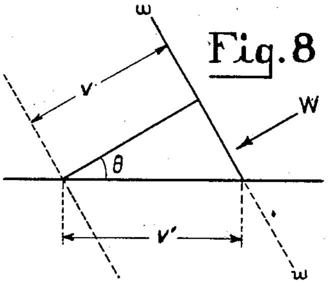


Fig. 9

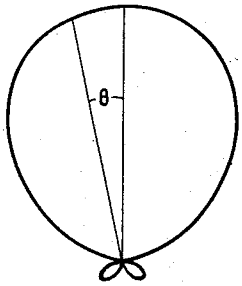


Fig. 10

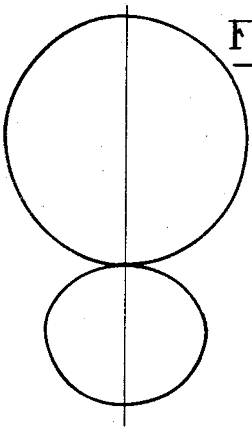


Fig. 11

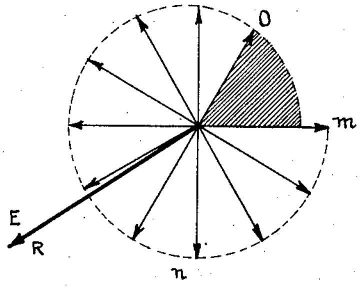
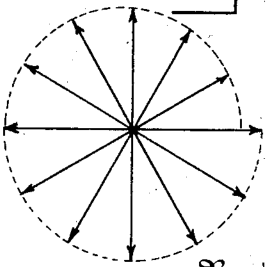


Fig. 12



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Patented July 28, 1931

1,816,614

UNITED STATES PATENT OFFICE

RICHARD HOWLAND RANGER, OF BROOKLYN, NEW YORK, ASSIGNOR TO RADIO CORPORATION OF AMERICA, A CORPORATION OF DELAWARE

WAVE ANTENNA

Application filed February 9, 1923. Serial No. 617,928.

This invention relates to improvements in radio receiving systems and more particularly to am improvement in the antenna described and claimed in the U. S. Patent No. 1,381,089, June 7, 1921, to H. H. Beverage.

It is an object of this invention to provide such an antenna which will give zero back end reception, that is, reception at the end nearest the transmitting station, regardless of the length of the antenna and the angle at which the wave strikes the antenna, and which will possess very strong directional properties regardless of the length of the antenna. It is a further object of the invention to provide an antenna giving sharp directional characteristics and zero back end reception with an antenna length which will be considerably less than that of the wave antenna now in use. It is a further object of this invention to provide an antenna which can be constructed relatively more cheaply than the usual form of wave antenna because of its decreased length and which will at the same time have the desirable qualities with respect to reception which distinguish the wave antenna from other forms of antennæ.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation together with ways in which the particular objects thereof may be attained, will best be understood by reference to the following description taken in conjunction with the accompanying drawings, in which

Figure 1 shows the usual form of wave antenna according to the patent referred to above,

Figure 2 shows my improved form of antenna,

Figure 3 shows the variations of the characteristics of this type of antenna with the length thereof,

Figures 4, 5 and 6 and 7 are vector diagrams illustrating and explaining the principles of the wave antennæ as made use of in my invention,

Figure 8 shows diagramatically a wave impinging on a section of a wave antenna,

Figure 9 shows the directional characteristics of an ideal wave antenna one wave length long,

Figure 10 shows the directional characteristics of an antenna ¼ wave length long according to the above cited patent,

Figures 11 and 12 are vector diagrams further illustrating the principles made use of in my invention.

Referring to Figure 1, the type of antenna invented and disclosed by Beverage and generally known as the wave antenna comprises a relatively long wire 1 suspended at a relatively small distance above the earth as compared with the antennæ previously used and grounded at one end at 3 through a resistance 2 and grounded at the other end at 7 through an inductance coil 4. Associated with this inductance coil 4 in inductive relation therewith, there is provided an inductance coil 5 connected to receiving apparatus R. Transmitting stations A and B are shown which are assumed to be in the plane of the antenna. The direction of the signals from these stations is shown by the arrows marked respectively A^1 and B^2.

It has been found by experiment that the variations of antenna length give a characteristic such as shown in Figure 3. It will be noted that the current at the receiving end, that is at the end remote from the transmitting station, increases with the length of the antenna. This increase will naturally not continue indefinitely since the losses in the antenna increase with the length thereof. On the other hand, the current at the back end or at the end toward the transmitting stations shows an entirely different characteristic. It will be seen that this current increases to a maximum at ¼ wave length and decreases to a minimum for ½ wave length. This variation repeats itself periodically.

As my invention has a particular relation to this action of the wave antenna this characteristic will be considered more in detail.

Referring again to Figure 1, let dx be a differential section of the antennæ at some point thereon and let dx' be another differential section some point along the antennæ between section dx and the receiver, and let the antenna be exactly one wave length long. Assume that waves are being radiated from transmitting station A and that such waves are passing along the antenna as shown by the arrow A^1 in the direction of the antenna. Assume also that the velocity of waves along the wire having the frequency of the transmitting station A is the same as the velocity of travel of the space waves radiated from station A. The differential amount of energy picked up by the small section dx may be represented by the vector dE in Fig. 4. This energy gives rise to a differential current dI flowing down the wire 1 toward the receiver R.

It is apparent that the antenna may be considered as divided into an infinite number of such differential sections and that each of these sections in turn acts to absorb a portion of energy dE from the space wave as it passes and that each of these portions of energy picked up may be considered as causing a current dI to flow to the ground at 7 through coil 4. In order to obtain a clear idea as to the action which takes place in the receiver in response to these differential amounts of current we will return to the consideration of the differential section dx'. This is assumed to be located at any point between section dx and the receiving end of the antenna 1.

It is apparent that the energy dE' which will be picked up by section dx' will be out of time phase with the energy dE picked up by the differential element dx and it will be seen further that this dephasing will be due to the time required for the space wave to travel from the element dx to dx'. Then if we represent the energy dE picked up by the element dx by the vector dE in Fig. 4, it is apparent that we may also represent the energy dE' picked up by dx' by a similar vector dE' where ψ is the angle representing the time required for the space wave to travel from dx to dx'. These vectors may also be considered to represent the currents dI and dI' due to such absorbed portions of energy. However, it will be seen that the differential current dI travelling along the wire 1 will be dephased exactly the same amount since it was assumed that the velocity of current propagation along the wire is the same as that of the space waves with respect to the antenna. It will thus be seen that the current dI' caused by the energy dE' will be in phase coincidence with the current dI and as these elements dx and dx' are not limited in their position along the line it will be seen that as long as the assumption concerning the velocities holds true that the currents flowing in the direction of travel of the space wave caused by the portions of energy picked up by any sections dx and dx' along the antenna will always be in phase at all points to the right of dx', in Fig. 1. This is more clearly shown by Fig. 5 in which the vectors a', b', c', d' etc. represent the currents flowing at points a, b, c, d, e, etc. spaced $\frac{1}{12}$ wave length apart due only to the energy picked up by the elements of the antenna at those particular points.

It will be seen that the resultant may be represented by E_r as shown in Fig. 5 wherein each of the vectors a', b', c', d' etc. is rotated through some angle less than 360° proportional to the distance of the points a, b, c, from the receiving end. For instance, vector a' is rotated through 360° since currents from A are dephased by that amount in flowing to the receiving end 7. In a similar manner vector b' is rotated through an angle of 360°—30°; c' through an angle of 360°—60° and so on.

As a result of this we see that when the wave front is moving parallel to the antenna and when the velocity of the waves in space is the same as the velocity of the currents in the wire, the currents due to the energy picked up by the antenna will be in phase at all points and the current vectors will lie along the same straight line and will add arithmetically to give the resultant current.

Let us now consider that waves of the same wave length are being radiated from station B and are travelling in the direction shown by arrow B^1, that is in the reverse direction and let us consider the conditions which will obtain in the antenna. It will be apparent that this may be considered as the same as if receiver R were moved to the other end of the antenna and the signals still considered as coming from A.

We will now assume that differential dx is taken at point a at the new receiving end 3 or back end. If we then consider differential current dI due to the energy picked up by this section of the antenna and another increment of current dI' due to the current picked up by section dx' at point b, $\frac{1}{12}$ wave length further on, it will be seen that there will be a 30° lag between the energy picked up at these two points. However, as the current dI' must flow to the receiving end 3 there will also be a 30° lag introduced by the time necessary for the current to flow to that point and as a result of this we see that these two currents will be 60° out of phase at the end 2.

Referring now to Fig. 6, vector a' represents the current at receiving end 3 due to the element of the antenna adjacent thereto, b' represents the current at 3 due to the section at b, $\frac{1}{12}$ of a wave length from end 2, c' the current at 3 due to the section 1/6 of a wave length, d' the current due to the section 1/4 of a wave length from 3, and vector e' the current due to the section 1/3 of a wave length from 3, and so on.

It will thus be seen that the current vectors representing the currents at the combining point no longer lie along the same straight line but are distributed symmetrically around a circle in such a manner that they cancel out and give a zero resultant. It will be seen that for an antenna 1 wave length long the currents at the back end are represented by vectors forming two concentric circles; that is to say, the vectors are rotated through a maximum rotation of 720°. This gives a zero resultant and accounts for the zero reception at multiples of ½ wave length as shown in Fig. 3.

It may be noted here that no account has been taken of attenuation, the effect of which is to decrease the length of the vectors. However, the effect of attenuation will be to transform the line connecting the ends of the vectors from a circle into a spiral which, if developed, would represent the usual hyperbolic curve of attenuation over a transmission line. As a result of this it will be seen that back end reception will not be exactly zero but that there will be a small amount of unbalance due to the attenuation in the line. However, for relatively short antennæ this will be quite small and for most purposes may be neglected.

We will now consider the case of a wave *w—w* as shown in Fig. 8 moving in a direction as shown by the arrow W making an angle with the antenna. If we consider v to be the velocity of the wave in space, it will be apparent that the velocity v' with which the space wave passes along the wire will no longer be the same as its velocity through space but will be

$$v' = v \sec\theta = \frac{v}{\cos\theta}.$$

It will be seen that this velocity will change with the angle θ until θ equals 90° where the velocity v' will be infinite and the energy picked up by the antenna will be substantially zero.

It is also to be noted that the energy due to each differential section will no longer be dE as before but will be $dE \cos\theta$ due to the fact that the differential section may be considered as a small loop set at an angle to the space wave.

Fig. 9 shows the directional characteristic of this antenna in response to waves impinging on it at any angle θ. It will be seen from this figure that this type of antenna is quite sharply directional particularly as to signals 180° directionally dephased. However, referring to Fig. 3 it will be seen that in order to take advantage of this the antenna must be at least ½ wave length long or some whole multiple of ½ wave length. There may be circumstances which prevent erecting an antenna this long and it is quite desirable under these circumstances as well as from a standpoint of economy to provide an antenna, for instance ¼ to ⅛ of a wave length long which will present the same directional characteristics as shown in Fig. 9. However, a normal antenna ¼ wave length has been found to have a directional characteristic such as shown by Fig. 10 and it will be seen that the small tails in Fig. 9 have been given way to a comparatively large loop for back end reception. While this loop is not as large as the loop for front end reception, nevertheless, in order to distinguish between front and back end reception some means must be provided for cutting out the back end reception by compensation which cuts down the strength of the front end signals.

Turning again to the vector analysis of the problem, it may be shown by a process similar to that employed above that the currents to be combined at the back end in a ¼ wave length antenna may be represented by vectors forming semi-circles as shown in Fig. 7 whose resultant is E_r. This also explains incidentally why the area of the back end loop is not as large as that of the front end loop. This is due to the fact that the current vectors for front end reception lie in the same straight line whereas those for back end reception lie on a semi-circle. It will be evident that we can obtain zero back end reception if by some means it is possible, so to speak, to stretch this semi-circle into a complete circle so as to provide that the resultant of these vector currents is zero.

This may be done by loading the antenna in such a manner that the velocity of current propagation along the line is less than the apparent velocity of the space wave along the wire whereby a greater lag is given the currents, but it will be seen that it will not be sufficient to load the antenna haphazardly, which might give a distribution of vectors as shown in Fig. 11, where the vectors are distributed through a sector *mno* of a circle *mn*. It will be seen that there are no vectors in the sector *om* and that the resultant of this distribution of vectors will be a vector E_r of considerable magnitude. However, if the vectors could be distributed in such a manner as to completely cover the area of the circle as shown in Fig. 12, substantially zero back end reception would be obtained for any particular length of antenna and any angle of incidence θ.

We will now turn to the consideration of the proper conditions to obtain such reception. It is apparent that the primary conditions to be obtained is a phase lag of 360° or a whole multiple thereof between currents due to the energy picked up in the section of the antenna adjacent to the receiver and the section thereof remote from the receiver. That is to say if

$$P=\left(\frac{1}{f}\right)$$

represents the period of the wave, the time required for the space wave to pass the length of the antenna, and for the current to flow back to the receiving end must be equal to this or to a whole multiple thereof; that is

$$P=\frac{1}{f}=\frac{l}{u}+\frac{l}{v'}$$

where l represents the length of the antenna, v' represents the apparent velocity of the space wave with respect to the wire and u represents the velocity of the currents along the wire. Since $v=\lambda f$, where v is the velocity of the space wave, λ the wave length, and f the frequency, we may substitute for f its value of

$$\frac{v}{\lambda}.$$

Transposing and simplifying we obtain the ratio

$$\frac{u}{v'}=\frac{l}{\lambda-l\cos\theta}.$$

Similarly, if a longer antenna is desired in order to get greater front end reception, we may calculate for a 720° dephasing of currents at the back end. Under these conditions

$$\frac{l}{u}+\frac{l}{v'}$$

must be equal to

$$2P=\frac{2}{f}=2\frac{\lambda}{v'}.$$

We thus arrive at the formula for zero back end reception in an antenna of any length which is

$$\frac{u}{v}=\frac{l}{n\lambda-l\cos\theta}$$

where n is any integer, 1 for a 360° phase difference, 2 for 720° etc. Knowing the velocity of the waves through space and knowing the angle at which they strike the antenna it is possible to calculate the amount of loading necessary to obtain any velocity u of the currents in the wire in order to obtain zero back end reception for any length of antenna, and for any angle θ which the wave makes with the antenna.

While I have shown, in Figure 2, one method of obtaining this result, that is by providing loading coils 7 along the antenna, other means of obtaining the same result, such for instance, as increasing the effective antenna capacity to ground by the addition of capacity shunted between the antenna and ground, will be apparent to those skilled in the art and I do not wish to be considered as restricted to the apparatus disclosed by Fig. 2.

It will be seen that I have provided means whereby the advantages of a wave antenna may be obtained in a relatively short antenna, for instance ⅕ of a wave length long or shorter, thus resulting in a considerably decreased cost of installation and upkeep without sacrificing any of the desirable directional qualities of the wave antenna.

Having described my invention, what I claim is:

1. In combination, an antenna system grounded at each end, and loading coils distributed along said antenna, said loading coils being distributed proportionally to the length of said antenna, whereby zero back-end reception is obtained for any antenna length.

2. The combination with an antenna grounded at each end of means for proportioning the natural constants of such antenna with respect to the length thereof to such values as to give zero back end reception for any antenna length.

3. An antenna provided with loading means distributed therealong, said loading means being so chosen and arranged as to give a ratio of velocity of currents in said antenna to the apparent velocity of space waves with respect to said wire, of

$$\frac{l}{n\lambda-l\cos\theta}$$

and less than unity wherein l is the antenna length, n is an integer dependent upon the electrical degrees of phase difference, λ is the wave length in space, and θ is the angle at which the waves impinge upon the antenna.

4. The method of eliminating back end reception in an antenna grounded at both ends which consists in loading said antenna in a manner proportional to its length so that the resultant of currents flowing therein toward the back end is substantially zero at the back end.

5. The method of loading an antenna grounded at both ends which comprises the regulation of the constants of said antenna in a manner to give a velocity of currents therealong equal to

$$\frac{vl}{n\lambda-l\cos\theta}$$

and the ratio of velocity and the said antenna and space currents is less than unity wherein v is the velocity of the space wave, l is the antenna length, n is an integer dependent upon the electrical degrees of phase difference, λ is the wave length in space, and θ is the angle at which the waves impinge upon the antenna.

6. The method of obtaining zero back end reception on an antenna of a length other than an even multiple of the received wave length and which is grounded at both ends which comprises loading such antenna in proportion to the length thereof in a manner to provide for 360° phase displacement between the currents due to the portions of energy received at each end thereof.

7. The method of obtaining zero back end reception of an antenna of a length other

than an even multiple of the received wave length and which is grounded at both ends which consists in proportion to the length thereof in loading said antenna in a manner to provide a whole multiple of 360° phase displacement between the currents due to energies received at each end of said antenna.

RICHARD HOWLAND RANGER.

CERTIFICATE OF CORRECTION.

Patent No. 1,816,614. Granted July 28, 1931, to

RICHARD HOWLAND RANGER.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 5, lines 3 and 4, claim 7, strike out the words "in proportion to the length thereof" and insert the same to follow the word "antenna" in line 4, same page and claim; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 3rd day of May, A. D. 1932.

M. J. Moore,
(Seal) Acting Commissioner of Patents.