

June 8, 1937.

P. F. GODLEY ET AL

2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934

6 Sheets-Sheet 1

Fig. 1.

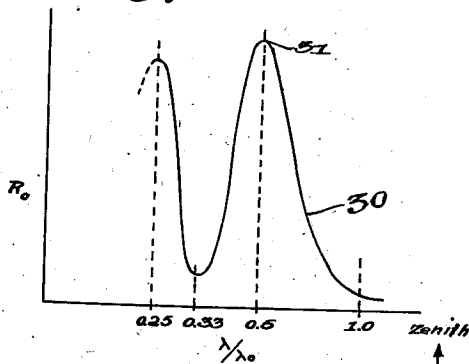


Fig. 5.

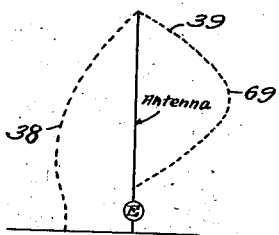


Fig. 6.

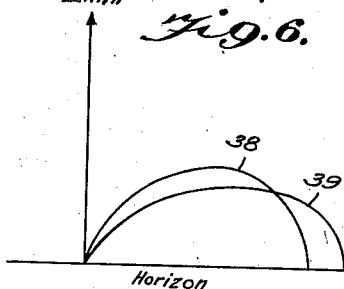


Fig. 2.

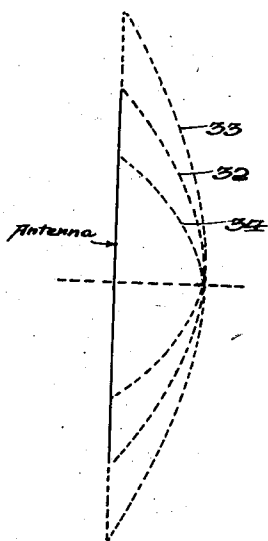


Fig. 3.

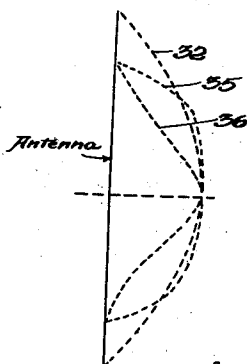


Fig. 4.

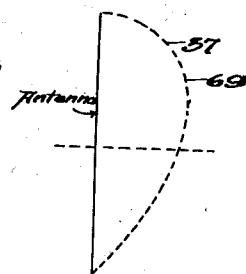
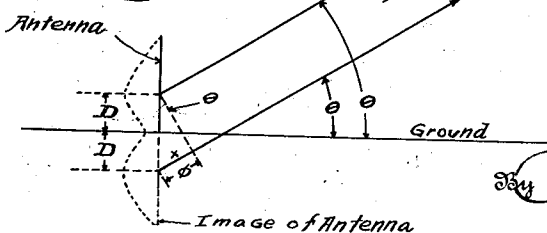


Fig. 7.



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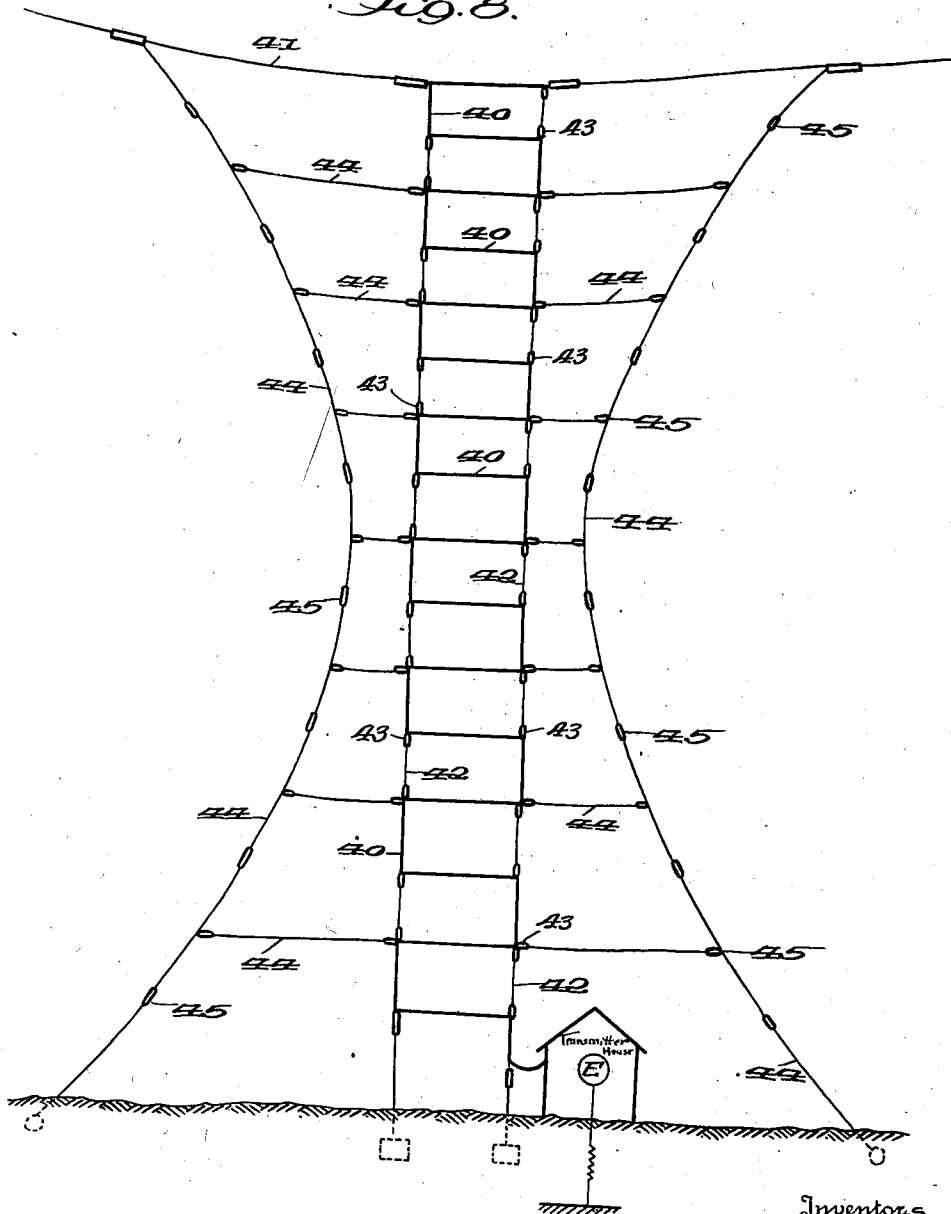
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RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

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6 Sheets-Sheet 2

Fig. 8.



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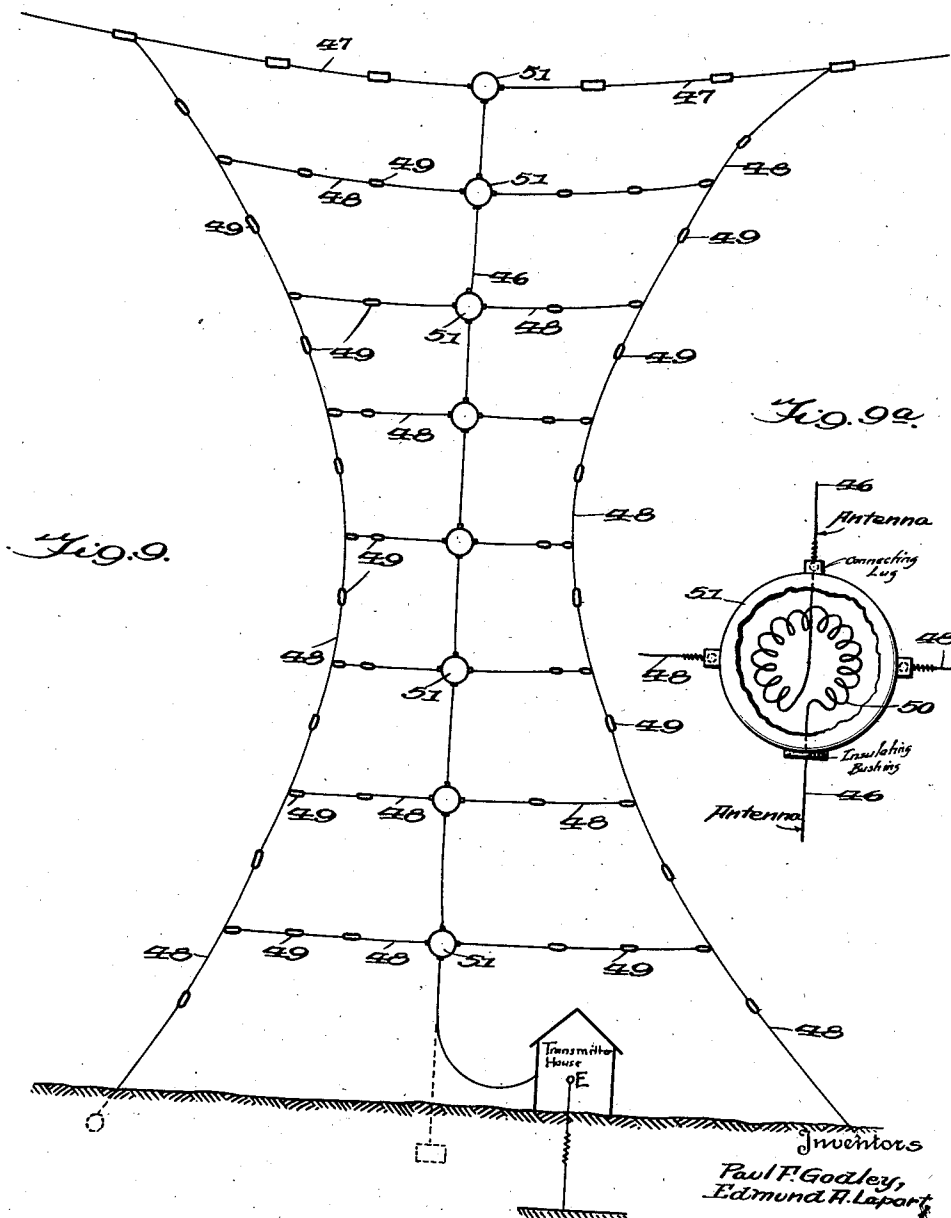
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RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934

6 Sheets-Sheet 3



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2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934

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Fig. 10.

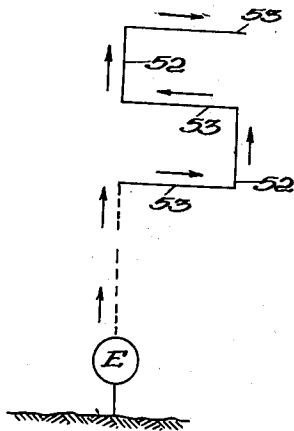


Fig. 11.

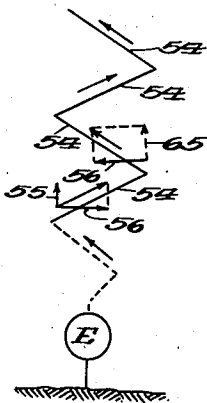


Fig. 12.

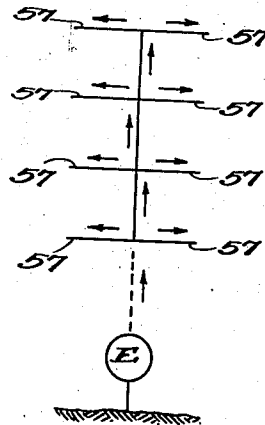


Fig. 13.

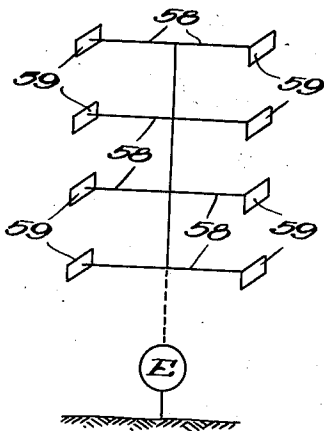
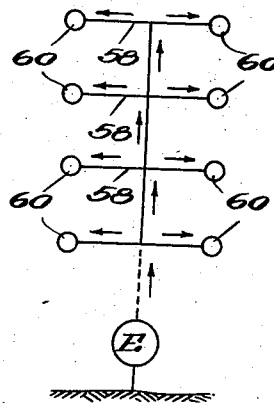


Fig. 14.



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RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934

6 Sheets-Sheet 5

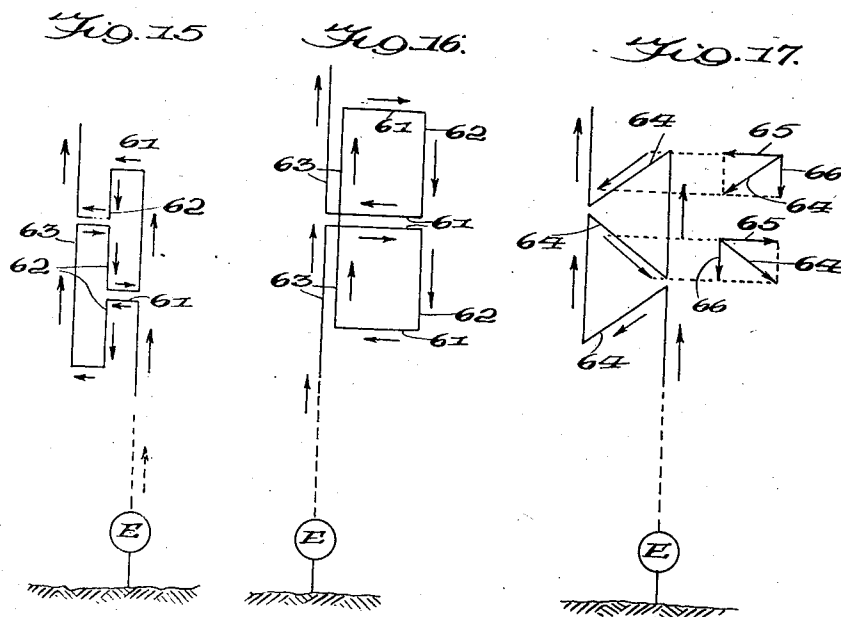
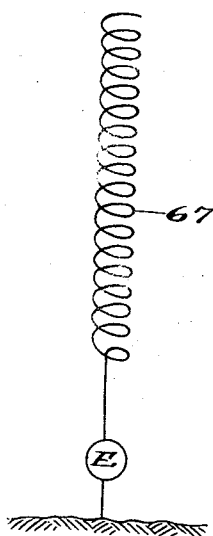


Fig. 18.



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2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934

6 Sheets-Sheet 6

Fig. 19.

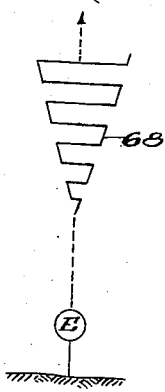


Fig. 20.

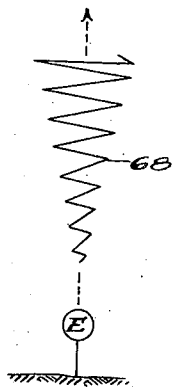


Fig. 21.

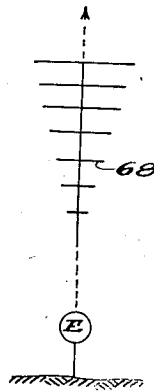


Fig. 22.

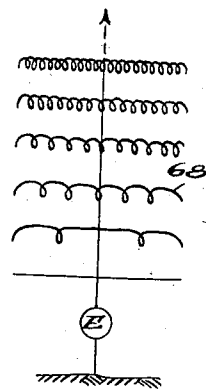


Fig. 23.

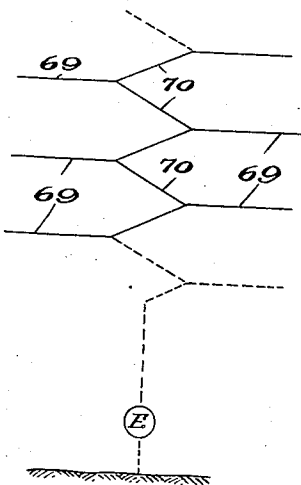
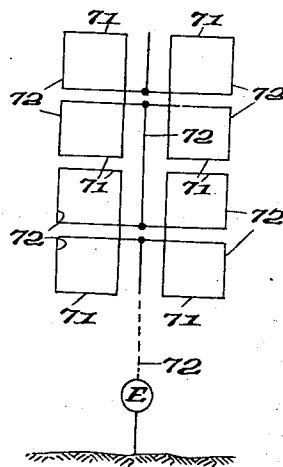


Fig. 24.



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2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

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Application April 10, 1934, Serial No. 719,931

3 Claims. (Cl. 250—33)

This invention relates to antenna systems and more particularly to a novel method of propagating electromagnetic waves from the system in a more desirable and efficient manner than heretofore obtained.

One object of the invention is to provide a novel method of controlling the distribution of radiant energy in space, and this object is accomplished by controlling the distribution of current in various portions of the antenna system.

Another important object of the invention is to provide a novel arrangement of apparatus for obtaining a wide variety of forms of current distribution in the antenna system employed.

Another object of the invention is to provide a novel system of the character designated in which the radiant energy emitted toward the zenith is reduced in order that the energy shall be concentrated at angles which are low with respect to the horizon and thereby minimize any deleterious effects of fading.

Another object of this invention is to provide an antenna system of the character designated, which shall increase the radiation efficiency of the antenna employed.

A further object is to provide a novel form of vertical antenna construction in which the height shall be only a fraction of the wave length.

These and other objects of the invention will be more apparent from the following specification and drawings, and specifically set forth in the claims.

As a preferred embodiment, we have shown the principles involved in our invention as applied to a vertical antenna but it will be readily apparent to those skilled in the art that many of these principles may be applied to other types of antennae.

It is well known in the antenna art that the transmitted power radiated from the antenna may be variously distributed in free space, with various intensities occurring at various angles with respect to the antenna. Waves emitted parallel to the ground are commonly referred to as ground-waves, while all other waves emitted at angles above the ground are called sky-waves. These waves may also be referred to as low-angle and high-angle radiations respectively. Cases frequently arise where it is very desirable to reduce one of the wave components with respect to the other. Thus it has been discovered that a resultant increase in the ratio of low-angle to high-angle emission, effects a reduction in the variation, or "fading", of received signals, or ad-

vantageously modifies the areas wherein such fading occurs.

Fading is now known to be the result of wave interference between those waves which pass directly (along the earth's surface) from the transmitter to the receiver and those waves which are propagated from the antenna at angles considerably above the horizontal, but which reach the receiving antenna because of their reflection from the ionosphere. Objectionable fading occurs when the ground wave and the sky wave are substantially of the same order of magnitude. We have discovered that by increasing the low angle emission and reducing the high angle emission the fading is thus diminished.

The desirability of increasing the low angle emission is recognized in the prior art, but none of the systems heretofore proposed accomplish this result in a commercially practical manner and one important feature of our invention is the provision of novel means for controlling the low angle emission by controlling the current distribution in the antenna.

Our invention will more readily be understood by reference to the attached drawings, in which:

Figure 1 shows a curve depicting the nature of the variation of the radiation resistance component of antenna impedance at the base with change of mode of operation.

Figure 2 shows several current distribution curves obtainable by this invention.

Figures 3 and 4 show other obtainable current distribution curves;

Figure 5 shows a comparison between current distribution curves of a uniform straight wire as used in present practice, and an antenna of the same height but built on the basis of this invention;

Figure 6 shows a polar diagram of the distribution of radiation in space as a result of the two conditions of Figure 5;

Figure 7 is a geometric representation of the conditions which produce the various forms of radiation distribution in space by wave-interference;

Figure 8 shows a method of controlling current distribution by folding a relatively long wire to occupy a given height;

Figure 9 shows a method of controlling current distribution by the addition of units of capacitance at intervals along the conductor;

Figure 9—A shows an enlarged sectional view of a special spherical element of capacitance and inductance used in Figure 9;

Figures 10 to 24 inclusive, show other con-

figurations and practical antenna systems for controlling the current distribution in any part of the system.

Referring more particularly to the drawings, Figure 1 shows the manner in which the radiation resistance (R_0) of an antenna system varies with respect to the mode of operation

$$\left(\frac{\lambda}{\lambda_0}\right)$$

in which λ_0 is the antenna fundamental wave length, and λ is the operating wave length. It will be noted that the curve 30 shows the radiation resistance at a maximum at a mode of 0.5 (point 31) which in practice may be many thousand ohms. Since the radiation efficiency is the ratio of the radiation resistance (R_0) to the total antenna resistance (R_t) (including the ground resistance (R_g), conductor resistance (R_c) and all other components of impedance which produce heat losses in the system) it is readily apparent that the building of an antenna which operates at or near the 0.5 mode (where a very high order of radiation efficiency is possible) is desirable.

In Figures 2, 3 and 4 we have shown the manner in which the current distribution may be modified from that obtained with a conventional straight antenna wire, (which has a velocity of propagation nearly equal to that in free space) the frequency of the exciting generator being assumed constant. The curve 32 in Figure 2 represents the normal half-wave distribution of current in a uniform straight wire. Curve 33 represents a half-wave of current distribution obtainable by uniformly increasing the velocity of propagation in the antenna, and curve 34 represents the distribution obtainable by uniformly decreasing the velocity of propagation. Curve 36 (Figure 3) shows the comparative distribution obtainable by an "accelerated" velocity, velocity increasing from current antinode to node. Curve 35 represents distribution resulting when the velocity is accelerated from node to antinode. Curve 37 (Figure 4) is obtained by making use of the tapering effect which will be more fully disclosed under Figures 19, 20, 21 and 22.

There is shown in Figure 6, an example of the change in the distribution of the radiant energy in space from a given antenna composed of a uniform straight wire as used in present practice, (curve 38) with current distribution as shown in Figure 5, and an antenna of the same height but constructed in accordance with this invention (curve 39) for the same frequency of operation but with modified current distribution in the system as shown in Figure 5.

The polar diagrams shown in Figure 6 are in terms of relative signal intensities observed at various angles in space and at constant radius, that is, on the surface of a hypothetical hemisphere with the antenna at its center. A glance at the two diagrams shows that curve 39 is concentrated at lower angles than curve 38, so fading would thereby be diminished, as well as the effectiveness of the antenna being increased by producing a high field intensity along the ground for a given power input.

The equation which gives the polar diagram of relative field strength distribution in space about a vertical antenna is:

$$H = aI \cos \theta \sqrt{(1 + k \cos \phi)^2 + (k \sin \phi)^2}$$

where

$$\phi = \frac{4\pi D}{\lambda} \sin \theta$$

Referring to Figure 7 for the nomenclature of the above equation, we assume that the distance to the point P is great enough so that lines drawn from P to the point of maximum current in the antenna, and to that due to the image, are parallel. D is the distance in meters of the center of current above ground level. The electrical distance in radians (in terms of free space velocity) between the center of current in the antenna and that in the image is:

$$\frac{4\pi D}{\lambda}$$

The wave length of operation λ is in meters. At the point P, image radiation lags behind radiation from the antenna by a certain distance "X", which, after accounting for the wave length, and velocity of propagation in free space, is interpreted as an angle ϕ , which is the angle between the vectors which represent, respectively, the field intensity of radiation due to the antenna, and that due to the image.

The above equation shows that, up to the point where D becomes a quarter wave length, an increase in D flattens the curves of field strength distribution as shown in Figures 5 and 6. As D exceeds this quarter wave length limit, the radiation distribution continues to flatten, but a parasitic lobe of high angle radiation forms, and continues to grow, gradually robbing energy from the main horizontal lobe. In broadcast antenna design, D would therefore be confined to a value of approximately a quarter wave-length, or slightly more, depending upon how large the parasitic lobe could be allowed to form before its presence became detrimental to be objectives of the case. An optimum compromise between these two factors is obtained when the height of the current antinode is approximately 0.28 wave length above ground. In the above equation, "K" represents the coefficient of reflection from the surface of the earth. For a perfectly conducting surface this is unity, and for high conductivity earth may approach unity closely.

The velocity of propagation (V) of currents in a linear antenna system is proportional to the expression:

$$\frac{1}{\sqrt{LC}}$$

where L and C are the inductance and capacitance per unit length of the system. To increase V, the product LC must be reduced; to decrease V, this product must be increased. The former is accomplished by adding units of capacitance at close intervals along a conductor in series with the distributed inductance of the wire, or inductance connected in parallel with the distributed capacitance of the wire to ground. Conversely, to decrease V, capacitance is added in parallel with the wire and inductance added in series. Still another method of reducing V is to increase the length of the conducting path included within a given height by folding the wire in a variety of ways.

Figures 8 to 23 inclusive show methods for taking advantage of the physical principles discussed above. Several general conceptions of practical antenna designs are shown in Figures 8 and 9. In Figure 8 the means for reducing the velocity of propagation (V) and thereby controlling current distribution is had by folding a relatively long wire 40 to occupy a given height and, by the proportions of the configuration, to produce a desired current distribution. Folding a wire for

the purpose of securing a greater electrical length is known in the art but so proportioning the folds that a desired predetermined current distribution is obtained is novel and forms an important part of our invention. In Figure 8 the antenna 40 is supported by a triatic 41 which is suspended between suitable elevated supports (not shown). Between the folds of the antenna 40 are rigging wires 42 connected to the antenna by insulators 43. Further supporting the antenna are rigging wires 44 broken into short electrical sections by insulators 45.

In Figure 9, the means for controlling current distribution by reducing the velocity of propagation is by the addition of units of capacitance at close intervals along the conductor and by the addition of units of inductance. The antenna 46 is supported by a triatic 47 suspended between suitable elevated supports (not shown). Rigging wires 48 broken into electrically short sections by insulators also support the antenna 46. At suitable intervals along the antenna 46 there are located inductance and capacitance units. While any suitable inductance and capacitance units may be used, we prefer to use a special inductance unit 50, housed within spherical elements of capacitance 51 and which is essentially toroidal in form. These units are in parallel with the distributed capacitance of the wire to ground and, by virtue of the relative proportions of the units of capacitance as well as the units of inductance in series thereto, produce a desired predetermined distribution of the current throughout the system. The use of capacitors and inductors distributed along a transmission line to change the velocity of propagation is, of course, well known in the telephonic art, but so far as we are aware, the use of inductors and capacitors so distributed along an antenna (perhaps at irregular intervals and of various magnitudes of capacitors and inductors) to produce a predetermined current distribution is novel.

By way of illustration, further examples of other configurations and practical means for obtaining any desired current distribution by controlling the velocity of propagation in any part of the antenna system are shown in Figures 10 to 24 inclusive. In those figures which show schematically the folding of the wire, arrows indicate the direction of current in the wire. In all of these figures, as well as in Figures 8 and 9, the antenna may be energized by means of a generator E (radio transmitter) connected in series with it at the base. In all of these figures also, it is assumed that the antenna is always less than 0.55 wavelength, a restriction of particular interest in broadcast applications as the cost of supporting towers is reduced to a minimum.

In Figure 10 it will be noted that the flow of currents in the vertical elements 52 are all in the same direction, while the currents in the horizontal sections 53 are successively in opposite directions, and being electrically close together, neutralize each other so far as external effects are concerned if of equal magnitudes. The wire folds are made sufficiently short electrically so that the currents in successive horizontal sections are of essentially equal magnitude. If desired, the sections 53 may be of unequal magnitude, thus producing a further variety of current.

In Figure 11 all the elements 54 are diagonal. These resolve themselves into vertical components 55 and horizontal components 56. From this point on, the problem is the same as in Figure 10 and many variations of current distribution

forms may be obtained as heretofore pointed out.

In Figure 12, the currents flowing into the branches 57 are made to oppose each other with neutral external effect, by placing branches opposite to each other as shown. In this case when the branches are less than one-quarter wavelength, they act as capacitances in parallel, this effect being due to reflections in the branches. If the length of the branches were between one-quarter and one-half wavelength, they would produce the effect of inductances in parallel with the antenna wire—an effect opposite from that produced by parallel capacitance. Radiation from these branches is maintained at a very low magnitude by making the branches short, and by placing branches in opposite directions at a given point. It is readily apparent from the preceding physical discussion that by using branches of various electrical lengths, uniform or of changing proportions, and by using various separations along the main antenna wire between branches, that a variety of different current distributions are obtained at will in the main antenna wire.

In Figures 13 and 14, there are shown illustrative examples of securing a major increase in the effect of the branches 58 upon the system without a like increase in their length, wherein conducting plates 59 or spheres 60 form a portion of the branch circuits.

In the forms shown by Figures 15 and 16, in addition to the horizontal components 61 balancing out, the one downward vertical component 62 balances out one of the two vertical upward components 63 so that there remains one active vertical upward component producing useful radiation, but with a much reduced velocity of propagation in the antenna system.

In Figure 17, the angular elements resolve themselves into horizontal components 65 and vertical components 66. Thus the problem is the same as in Figures 15 and 16.

In Figure 18, the relatively long wire 67 is spirally disposed, but it may be so proportioned as to obtain any of a number of current distribution forms. There have been applications of folded and spiralled wires for short wave antennae in the previous practice of the art, but primarily for reduction of or elimination of radiation from dipole elements in a radiating system, which contained reversed currents.

Figures 19, 20, 21 and 22 show schematically the folding or spiralling of the wire composing the antenna 68 in such a manner as to produce a gradual acceleration in the velocity of propagation, positive or negative, as desired. By utilizing the new possibilities resulting from this tapering effect, various useful forms of current distribution, such as shown in curves 35 and 36 (Fig. 3) and curve 37 (Fig. 4) as well as others may be obtained. The form shown by curve 37 of Figure 4 is of primary importance in designing broadcasting antennae, which are relatively low, but which may be made to have a relatively great effective height by raising the center of current 69 (Fig. 4) above that which is obtained by common existing antenna practice. Figure 5 shows qualitatively a modification of current distribution which produces very desirable results for broadcast antennae. Curve 38 represents the current distribution resulting from the commonly used uniform straight wire antenna of approximately $\frac{3}{8}$ wavelength height. Curve 39 represents a modification of current distribution (such as may be had by the application of our invention) in an antenna of the same height. With

curve 39 of Figure 5, the center of current 69 is very much higher above ground level than is the case in curve 38. The relative distribution of field intensities for various angles above the horizon for the two current distributions 38 and 39 are shown in Figure 6.

By means of the control of the velocity of propagation, the current entering the ground terminal is reduced by producing a current node at the ground terminal thereby further increasing the efficiency of the antenna system. This is another important feature of our invention.

The principles of this invention may be further utilized in a variety of ways by combinations of two or more methods of arranging the conductors of the antenna, examples of which are shown in Figures 23 and 24. In Figure 23, side branches 69 are attached at the junctures of angular elements 70 to produce a novel current distribution form. In Figure 24, some of the horizontal components 71 and some of the vertical components 72 are cancelled out, thus shortening the height needed. The utility of any particular form is dependent upon the circumstances in each particular design problem.

A multiplicity of radiators of the type described herein may be beneficially applied as radiating elements in a directive antenna array.

It will thus be apparent to those skilled in the art that we have described means for obtaining a very wide range of desired current distribution forms in an antenna. Some of these apparent desirable results obtained by the novel method of controlling current distribution in an antenna system are raising the center of current, decreasing the loss in the ground connection by decreasing the current flow therein, and eliminating fading by increasing the low angle emission, and also increasing the efficiency of the antenna system. This also becomes useful in solving special problems that frequently arise in connection with reception.

This invention is not limited in its application to the particular construction or constructions herein illustrated, as various changes might be made in the construction or constructions shown, without departing from the spirit of this invention, as set forth in the appended claims.

Having thus fully described our said invention, what we claim as new and desire to secure by Letters Patent is:

1. In an antenna system having one or more reactance units in various sections of the antenna, the method of obtaining non-sinusoidal current distribution which comprises gradually increasing the reactance values in successive units as the distance from the center is increased, whereby a natural velocity of propagation is maintained in the lower sections of the antenna and reduced toward the upper end.

2. In a vertical low velocity antenna of the grounded type for producing uniform radiation in all directions in a horizontal plane, means for controlling the distribution of current in said system whereby the radiated energy in vertical planes is concentrated at low angles, and means associated with said controlling means whereby the center of current is caused to approach an optimum height above the reflecting ground level of approximately 0.28 wavelength.

3. In a vertical antenna of the grounded type for producing uniform radiation in all directions in a horizontal plane and of a length less than one-half wavelength, means for controlling the distribution of current in said system whereby the radiated energy in vertical planes is concentrated at low angles, and means associated with said controlling means whereby the center of current is caused to approach an optimum height above the reflecting ground level of approximately 0.28 wavelength.

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Certificate of Correction

Patent No. 2,083,260.

June 8, 1937.

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It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 75, last portion of equation, for " $\sin \phi$ " read $\sin \theta$; 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 24th day of August, A. D. 1937.

[SEAL]

LESLIE FRAZER,
Acting Commissioner of Patents.