Aug. 2, 1938. C. A. NICKLE 2,125,804

ANTENNA

Filed May 25, 1934

Fig. 1.

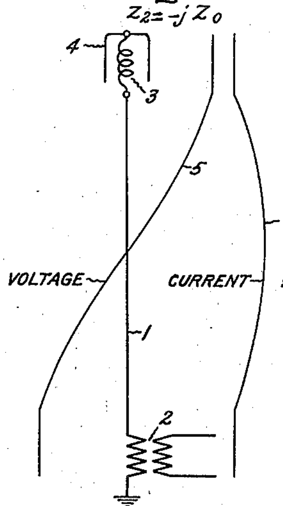


Fig. 2.

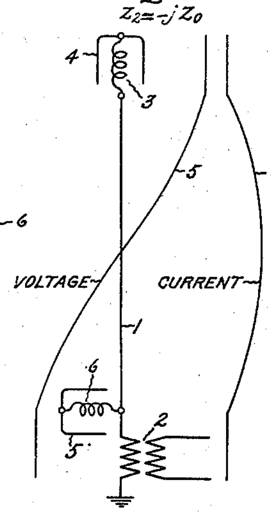


Fig. 3.

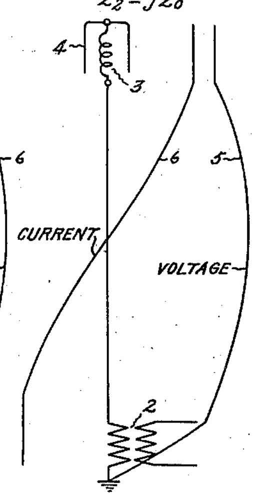


Fig. 4.

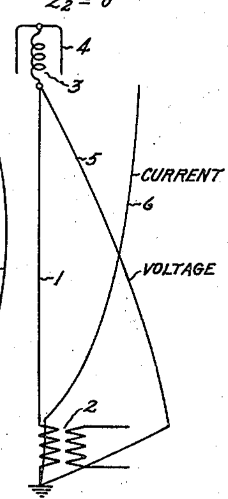


Fig. 6.

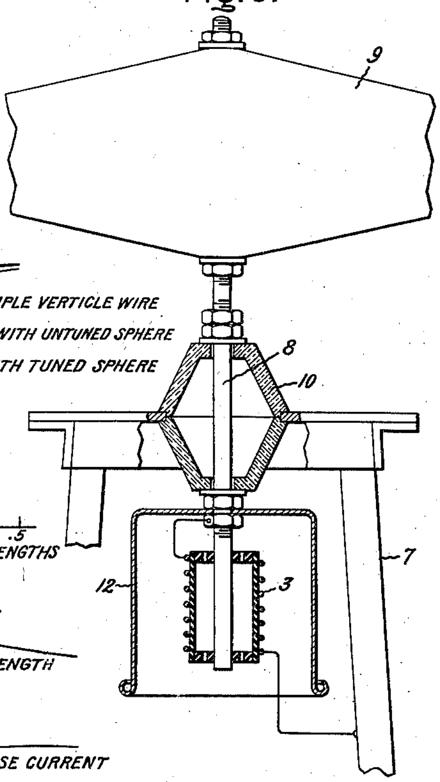


Fig. 5.

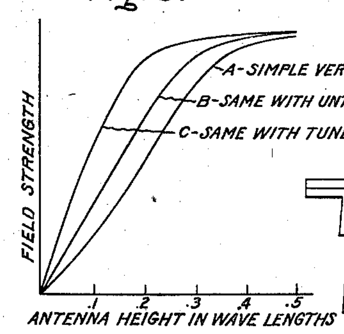


Fig. 7.

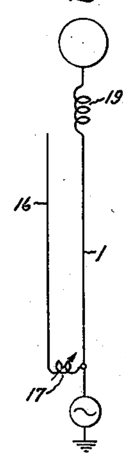


Fig. 8.

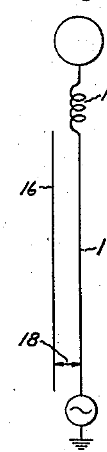
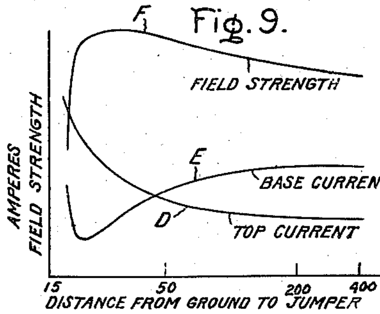


Fig. 9.



Inventor:
Clifford A. Nickle,
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His Attorney.

Patented Aug. 2, 1938

2,125,804

UNITED STATES PATENT OFFICE

2,125,804

ANTENNA

Clifford A. Nickle, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application May 25, 1934, Serial No. 727,409

17 Claims. (Cl. 250—33)

My invention relates to antennae and more particularly to antennae having a physical length less than sixty-four one-hundredths of a wave length of the frequency at which the antennae operate.

One object of my invention is to provide means whereby the efficiency of such antennae is increased.

A further object of the invention is to provide means whereby wide flexibility is afforded in adjustment of the current distribution in such an antenna so that practically any desired current distribution may be obtained. It is a particular object of my invention to provide means whereby the current may be elevated in the antenna, that is, whereby the current maximum, or loop, may be caused to occur at a point high in the antenna, or even at the top.

A still further object of my invention is to provide means whereby ground losses of the antenna are substantially reduced.

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 further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Figs. 1 to 4 conventionally illustrate my invention, Figs. 5 and 9 illustrate certain characteristics thereof, Fig. 6 illustrates a practical embodiment of my invention and Figs. 7 and 8 illustrate certain modifications of my invention.

Referring to Figs. 1 to 4 inclusive of the drawing, I have shown in each of these figures a vertical antenna which may be of any desired height less than about one-half wave length of the frequency at which the antenna operates. These antennae may operate either as transmitting antennae or receiving antennae and are connected to the apparatus with which they are associated through coupling means **2** which may be of any desired form but which is illustrated as a transformer. At the top of each antenna is shown an inductance coil **3** which is connected between the top of the active portion of the antenna, that is, that portion of the antenna which is exposed with respect to radiant energy, and a capacitance area. This capacitance area may have any desired form. It may comprise the horizontal portions of the ordinary L, T, or "umbrella" type antenna or it may be a sphere, or cylinder closed, if desired, at the top and enclosing the coil thereby to afford protection to the coil from the weather.

The use of capacitance areas at the top of a vertical antenna is of course well known. It has been found, however, that extremely important advantages may be obtained by the use of a coil at the top of the antenna connected between the capacity area and the antenna, the coil and capacity area being properly proportioned to produce desired current distribution in the radiating portion of the antenna. Certain of these advantages are apparent from curves **5** and **6** of Figs. 1 to 4 representing respectively the voltage and current distribution on the antenna produced by certain specific adjustments of the impedance comprised by the coil **3** and capacitance area **4** when used on a quarter wave antenna. In Figs. 1 and 2 this impedance is equal to the surge impedance of the antenna and is capacitive. That is

$Z = -jZ_0$ where Z represents the impedance of the coil and capacitance in series and Z_0 represents the surge impedance of the antennae.

In Fig. 3 the total impedance is equal to the surge impedance but is inductive and in Fig. 4 the total impedance is zero. That is, the inductance **3** resonates with the capacitance between area **4** and the earth, or the top of the antenna is short circuited to earth. In Figs. 1 and 2 it will be observed that the current is equal at both ends of the antenna and is maximum in the middle. Since the antenna of these figures is one-quarter of a wave-length long and the current is equal at both ends the electrical length of the antenna and top impedance is, therefore, three-eights of a wavelength. In Fig. 3 the current is equal at both ends and zero at the middle or at a point one-eighth of a wavelength above the ground. The electrical length of the antenna plus top impedance is thus five-eighths of a wavelength. In Fig. 4 the current has a maximum at the top and is minimum at the base. Its electrical length is thus one-half of a wavelength.

The voltage distribution on the antennae is, of course, 90° displaced in phase with respect to the current distribution.

These particular values of the impedance placed at the top are chosen for illustration purposes only since any other distribution may be obtained by proper choice of value of inductance employed with respect to the capacity between the capacity area and earth. Further, it will be understood that my invention is in nowise limited to quarter wave antennae but is applicable to any antenna of less than .64 of a wavelength in length, this dimension having been found to be the optimum height of a vertical antenna. In general, however, it will be found that when the antenna is of length in excess of a half wavelength the desired value of reactance at the top may be obtained by the use of a capacity area without any neutralization by use of series inductance.

These values of impedance may be confirmed, and a better understanding of the invention had, by reference to the following consideration of my invention.

We know from transmission line theory that the current at any point in a transmission line may be expressed by the following equation.

$$i_\phi = e_b\left[\frac{j\frac{Z_2}{Z_0}\sin\phi + \cos\phi}{Z_2\cos\theta + jZ_0\sin\theta}\right] \quad (1)$$

where

i_ϕ=current at any point in the line
e_b=impressed voltage
ϕ=distance of the point from the end of the line expressed in degrees
θ=total length of the line expressed in degrees
Z_2=impedance in which the line is terminated
Z_0=surge impedance of the line

$$j=\sqrt{-1}$$

We also know that the voltage and impedance at any point ϕ in the line may be expressed by the following equations.

$$e_\phi = e_b\left[\frac{Z_2\cos\phi + jZ_0\sin\phi}{Z_2\cos\theta + jZ_0\sin\theta}\right] \quad (2)$$

$$Z_\phi = \frac{e_\phi}{i_\phi} = \frac{Z_2\cos\phi + jZ_0\sin\phi}{j\frac{Z_2}{Z_0}\sin\phi + \cos\phi} \quad (3)$$

If we wish the current at the two ends of the antenna to be equal, with a maximum point at the middle of the antenna, as indicated in Figs. 1 and 2, then let $\phi=0$ in Equation 1 and we obtain an expression as follows for current at the top of the antenna.

$$i_{\phi=o} = \frac{e_b}{Z_2\cos\theta + jZ_o\sin\theta} \quad (4)$$

Similarly letting $\phi=\theta$ in Equation 3 we get the following expression for current at the bottom of the antennae.

$$i_{\phi=o} = e_b\left[\frac{j\frac{Z_2}{Z_o}\sin\theta + \cos\theta}{Z_2\cos\theta + jZ_o\sin\theta}\right]$$

Since these two currents i_ϕ are equal and of like polarity

$$\frac{e_b}{Z_2\cos\theta + jZ_o\sin\theta} = \frac{je_b\frac{Z_2}{Z_o}\sin\theta + e_b\cos\theta}{Z_2\cos\theta + jZ_o\sin\theta}$$

$$1 = j\frac{Z_2}{Z_o}\sin\theta + \cos\theta$$

or

$$Z_2 = -\frac{jZ_o(1-\cos\theta)}{\sin\theta} \quad (5)$$

This equation expresses the value of impedance which the coil **3** and capacity area **4** must be adjusted to have for an antenna of any desired length to produce the current distribution in question. If the antenna be a quarter wave antenna $\theta=90°$ then

$$Z_2 = -jZ_0 \quad (6)$$

If we wish the current distribution indicated by Fig. 3 then

$$i_{\phi=o} = -i_{\phi=\theta} \text{ and } Z_2 = j\frac{Z_0(1-\cos\theta)}{\sin\theta} \quad (7)$$

or, for a quarter wave antenna where $\theta=90°$

$$Z_2 = jZ_0 \quad (8)$$

To produce the current distribution indicated in Fig. 4 it will be noted that the current at the bottom is zero. This means that the impedance Z_ϕ at this point is infinite or that the denominator of the right-hand term in Equation 3 is equal to zero, i. e.,

$$j\frac{Z_2}{Z_0}\sin\phi + \cos\phi = O$$

$$jZ_2\sin\phi = -Z_0\cos\phi$$

$$Z_2 = jZ_0\cot\phi$$

but since $\phi=\theta$ in this case

$$Z_2 = jZ_0\cot\theta \quad (9)$$

Since for a quarter wave antenna

$$\theta=90°$$

$$Z_2 = O \quad (10)$$

That is, for minimum current at the bottom and maximum current at the top of a quarter wave antenna the top of the antenna should be short circuited to ground. This may be effected by adjusting the coil **3** for resonance with the capacity between the capacity area and the earth.

Thus we have Equations 5, 7, and 9 by which we may calculate the impedance necessary at the top of the antenna to produce current distributions corresponding to Figs. 1, 3, and 4 respectively for antennae of any length, and Equations 6, 8, and 10 respectively for quarter wave antennae.

By a similar process which will now be apparent to one skilled in the art the impedance at the top of the antenna necessary to produce a desired current distribution in an antenna of any length may readily be calculated.

My invention has the advantage that the desired current distribution may be obtained without the use of any large or expensive structure to afford the necessary capacity at the top. That is, a portion, or all, of the reactance of the actual capacity existing between the capacity area and earth may be tuned out by the reactance of the inductance. Thus, for example, for a quarter wave antenna any desired sinusoidal current distribution, including those with current loops high on the exposed portion of the antenna, as indicated by Figs. 1, 2 and 4, may be obtained by use of a sphere and a proper coil neither of which need be of objectionable dimensions.

If the antenna be one having a length less than one quarter of a wavelength Z_2 should be inductive to produce a current node along the length of the antenna. If the antenna has a length greater than a quarter of a wavelength then Z_2 should be capacitive to produce a current node along the length of the antenna. Of course in the latter case the purpose of the inductance is to permit a desired capacity reactance to be obtained without using an undesirably large capacitance area. That is, any excessive capacity reactance is neutralized by the inductive reactance. If minimum current at the bottom is desired in an antenna of less than one quarter wavelength Z_2 is inductive, and if the antenna be of length greater than a quarter wavelength Z_2 is capacitive.

In Fig. 5 I have illustrated certain characteristic curves made from experimentally obtained data and which illustrate the gain in field strength obtained by the use of my invention in a radiating antenna. These curves were taken by exciting the antenna with constant power of 7,150 kc. Curve A was made by observing the variation of field strength at a distant point on the earth caused by variation of the height of a simple vertical wire. Curve B was obtained in the same way except that the vertical wire had a sphere of 12 inches in diameter connected to the top. Curve C was obtained in the same way except that a coil was connected between the sphere and wire at the top and adjusted in each case to produce maximum field strength. It will be observed from these curves that a very substantial gain in field strength is obtained by the use of my invention. In fact, practically the same field intensity is produced by a quarter wave antenna using my invention as is produced by a half wave antenna of the simple vertical type. The gain resulting from my invention is even greater for shorter antennae. Thus my invention is of great importance in locations and under conditions where it is desirable to avoid high antenna structures.

Of course the gain in field strength produced by my invention is dependent upon the type of coil used and the size of the sphere, the field strength increasing, in general, with increase in size of the sphere. Any losses in the coil, necessarily, detract from the advantages gained by the use of my invention and accordingly a coil having minimum losses is desirable. In general the larger the power factor of the coil the smaller the reactance of the capacity produced by the area 4 should be. For example, for antennae having a length between $\frac{1}{8}$ and $\frac{1}{4}$ of a wavelength if the coil has a power factor of .0025 the reactance of the capacity should not exceed 2,500 ohms. If the power factor of the coil be .005 the reactance of the capacitance should not exceed 1,250 ohms, and if the power factor be .01 the reactance should not exceed 625 ohms. The size of the sphere to be used is also affected by the ground resistance. For example, if the ground resistance be high the gain resulting from the use of my invention is greater than would be the case were the ground resistance low. This is by reason of the increased reduction of losses in the ground. Thus where the ground resistance is high, marked gain may be secured by the use of a relatively small sphere.

The gain in field strength produced by my invention is believed to be due first to the reduction of current in the ground connection thereby reducing ground losses and permitting more of the power supplied to the antenna to be consumed in radiation. The second reason for the increase in field strength is believed to be in the change in radiation resistance at the current loop, that is, at the point in the antenna of maximum current. For a quarter wave antenna operating with maximum current at the top, as shown for example in Fig. 4, the loop radiation resistance is approximately 32 ohms in contrast to the usual quarter wave antenna resistance of 36 ohms. This accounts for approximately $5\frac{1}{2}\%$ increase in ground wave field intensity.

Consider, for example, a simple vertical antenna of the quarter wave type having a ground resistance of 10 ohms and a loop radiation resistance of 36 ohms. In such a system if 100 watts be supplied to the antenna 78 watts are radiated whereas 22 watts are lost in the ground connection. This may be considered to produce a field strength of $\sqrt{78}$ or .883 units at a certain distance from the antenna. On the other hand, if we assume that the antenna be tuned for maximum current at the top and that the ground resistance be still 10 ohms, 98 watts are then available for radiation, whereas only 2 watts are lost in the ground. Under these conditions the field strength will be $1.055\sqrt{98}$ or 1.045 units or an improvement in field strength of about 19 percent. This means about a 40 percent increase in received power at any remote point.

An antenna tuned as illustrated in Fig. 4 is to be preferred for broadcast service, for example, where it is desired to produce a maximum of radiation horizontally, i. e. a maximum of field strength in the ground wave. A current distribution of the kind shown in Fig. 3 may be used where a high angle radiation is desired. In Figs. 1 and 2 the radiation is horizontal with a greater proportion of sky wave than is obtained by the current distribution of Fig. 4.

Since it is an object of my invention to obtain these effects by reason of desired current distribution it will be understood that I contemplate the use of an antenna having sufficient length relative to the wavelength at which it operates that the current distribution along the length of the antenna may determine the direction in which waves are radiated from the antenna into space, or the direction in space from which waves are received upon the antenna. This is not true to any material degree in very short antennae such as antennae of length less than one-sixteenth of a wavelength of the wave at which they operate. In such antenna, irrespective of the portion of the standing wave of current which exists on the antenna the wave is radiated in substantially the same direction. I therefore contemplate the use of my invention in connection with antennae having actual lengths between $\frac{1}{16}$ and $\frac{64}{100}$ of the wave at which they operate.

It will be observed that in Fig. 2 a second capacity area **5** tuned by means of a coil **6** is connected to the base of the antenna just above coupling device **2**. This device serves to carry the reactive component of the antenna current to ground. That is, in any antenna on which the voltage node, or antinode, is above the ground there exist reactive voltamperes at the base of the antenna. The reactance of the unit **5**, **6** may then be adjusted relative to the impedance looking into the antenna to cause this unit to carry the entire reactive current. In other words, the reactive impedance to ground of this device is equal and opposite to that looking into the antenna. In this way only energy current is supplied by transformer **2**. With a current distribution like that in Fig. 2 the impedance of unit **5**, **6** is equal to that of the unit **3**, **4** at the top of the antenna. This device thus obviates concentrated current in the ground and reduces ground losses.

In Fig. 6 I have shown one practical embodiment of my invention in an antenna of the tower type. In this figure I have represented at **7** the top of a tower antenna. The coil **3** is arranged within the structure of the tower top, the bottom of the coil being connected to the tower structure and the top of the coil being connected to a conducting member **8** extending to a capacity area **9** arranged above the top of the tower. This capacity area **9** and conductor

8 are insulated from the tower by means of an insulating member 10. The capacity area 9 may be of any suitable structure and size and, by reason of my invention, need not be objectionably large. A shield 12 is shown supported from the conducting member 8 and surrounding the coil 3 whereby the coil is shielded from the metallic portion of the tower.

This embodiment of my invention is described and claimed in an application Serial No. 727,419, Patent No. 2,059,186, October 27, 1936, entitled Antenna structure, filed simultaneously by W. W. Brown and assigned to the same assignee as my present application.

Some inconvenience in the use of my invention results from the desirability of adjusting the coil which is located at the top of the antenna. To obviate this difficulty, structures have been proposed of the kind shown in Figs. 7 and 8 in which an additional conductor 16 is arranged in parallel with the vertical antenna, this conductor and the vertical antenna forming a transmission line. This form of my invention is described and claimed in a copending application, Serial No. 727,437, Patent No. 2,101,674, December 7, 1937, entitled Antenna, filed simultaneously herewith by Robert B. Dome, and assigned to the same assignee as my present application. In Fig. 7 the conductor is shown connected to the base of the vertical antenna through a variable impedance 17 and in Fig. 8 it is shown connected to the vertical antenna by a jumper 18 which may be movable upwardly and downwardly along the length of the antenna.

It is well known from transmission line theory that the impedance looking to the open end of a transmission line may be varied either by varying the impedance at the opposite end of the transmission line or by variation of the length of the transmission line. Thus, for example, in Fig. 7 the inductance looking into the top of the transmission line may be varied if desired by variation of the inductance 17 located at the base. Thus in this way an effective inductance is produced at the top of the antenna by the use of the conductor 16 and inductance 17 which is variable as desired from the ground. In Fig. 8 the same effect is produced by variation of the jumper 18 upwardly or downwardly along the length of the antenna.

It has been found, however, in the use of such a system that a very large current flows in the transmission line at the base of the antenna, that is, in the inductance 17 or the jumper 18. To reduce this current it is proposed to divide the require inductance at the top of the antenna into a fixed portion and a variable portion, the fixed portion being arranged at the top of the antenna as indicated at 19 in Figs. 7 and 8 and the variable portion being produced by use of the transmission line and connections 17 and 18 as previously described.

In Fig. 9 I have shown certain relations obtained from experimental data on an antenna of the type shown in Fig. 8 with the exception that the fixed inductance 19 at the top of the antenna was not employed, the entire inductance at the top being made up by use of the transmission line conductor 16 and jumper 18 in connection with antenna 1. These curves are plotted to logarithmic coordinates and pertain to an antenna excited by the frequency of 7,150 kc and having a height of 408 inches or slightly less than a quarter of a wavelength, and having a 12-inch sphere at the top. As the jumper was moved from the ground to a height of 400 inches the top current was found to reduce in a manner indicated by the curve D at a progressively decreasing rate. The base current was found first to decrease to a minimum value and then to increase as shown by the curve E, whereas the field strength at first rapidly increased to a maximum value and subsequently decreased.

It will thus be seen that the variation in field strength, base and top current is highly critical over a certain relatively narrow range of variation in inductance and is less critical at smaller values of inductance. However, the adjustment for maximum field intensity is not critical unless the adjustment be made very close to the value which produces minimum current at the base. It will further be observed that a substantial gain in field intensity is produced with an adjustment which produces equal currents at the top and base of the antenna, or at even smaller values of inductance.

It will be observed from Fig. 9 that with the jumper 18 at the top of the antenna where the transmission line adds no inductance the current at the top of the antenna is small relative to that at the base. Since the antenna is a quarter wavelength long loaded by capacity at the top a node of current occurs at the top and another substantially one-quarter of a wavelength below the base. Upon moving the jumper down the first changes in inductance have little effect on the current distribution. Further increases in the inductance cause the top current to increase and the base current to reduce until they become of equal value. The antenna is now longer than before by reason of the added inductance, i. e., a larger portion of a wavelength now appears on the inductance and radiator, this portion being three-eighths of a wavelength as is apparent from the equal currents at the top and base. Thus the lower node has moved upward one-eighth of a wavelength and now exists only one-eighth of a wavelength below ground. The current distribution is thus that illustrated in Figs. 1 and 2 and it will be observed from curve F of Fig. 9 that the field intensity at a distant point on the earth is nearly a maximum. As the inductance is increased by moving the jumper downward the field intensity attains a maximum as indicated by curve F. The top current increases and the bottom current decreases to a ratio of about .56 as measured from Fig. 9. The nodal point is still below the base, since a minimum of current at the base has not been attained, by about .08 of a wavelength as may be readily computed from the ratio .56 of currents at the base and top. The electrical length of the antenna is now .42 of a wavelength. Upon further movement of the jumper downward a minimum, or nodal point, of current at the base is attained with large current at the top and a slight reduction in field strength at the distant point. The electrical length is now .5 wavelength.

Upon further increase in inductance the current increases at the base of the antenna the electrical length of the antenna having increased beyond one-half wavelength and the nodal point of current having now risen above ground. It is noted, however, that the current at the top also increases. This is by reason of reduction in radiation resistance of the antenna when its electrical length increases beyond a half wavelength. It will also be observed that the field strength at a distant point on the earth reduces. This is due to increased current and hence increased losses in the ground, to increased losses in the inductance and to reduced radiation resistance.

Thus as shown by Fig. 9 an increase in inductance from zero causes the current distribution to be changed from that of an antenna having an electrical length of one-quarter of a wavelength through that corresponding to one having an electrical length three-eighths of a wavelength (Figs. 1 and 2) to that of an antenna having length equal to or greater than one-half of a wavelength (Fig. 4). Fig. 3 shows the nodal point moved upward to the middle of a quarter wave antenna whereby the electrical length is five-eighths of a wavelength. Thus any desired current distribution may be obtained.

It has been found experimentally that practically these same relations obtain in an antenna of the type shown in Figs. 1 to 4 if the inductance at the top be varied over a wide range.

It will, of course, be understood that the forms of my invention described herein are set forth by way of clearly illustrating the principles involved and that various modifications of my invention will occur to a person skilled in the art. I, of course, contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent in the United States, is:

1. The combination of a vertical antenna having a portion exposed with respect to radiant energy, the length of said portion being not greater than one quarter of a wavelength of the frequency at which the antenna operates, and an impedance connected between the top of said portion and the earth having a value such that a nodal point of current occurs along the length of said portion and between the ends thereof, said nodal point being positioned to produce maximum radiation in a desired direction in the vertical plane.

2. The combination of a vertical antenna having a length not greater than one quarter of a wavelength of the frequency at which the antenna operates, a connection between the base of said antenna and the earth, and an additional connection between the earth and the top of said antenna, and means to cause said additional connection to carry current greater than the current flowing between the base of said antenna and the earth.

3. In combination, a vertical grounded antenna having a length less than .64 of a wavelength of the frequency at which the antenna operates and a conductive path, other than said antenna, extending between the top of said antenna and the earth said conductive path comprising a reactive impedance having a value approximately

$$Z_o\left(\frac{1-\cos\theta}{\sin\theta}\right)$$

where Z_0 is the surge impedance of the antenna and θ is the length of the antenna expressed in degrees.

4. In combination, a vertical grounded antenna having a length less than .64 of a wavelength of the frequency at which the antenna operates and a conductive path, other than said antenna, extending between the top of said antenna and the earth, said conductive path comprising a reactive impedance having a value approximately $Z_0 \cot\theta$ where Z_0 is the surge impedance of the antenna and θ is the length of the antenna expressed in degrees.

5. In combination, a vertical grounded antenna having a length not greater than a quarter of a wavelength, a conductive path other than said antenna, extending between the top of said antenna and the earth, said path having an impedance, which is so proportioned relative to the length of the antenna and its surge impedance as to produce a current maximum relatively high on the antenna and maximum radiation horizontally.

6. A vertical antenna having a reactance connected between its topmost end and ground equal to the surge impedance of the antenna, said reactance being included in a path between said topmost end and ground other than through said antenna.

7. A vertical antenna, a capacitance area at the top of said antenna, an inductance connected between said capacitance area and said antenna, said inductance having such a value that the effective series reactance of said inductance and the capacity between said capacity area and ground are such as to produce infinite impedance at a point along the length of said vertical antenna, the length of said vertical antenna being sufficiently great that the direction of maximum radiation is dependent upon the position of said point of infinite impedance and said point of infinite impedance being positioned to produce maximum radiation in a desired direction in the vertical plane.

8. A vertical grounded antenna having a length not greater than one quarter of a wavelength, and means so constructed and arranged that the impedance existing between the topmost point thereof and ground is inductive.

9. In combination, a vertical grounded antenna, and an impedance connected between the top thereof and the ground adjusted to a value on the base current-impedance characteristic where the base current varies over a relatively large range upon any substantial change in said impedance.

10. In combination, an antenna, a high frequency circuit connected between said antenna and ground, and a path between said antenna and ground across said high frequency circuit, said path having reactance substantially equal and opposite to that looking into said antenna, said path including in series the capacitance between earth and a capacity area of sufficient dimensions to obviate concentrated ground current.

11. In combination, an antenna having a vertical portion exposed with respect to radiant energy, said portion having a length not greater than a quarter of a wavelength of the oscillations at which the antenna operates, a connection between the base of said portion and the earth, and a second connection between the top of said portion and the earth, said second connection having an impedance of such a value as to produce a current node between the ends of said exposed portion of the antenna and positioned to produce maximum radiation in a desired direction.

12. In combination, a vertical antenna having a length not greater than a quarter of a wavelength of the frequency at which the antenna operates, high frequency apparatus connected to said antenna, and means to produce a nodal point of current along the length of said antenna between the upper end thereof and the point of connection of said antenna with said high frequency apparatus and at such a point as to produce maximum radiation at high altitudes.

13. In combination, a vertical antenna having a capacity area at the top, an inductance, the top of said antenna being connected to said capacity area through said inductance and said inductance having such a value that the series impedance of said inductance and the capacity between said capacity area and the earth, is inductively reactive.

14. The combination, in a vertical antenna having a length between one-sixteenth and sixty-four one-hundredths of a wavelength of the wave at which the antenna operates, a capacity area connected to the top of said antenna and a coil included in the connection between the top of said antenna and said capacity area, said coil being so proportioned relative to said capacity area that the current at a point on said antenna substantially above the base is substantially greater than the current at the base of said antenna thereby to direct radiation from said antenna in a desired direction in the vertical plane.

15. The combination of a vertical antenna having an actual height less than sixty-four one-hundredths of the wavelength at which said antenna operates and greater than one-sixteenth of said wavelength, high frequency apparatus connected to said antenna near the base thereof, said base being connected to ground, and means to direct radiation from said antenna in a desired direction in the vertical plane, said means including means to produce a point of minimum current along the length of said antenna between the ends thereof, and comprising a capacity area at the top of said antenna, and an inductance connected between said capacity area and top.

16. An antenna comprising a vertical section one-quarter of the length of the communication wave, a connection from the bottom of said vertical section to ground, a capacity element at the top of said vertical section, and an inductance serially connected between said vertical section and capacity element and also located at the top of said vertical section, said inductance having such a value as to make the effective electrical length of said antenna equal to 0.58 of the length of the communication wave, whereby there is obtained a reversal in sign in the current distribution at a distance of 0.08 of the working wave above ground.

17. An antenna comprising a vertical section of a given physical length, appreciably less than 0.64 wavelength, a capacity element at the top of said vertical section, and an inductance serially connected between said vertical section and capacity element and also located at the top of said vertical section, said inductance having such a value as to make the effective electrical length of said antenna greater than the physical length of the vertical section but less than 0.64 wavelength and such as to result in maximum radiation horizontally.

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