April 11, 1939. J. F. MORRISON 2,153,768

ANTENNA SYSTEM

Filed May 9, 1936

FIG 2A

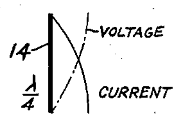


FIG 2B

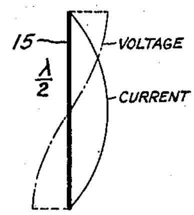


FIG 2D

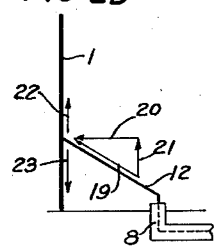


FIG. 3A

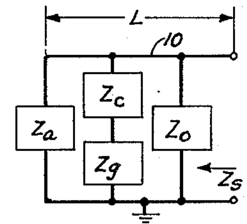


FIG 1

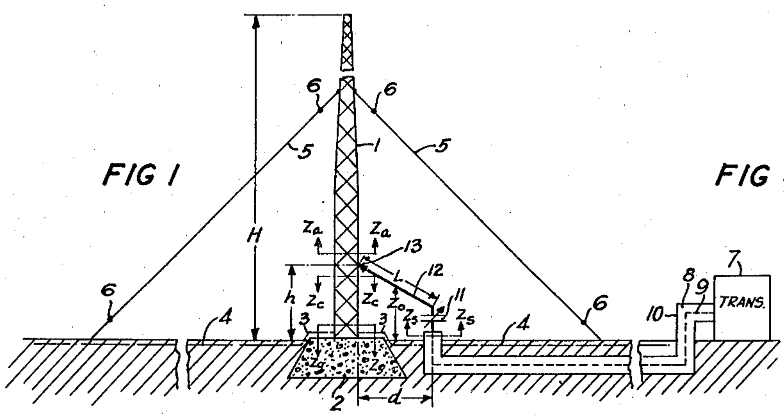


FIG 4

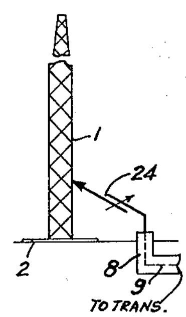


FIG 2C

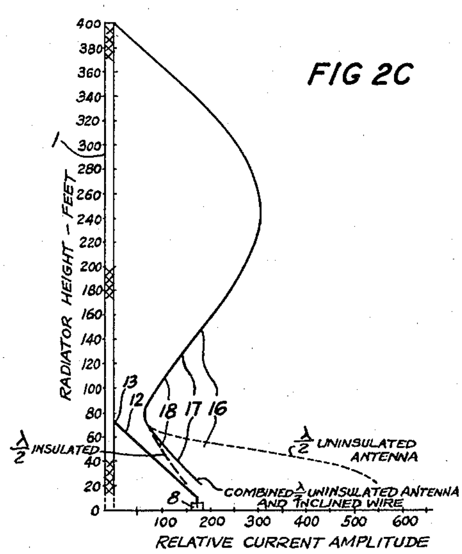
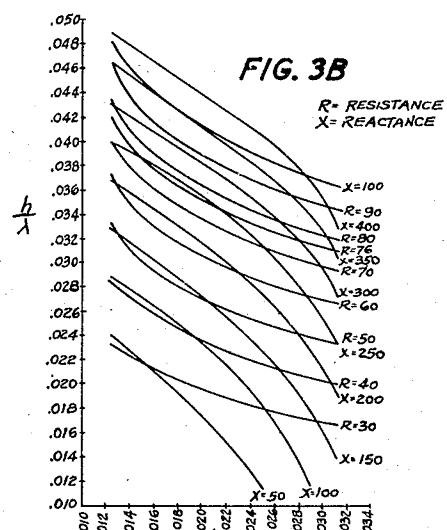


FIG. 3B



INVENTOR
J. F. MORRISON
BY A. J. Zerbarini
ATTORNEY

Patented Apr. 11, 1939

2,153,768

UNITED STATES PATENT OFFICE

2,153,768

ANTENNA SYSTEM

John F. Morrison, Boonton, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application May 9, 1936, Serial No. 78,751

11 Claims. (Cl. 250—33)

This invention relates to antennas and particularly to broadcast antennas.

As is well known, quarter wave or half wave-length tower or vertical mast type antennas are rapidly replacing wire type antennas, such as the T antenna, in the broadcast field. Possibly because of the assumption generally entertained that the voltage distribution in a radiator is sinusoidal and in the case of a half wave-length radiator is a maximum at both radiator terminals, the half wave-length tower antennas now in use, as far as applicant is aware, are series-excited and base insulated. Also, as far as applicant is aware, the quarter wave-length antennas in use are base insulated, although the use of a grounded shunt-excited quarter wave-length antenna has been suggested. It now appears that the voltage distribution in vertical radiators is complex rather than sinusoidal and that vertical antennas, regardless of length, may be satisfactorily connected directly to the earth and the costly equipment ordinarily associated with broadcast antennas, such as base insulators and lightning discharge devices, eliminated.

It is one object of this invention to efficiently radiate energy utilizing a minimum of equipment.

It is another object of this invention to reduce the cost of broadcast antenna systems designed to radiate a relatively large amount of power.

It is still a further object of this invention to improve the operation of shunt-excited grounded quarter wave-length vertical antennas.

According to one embodiment of the invention, a tower or vertical mast antenna having a wave-length of approximately .58 wave-length is connected to the earth or to a ground radial screen through a path of zero impedance. The transmitter is connected to an intermediate point on the tower by means of a line comprising a coaxial buried non-radiating section adjacent the transmitter and a radiating section adjacent the tower. The radiating line section is rigidly or adjustably associated with the tower, the connection or tapping point being critically chosen so that the resistance component of the impedance terminating the coaxial line section equals the surge impedance of said coaxial section. A reactance of the distributed or lumped type is included in the radiating line to compensate or balance the reactance of the coaxial line terminating impedance. The radiating line section is inclined or angularly related to the tower, whereby the radiation therefrom neutralizes the undesired radiation from the lower antenna portion.

The invention will be more fully understood from the following description taken in connection with the drawing on which like reference numerals designate elements of similar function and on which:

Fig. 1 illustrates one embodiment of the invention;

Figs. 2A, 2B, 2C and 2D are diagrams useful in explaining the operation of the system of Fig. 1;

Fig. 3A represents schematically the impedance terminating the coaxial line included in the system of Fig. 1;

Fig. 3B illustrates curves representing the various transmission line terminating impedances obtainable in the system of Fig. 1; and

Fig. 4 represents a slightly different embodiment of the invention.

Referring to Fig. 1, reference numeral 1 designates a fabricated tower vertical mast antenna mounted directly on a concrete ground base 2 and conductively connected through a path of zero impedance comprising straps 3 to a ground screen 4. The antenna 1 may have any practical height H, but is preferably .58 wave-length high, and it may, if desired, be of the solid mast type. The antenna 1 may, if desired, be supported by means of guy wires 5 and associated insulators 6. Reference numeral 7 designates a radio frequency transmitter, and numeral 8 designates a low impedance coaxial transmission line having an inner conductor 9 and an outer conductor 10 which is preferably buried throughout substantially its entire length. The ratio of the outside diameter of the inner conductor to the inside diameter of the outer conductor is preferably in the neighborhood of 3.7. The inner conductor 9 which may be tubular or solid, is connected through an adjustable capacity 11 to an inclined radiating line conductor 12, the inclined conductor 12 being adjustably or rigidly associated with an intermediate or tapping point 13 of the antenna 1.

Reference is now made to Figs. 2A, 2B, 2C and 2D for the purpose of explaining the operation of the system of Fig. 1. In Figs. 2A and 2B, reference numerals 14 and 15 designate free space antennas well known in the art and having respectively a quarter and a half wave-length. As indicated by the curves of these figures, sinusoidal voltage and current distributions are assumed in accordance with the theory heretofore considered correct. The curves reveal that in the case of an energized half wave-length radiator, the voltage at each terminal or end is a maximum and in the case of an energized quarter wave-length radiator, the voltage has a maximum value at one terminal and a zero value at the other terminal which may be considered the lower terminal. Consequently, it has heretofore been deemed necessary to insulate from the ground, which possesses a zero potential ordinarily, the lower high potential terminal of vertical half wave-length and aperiodic antennas; and that grounding the lower zero potential terminal of the vertical quarter wave-length antenna would not affect its operation.

As indicated by curve 16 of Fig. 2C, however, the grounded antenna 1 of the system of Fig. 1 is energized by transmitter 7 and has an aperiodic length or a length equal to approximately a half wave-length, the current distribution and, therefore, the voltage distribution which is in quadrature with the current not being sinusoidal but complex. Curve 16 is based upon actual measurement and shows that the antenna current adjacent the lower terminal of the approximately half wave-length radiator is a maximum and substantially a minimum at the tapping point 13. It should be noted that the standing wave current in a sense passes through a minimum value and reverses at point 13, wherefore the current represented by the portion of curve 16 below the tapping point 13 is substantially out of phase with the current represented by the portion of curve 16 above the tapping point 13. The coupling current in the lower antenna portion radiates energy and assists the radiation as produced by the antenna current therein, whereby an intense field is established by the lower antenna portion, as indicated by curve 16. This lower antenna field unless reduced would, applicant believes, unfavorably affect the total radiation, elevate the direction of maximum antenna action and diminish the desired ground wave propagation while increasing the undesired sky wave propagation. As will be explained presently, however, the conductor 12 is deliberately inclined so that its radiation neutralizes in part, if not completely, the radiation from the lower portion of the antenna 1 caused by the coupling current whereby the resultant radiation for the complete system comprising antenna 1 and conductor 12 corresponds to the current distribution illustrated by curve 17. Curve 18 illustrates, by way of comparison, the current distribution of a .58 wave-length or approximately half wave-length series-excited or base insulated antenna of the prior art; and it will be observed that the radiation effects produced by the grounded antenna of this invention and the costly antenna of the prior art are substantially the same.

Referring to Fig. 2D, the field cancellation effect secured by inclining conductor 12 will now be explained. Arrow 19 represents the direction of flow at a given instant of the current in conductor 12 and corresponds to the direction of the field initially radiated thereby. The field has a horizontally polarized component 20 and a vertically polarized component 21. The current supplied over conductor 12 to the tower divides at the tapping point 13 and flows in opposite directions therefrom. The resulting vertically polarized field radiated by the upper antenna portion is represented by arrow 22 and the oppositely directed vertically polarized field established by the lower antenna portion is represented by arrow 23, field 23 being stronger than field 22. As indicated by this vector diagram, field 21 opposes field 23 and substantially eliminates the effect produced by the coupling current. The vector diagram of Fig. 2D is applicable to vertical antennas excited at an intermediate point and having any length including a quarter wave-length or a half wave-length since the coupling current field and field of inclined conductor 12 oppose. It is believed to be apparent, therefore, that improved radiation may be obtained not only in the case of shunt-excited aperiodic antennas but also in the case of shunt-excited grounded quarter wave-length antennas by supplying the energy thereto over a radiating conductor angularly related to said antenna. It may be added that optimum results are secured by utilizing the inclined, rather than the vertical or horizontal position, for conductor 12, Fig. 2D, since in the case of the horizontal position no vertically polarized wave cancellation is achieved and in the case of the substantially vertical position, a large portion of the antenna 1 is rendered ineffective when the tapping point 13 is exceedingly high, as it must be, in order to obtain the proper terminating impedance for line 8.

Referring now to Figs. 1 and 3A, the manner of securing a proper terminating impedance for line 8 will be explained. The load impedance Z_s terminating the line 8 comprises the surge impedance Z_o between the line conductor 12 and the ground, the distributed impedance Z_a of the upper portion of the antenna and an impedance connected in shunt thereto comprising the impedance Z_c of the lower antenna portion, which impedance is serially connected to the ground impedance Z_g. As indicated by Fig. 3B, by properly fixing or adjusting the dimensions h and/or d, indicated in Fig. 1, the proper value of resistance and reactance for terminating line 8 may be easily secured, the symbols r and x associated with the curves of Fig. 3B representing, respectively, resistance and reactance. To illustrate, a resistance of 60 ohms and a reactance of 200 ohms may be obtained by making dimension h equal to approximately .03 wave-length, and dimension d equal to approximately .022 wave-length, or by adjusting h to equal .037 wave-length approximately, and d .012 wave-length. In systems actually used experimentally, conductor 12 was inclined at an angle of between 40 to 50 degrees, h and d were each made equal to approximately 80 feet, the antenna being approximately 500 feet high, in order to eliminate the effect of the coupling current and to satisfactorily terminate line 8.

The terminating impedance Z_r of the inclined conductor is given by the following equation:

$$Z_r=\frac{Z_a(Z_s+Z_g)}{Z_a+Z_c+Z_g} \qquad (A)$$

where

Z_a=the antenna impedance above the tap position.

Z_c=the impedance of the antenna structure below the tap position.

Z_g=a correction factor explained in the text.

The sending end impedance Z_s of the inclined conductor is then by transmission line theory for a loss-less line

$$Z_s=\frac{Z_oZ_r(1+\tan^2\beta)}{Z_o^2+Z_r^2\tan^2\beta}+j\frac{\tan\beta(Z_o^2-Z_r^2)}{Z_o^2+Z_r^2\tan^2\beta} \qquad (B)$$

where

$\beta=2\pi$ times the length of the inclined conductor in wave-lengths (radians).

Z_o=characteristic impedance of the inclined conductor

$$\cong 138\log_{10}\frac{4D}{t} \qquad (C)$$

where

D=the average height of the inclined conductor above ground.

t=the diameter of the inclined conductor.

Instead of using a lumped condenser 11 for compensating or balancing the distributed inductive reactance of the lower portion of antenna 1, an adjustable distributed capacity 24, Fig. 4, may be utilized. The distributed capacity comprises a plurality of adjustably spaced conductors as, for example, two or four conductors. The modification illustrated by Fig. 4 has the advantage that it is simpler and more economical.

Although the invention has been described in connection with certain embodiments, it is to be understood that it is not to be limited to such embodiments and that other arrangements may be successfully employed without exceeding the scope of the invention.

What is claimed is:

1. In combination, an antenna connected to a conducting surface through a path of zero impedance for energy of the operating frequency and having a length other than a quarter wavelength or an odd multiple thereof, and energizing means connected to an intermediate point of said antenna.

2. In a radio broadcast system, a vertical tower type antenna having a height in the order of .4 to .6 wave-lengths and its lower terminal connected to the earth through a path of zero impedance, a source of radio frequency energy, and means connecting said source to an intermediate point in said antenna.

3. In a radio system, a half wave-length vertical radiating antenna having its lower terminal connected to a ground screen through a path of zero impedance, substantially, and means for energizing said antenna at an intermediate point thereof.

4. In a radio system, a vertical radiating antenna having a length other than a quarter wave-length or an odd multiple thereof, said antenna having its lower terminal connected to the earth through a path of zero impedance, substantially, and means connected to said antenna for causing the antenna portions above and below an intermediate point thereof to establish dissimilarly phased radio fields and for diminishing the intensity of the field established by the antenna portion below said point whereby a strong ground wave field is produced.

5. In a radio system, a vertical antenna having its lower terminal connected directly to the earth for currents of the operating frequency and a height other than a quarter wave-length or a multiple thereof, and means for causing current to flow in said antenna comprising a source of energy and a line comprising a conductor connecting said source and an intermediate point of said antenna whereby a strong field is established by said antenna.

6. In a radio system, a vertical antenna having its lower terminal directly connected to ground, a source of radio frequency energy, a line comprising a conductor connecting said source to an intermediate point of said antenna, and a reactance included in said conductor and having a value and characteristic equal and opposite, respectively, to the primary reactance of the antenna portion below said connecting point.

7. In a radio system, a vertical antenna having a length in the order of .4 to .6 wave-lengths, said antenna having its lower terminal directly grounded, a source of radio energy frequency and a conductor connecting said source to an intermediate point of said antenna and having an inclined radiating portion adjacent said antenna.

8. I a radio system, a vertical tower antenna, a source of energy, a line connecting said source and antenna, said line comprising a non-radiating coaxial section adjacent the source and a radiating section adjacent the antenna, said radiating section being inclined, whereby the field radiated by said section includes a vertically polarized component oppositely directed or phased with respect to the vertically polarized component radiated by the antenna portion below said connecting point and a maximum field is radiated horizontally.

9. In combination, a vertical transmitting antenna having a height other than a quarter wavelength and its lower terminal directly grounded, a source of radio frequency energy having one terminal directly grounded, and a coaxial transmission line having its outer conductor grounded and its inner conductor connected between the remaining terminal of the source and a point on said antenna at which the impedance terminating said line equals approximately the surge impedance of the line.

10. In a radio system, a vertical grounded antenna, a source of radio frequency energy, a buried coaxial line, connected to the terminals of said source, an inclined linear conductor connected to an intermediate point of said antenna, a capacitive reactance connected between said inclined conductor and the inner conductor of said line, the length and inclination of said conductor being critically chosen and such as to prevent reflection on said line.

11. A system in accordance with claim 10, said capacitive reactance comprising a plurality of spaced linear conductors.

JOHN F. MORRISON.