May 28, 1968 J. H. MULLANEY 3,386,098

ELECTRICALLY SHORT TOWER ANTENNA WITH CONTROLLED BASE IMPEDANCE

Filed Oct. 23, 1965 4 Sheets-Sheet 1

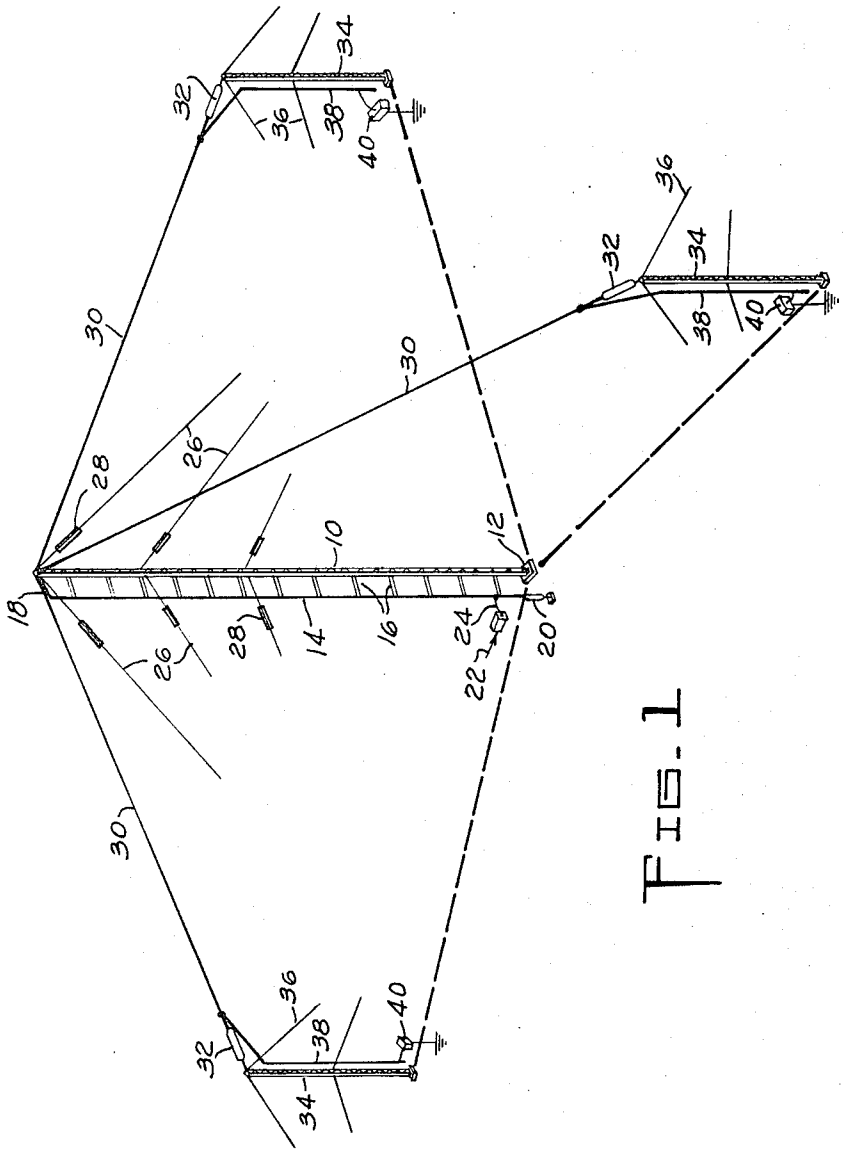


FIG. 1

INVENTOR:
JOHN H. MULLANEY,

BY Homer R. Montague
ATTORNEY

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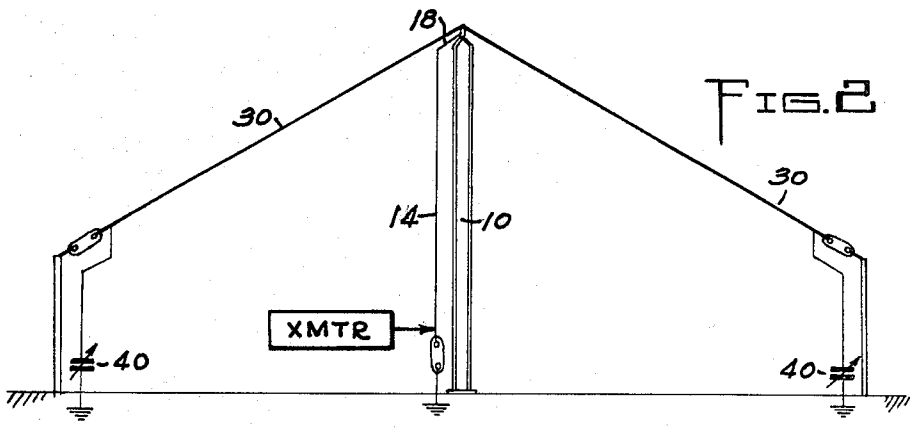


FIG. 2

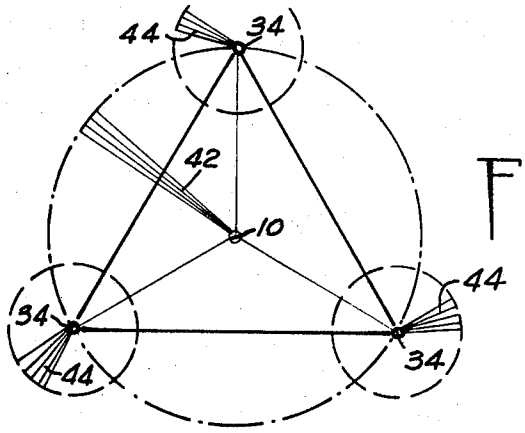


FIG. 3

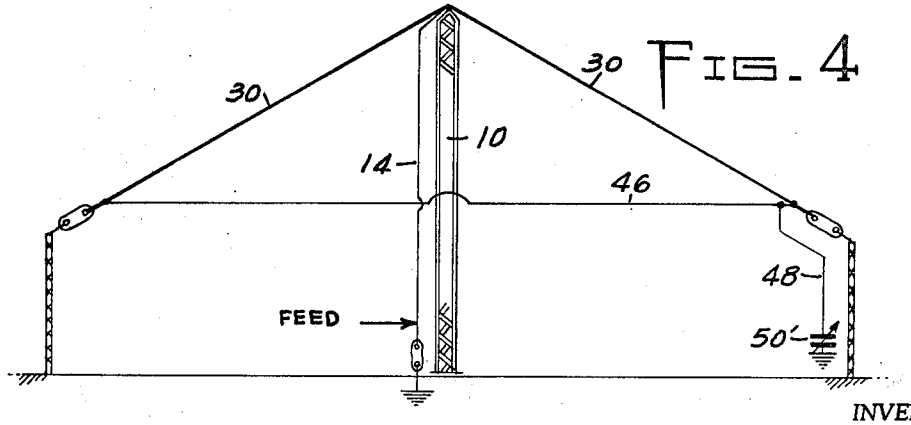


FIG. 4

INVENTOR:
JOHN H. MULLANEY,

BY Homer R. Montague
ATTORNEY

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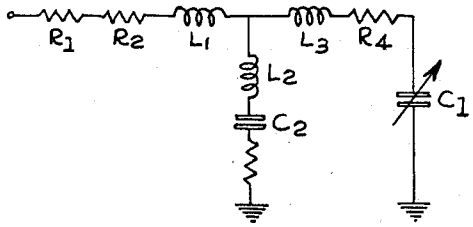


FIG. 5

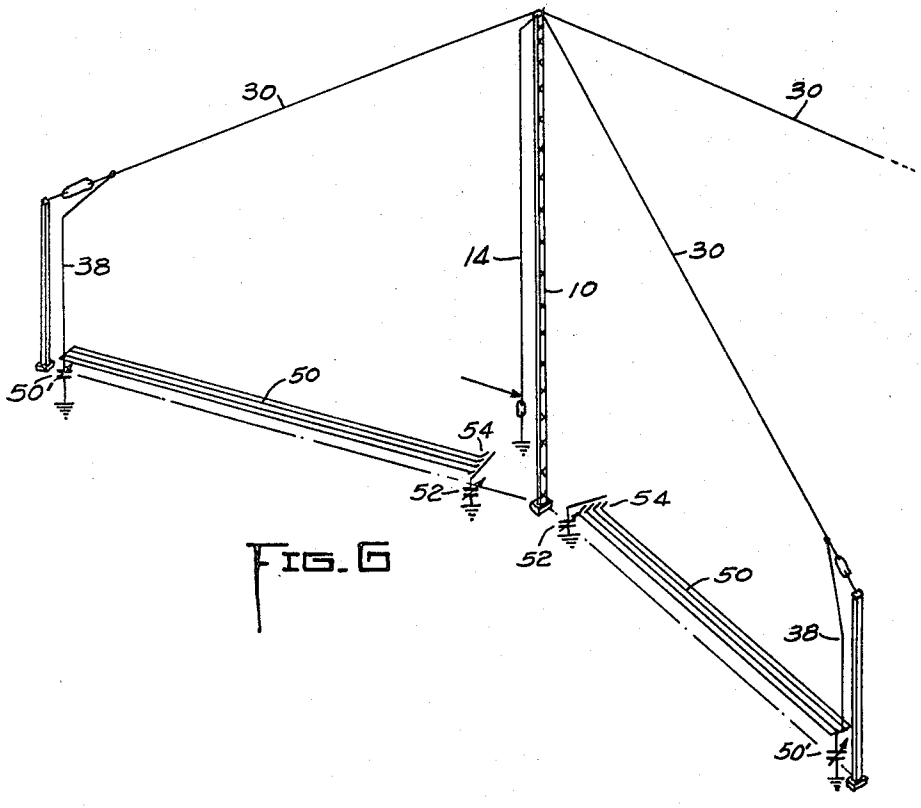


FIG. 6

INVENTOR:

JOHN H. MULLANEY

BY Homer R. Montague

ATTORNEY

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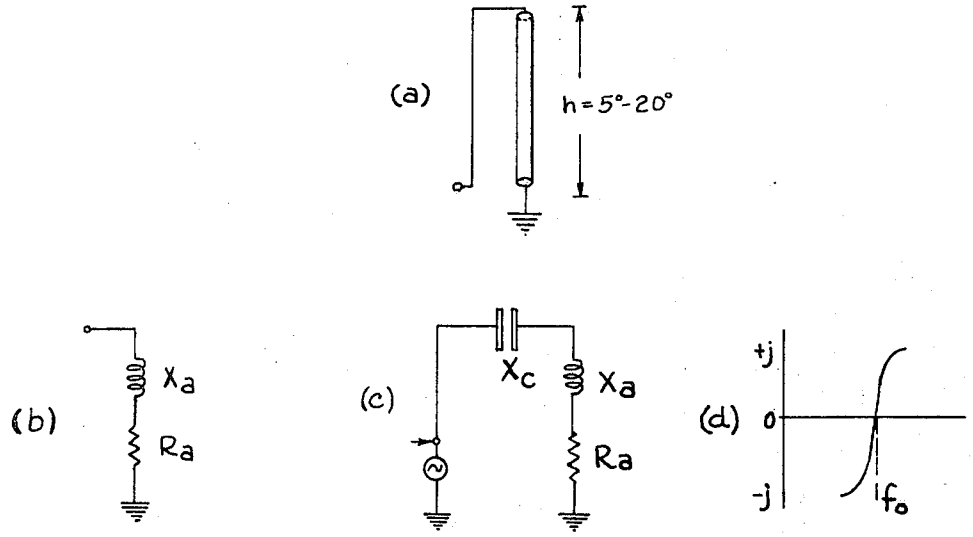


FIG. 7

INVENTOR:
JOHN H. MULLANEY

BY Homer R. Montague
ATTORNEY

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3,386,098

ELECTRICALLY SHORT TOWER ANTENNA WITH CONTROLLED BASE IMPEDANCE

John H. Mullaney, Potomac, Md., assignor to Multronics, Inc., Rockville, Md., a corporation of Maryland

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7 Claims. (Cl. 343—752)

This invention pertains to radio wave antennas, and particularly to improvements in transmitting antennas of the vertical tower type which have a relatively short length (height) in terms of the wave length of the radiation with which they are to be used. Heretofore, such very short antennas, having electrical lengths as short as 5 to 20 degrees or the like, have been achieved by the use of "top loading" (i.e., the use of upper guy structure as an umbrella, or the use of a spoke or outrigger to provide capacitance to ground), or by means of series inductances in the vertical radiator itself. The object of such expedients has been the raising of the radiation resistance by approximating the ideal of a resonant condition, but in all cases the accomplishment of even a portion of the desired increase in radiation resistance has carried with it a departure of the antenna's feed-point or base impedance from the value at which optimum energy-transfer from the transmitter to the antenna could be obtained. A serious reduction in useful bandwidth of the antenna resulted. Extremely short antennas, down to the order of 3 to 5 degrees in length, could not be obtained by such constructions without prohibitive sacrifice of bandwidth, or the practical impossibility of exciting them effectively.

It is accordingly a principal object of the invention to provide an antenna, especially for transmitting purposes, which is extremely short as compared with those known heretofore, yet characterized by relatively good radiation resistance, and with provision for adjustment of the base or feedpoint impedance so as to obtain a reasonable energy-transfer coefficient and controlled band-width characteristics. A further object is to provide such an antenna which is structurally simple and devoid of the need for mounting the tower or mast upon insulators, and which eliminates the need for isolation of circuits in regard to lighting systems on the tower. The arranegment also protects the tower from lightning, and makes unnecessary the use of large helixes or inductance elements at the tower base for resonating purposes.

In general, the antenna of the present invention is of the folded unipole type, using a conductive mast which has its lower end grounded and which is only a small fraction of one wave length in height, the same being fed at its upper end from a conductor paralleling the mast from the ground level but spaced from the mast an even smaller fraction of a wave length, to achieve the folded configuration. The tower or mast, as will be understood, has a cross-section many times as great as the size of the wire constituting the feed or fold, yet from one viewpoint the combination of the mast or tower radiator and its feed wire or fold simulate a two-wire transmission line. As many as six of the fold wires may be used, to increase the bandwidth of the antenna. In addition, the main vertical mast or tower is excessively top-loaded (by ordinary standards) by means of a plurality of conductors extending cone-wise from the top of the mast toward the tops of guyed termination poles spaced about the tower, and connected to these poles by means of insulative connections near the bottom ends of these loading wires or conductors. The lower end of each loading conductor is connected to ground through a variable capacitance, to allow adjustment of the effective capacitive reactance loading, and hence control of the feed-point impedance of the antenna. The

use of individual tuning capacitors in the loading conductors enables some degree of directionality to be obtained, or allowance to be made for the effects of nearby conductive structures, and is preferred for that reason; however, the lower ends of all of the loading conductors, adjacent their connections to the insulators at the top of the respective guy termination poles, may be connected to one another by a peripheral ring or skirt wire, in turn grounded through a single capacitor, as an alternative arrangement within the scope of the invention. An extensive ground system is preferably used under the main tower, and is interconnected to individual ground systems under the respective termination poles.

I have found that guy termination poles having physical heights of about one-third of the height of the main tower, and spaced from the tower by at least the tower's own height, yield adequate top-loading effect when the other conditions are met, although they may be taller and farther out where the added cost can be borne.

In operation, and from one viewpoint, the antenna system of the invention presents the aspect of a tuned tank circuit vertically oriented in space relative to the ground plane, but with the added feature of the utilization of a feedpoint which is in effect electrically tapped-down along the tank circuit to provide for a suitable impedance at the feed point for connection to the source of wave signals. This aspect of the invention allows a suitable feed-point impedance to be selected without serious decrease in the radiation resistance achieved by means of the combination of folded-unipole construction with "excessive" top loading as compared with the degree of top loading conventionally employed with simple vertical radiators. From another viewpoint, the invention achieves its improved results from the increase in band width resulting from a decrease in antenna "Q" resulting from off-resonance operation of the combined circuit. In either case, the invention is also mechanically advantageous, since it does not require electrically strong (high-voltage) insulators, capacitors or inductors in the main tower or mast circuit, and which have heretofore been needed whenever the mast or tower could not be of the directly grounded type.

The invention will be disclosed below in considerable detail, in connection with a preferred embodiment and variants thereof, but it is to be understood that this disclosure is for purposes of illustration and explanation rather than of limitation, and that the invention comprehends all variations of such details as fall within the scope of the appended claims.

In the accompanying drawings,

FIG. 1 is a view in perspective of one preferred form of the invention.

FIG. 2 is a view thereof in elevation.

FIG. 3 is a plan view schematically showing the arrangement of the ground conductor system of the foregoing embodiment.

FIG. 4 is a view similar to FIG. 2 of a modified form of the invention.

FIG. 5 is a schematic diagram of the equivalent circuit of the new antenna.

FIG. 6 is a fragmentary perspective view of an antenna, similar to FIG. 1, but with added transmission lines to enable centralized control of the phases of currents in the down leads of the top loading conductors.

FIG. 7 is a series of diagrams illustrating the theoretical basis for proportioning the components of the invention.

In FIG. 1 of the drawings, the main mast or tower of the antenna is indicated at **10**, supported at the ground by a base **12** but not necessarily insulated from the ground plane. The mast is of conventional girder construction, and forms the main radiator of the system, being electri-

cally conductive and having a physical height of considerably less than a quarter of the radiated wave length; heights as short as 5 degrees (360 degrees being a full wave length) may be used, especially at the lower frequencies where tower height for a quarter-wave antenna is a serious limiting factor.

Paralleling the tower is a relatively smaller fold conductor **14** held from the tower by spaced stand-off insulators **16** and at a distance from the tower which is of the order of 3 to 5 feet, or a very small fraction of the operating wavelength. This fold conductor is connected to the top of the tower as at **18**, and its lower end is guyed to the ground through the insulator **20**. The feeding or input connection to the wave transmitter **22** is indicated at **24**. It will be understood that the tower guy wires **26** are insulated by usual strain insulators **28** from the tower, to physically stabilize the same.

Three top-loading conductors **30** are also connected to the top of the tower, equally spaced in azimuth about its vertical axis, and these are connected through strain insulators **32** to the tops of respective termination masts or poles **34**, themselves individually guyed to ground by guys **36**. The poles **34** are preferably at least one-third the height of the main tower, and are spaced as far from the tower as space limitations permit, to achieve the maximum capacitance to ground. The poles are preferably at a distance from the tower at least equal to the tower's height. The end of each top-loading conductor **30** is connected by a conductor **38** to a termination unit **40** comprising essentially a variable capacitor unit in series to ground.

To provide an adequate grounding system, the lower end of the main tower **10** is connected (FIG. 3) to the inner ends of a large number of buried conductors **42** of low resistance, extending radially outward from the tower base. The outer ends of those conductors near the bottoms of the poles **34** are preferably bonded electrically to similar sets of buried radial conductors **44**. Only a few of these radial conductors are shown, the others being omitted to avoid confusing the drawing.

The modification of FIG. 4 includes a peripheral skirt wire or conductor **46** connecting the outer ends of all of the top-loading wires **30**, and in turn connected to ground by a down-lead **48** through the capacitor **50'**. The use of such a skirt increases the top-loading capacitance, but of course it prevents the possibility of individual phase-control of the currents in the top-loading conductors.

In the modification of FIG. 6, a part of which has been omitted as unnecessary, the lower ends of the down-leads **38** are not grounded through capacitors at that point, but are connected through multiple-conductor open-wire transmission lines **50** to grounded capacitor units **52** located near the base of the main tower, for more convenient control of the phasing of currents in the top-loading conductors.

FIG. 5 is a typical schematic of the equivalent circuit of the antenna. R_2 and L_1 represent the resistance and inductance of the vertical fold wire **14**, while R_3, L_2 and C_2 represent the resistance, inductance and capacitance of the grounded vertical tower **10**. L_3, R_4 and C_1 represent the parallel combined inductance, resistance and capacitance of the three top-loading guy wires **30** including the adjustable guy termination tuning capacitors **40**. C_1 is the only adjustable element (other than those controlled by the physical layout), and by its adjustment the feed point resistance can be controlled. R_1 is the feed point resistance, and values of R_1 are readily obtainable in the order of 100 ohms or less in a typical case. One can, if desired, set the guy termination tuning to produce a feed point resistance of 50 ohms. The inductive reactance may then be cancelled out (resonance condition) to attain a pure 50-ohm resistance that can be fed directly from a standard coaxial cable. This is practically a zero-loss tuning condition, since a capacitor is used for resonating the feed point. Other values may of course be used depending upon specific values of bandwidth and radiation efficiency required. In such cases, a simple L matching network may be used to transform the characteristic impedance of the transmission line down to the antenna feed-point resistance while simultaneously cancelling the antenna's reactance.

The net or dynamic bandwidth of the antenna is determined by computing the net reactance for its parallel and series equivalent circuits and then combining these by algebraic addition of ordinates, as elaborated below. It is to be noted that the parallel equivalent circuit is to be tuned to one side of the series resonant frequency so that a non-symmetrical impedance curve is obtained.

The theoretical basis underlying the invention is best illustrated in the diagrams of FIG. 7. In (*a*), a conventional folded unipole antenna is shown without any top loading, and with an electrical height of from 5 to 20 degrees. The larger cross-section vertical represents the tower, and the small wire represents the fold. Such an antenna is the equivalent of a two-wire transmission line with unequal-size conductors. For the lengths indicated, the feed point will exhibit a small resistance and an inductive reactance; the resistance value will be a function of the height of the tower, spacing of the folds (one or more can be used), the cross section of the tower, and that of the fold wire. Diagram (*b*) is the equivalent circuit for this folded unipole, the total resistance R_a including both the radiation resistance and the loss resistance of the circuit. In order to feed power to the unipole, the conjugate reactance X_c is as indicated in diagram (*c*). Assuming the generator to have the same resistance (R_a) we would have a resonant condition at the feed point (indicated throughout these diagrams by a small circle). A measuring bridge connected to the feed point would show that the impedance for frequencies above the resonant frequency would be positive, and for frequencies below resonance the impedance would be negative. The net impedance variation with frequencies away from the resonant frequency f_0 is indicated in diagram (*d*).

Referring now to diagram (e), the unipole is shown shunted by a large capacitance indicated by X_{c1}, indicated as variable, and corresponding to the top loading and the variable capacitances connecting the same to ground via the down leads (all considered in parallel with one another). It is clear that this parallel circuit, with proper circuit parameters, can be made to exhibit a different value of resistance (than R_a) and to have a smaller reactance. However, depending on the value of X_{c1}, the frequency at which this is achieved may be above or below the resonant frequency. According to the principles of the invention, the choice is made so that, for example, at the selected value of operating frequency, the net reactance of circuit (e) will be positive; that is, the frequency f_{01} in diagram (g) is higher than the frequency of resonance, f_0, of diagram (d). The equivalent circuit for this condition is as shown at (f), where the new value of resistance is indicated by R_{at}, and the inductive reactance is X_s. Choice of a negative net reactance for circuit (e) is equally valid.

When the conjugate impedance of the generator is supplied as at X_c in diagram (i), the effective impedance obtained is the resultant of the vertical addition of the ordinates of the curves of (d) and (g), shown superimposed in diagram (j). It will now be seen that there is a value of applied frequency at which the positive reactance due to the folded unipole is equal in magnitude, but opposite in sign, to the negative reactance provided by the top loading and its tuning capacitances. It is this value of frequency which is chosen as the "operating" frequency F_x to yield a desired bandwidth of operation. It is to be noted that this operating frequency is different from both f_0 and f_{01}. While it is possible to operate somewhat off of this value, for example if multiplex operation is involved, the value indicated is greatly preferred for actual resonance with reference to the generator (transmitter).

The variation shown in FIG. 6 uses the wires of the

transmission lines 50, suspended above and insulated from the ground, as a variable-area capacitor plate against the ground. These wires can thus supply a part of the capacitance total required, which may be considerable, especially at low frequencies, and would otherwise require high-voltage capacitors at 50' beyond the commercially available sizes. The individual wires of the lines may be selectively connected into the circuit by switches indicated at 54, and hence the value of auxiliary parallel capacitance may be nicely adjusted. At some frequencies, these wires may make the use of the "main" capacitors 50' unnecessary.

The invention has been described above from both theoretical and practical viewpoints as they apply to specific and preferred arrangements, but these are given by way of instruction and explanation, and not for purposes of limitation. Accordingly, the invention is intended to cover all modifications of the systems shown as fall within the scope of the claims.

I claim:

1. An antenna comprising a folded unipole having a vertical radiator of a length equal to a small fraction of the operating wavelength and a feed fold parallel thereto and spaced therefrom a small fraction of the radiator length, said radiator and fold being connected together at their ends remote from a ground plane from which the radiator rises; top loading conductors extending conewise, from the connected ends of said radiator and fold, towards the ground plane, and a series capacitor connected from the distal end of each of said top loading conductors to ground; said components being so related that at the operating frequency the positive reactance component due to said folded unipole referred to its feed point is substantially equal in magniude but of opposite sign relative to the combined negative reactance component due to said top loading conductors and said capacitors.

2. An antenna according to claim 1, and a skirt wire connecting the distal ends of said top loading conductors.

3. An antenna according to claim 1, and an open-wire transmission line connected from the distal end of each top loading conductor, and at least in part running closely above ground towards the base of said vertical radiator; and capacitance means connecting the inner end of each of said lines to ground.

4. An antenna according to claim 1, in which said series capacitors are variable capacitors.

5. An antenna according to claim 1, in which the distal ends of said top loading conductors are guyed to respective poles spaced from said vertical radiator.

6. An antenna according to claim 1, in which the distal ends of said top loading conductors are guyed to respective poles spaced from said vertical radiator by distances at least substantially equal to the height of said vertical radiator, said poles securing said ends of said conductors above ground by a distance at least substantially one-third of the height of said vertical radiator.

7. An antenna according to claim 1, including a plurality of ground conductors buried in the ground and connected to the base of said vertical radiator.

References Cited

UNITED STATES PATENTS

2,298,900	10/1942	Peters	343—874
2,998,604	8/1961	Seeley	343—874 XR
3,345,635	10/1967	Fenwick et al.	343—752 XR

ELI LIEBERMAN, *Primary Examiner.*

M. NUSSBAUM, *Assistant Examiner.*