TACTICAL HIGH FREQUENCY ANTENNA

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Filed: May 17, 1974
Appl. No.: 470,777

U.S. Cl. 343/703; 343/712; 343/745; 343/752
Int. Cl. H01Q 1/32; H01Q 9/18
Field of Search 343/703, 750, 745, 752

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UNITED STATES PATENTS

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ABSTRACT
An electrically short (less than $\lambda/4$) antenna for operation in the frequency range from 2 to 30 megahertz (MHz). The antenna system contemplated by the subject invention comprises a short inductively loaded vertical radiating element having a capacitive top termination, a ground system and an automatic remote control of the tuning of the antenna which senses the state of resonance of the antenna and operates to drive a tuning reactance, e.g. a variable capacitor in series with the vertical radiator element to provide the required $\lambda/4$ resonance at a given operating frequency.

14 Claims, 4 Drawing Figures
TACTICAL HIGH FREQUENCY ANTENNA

The invention described herein may be manufactured and used by or for the government for governmental purposes without payment of any royalty thereon or therefor.

BACKGROUND OF THE INVENTION

The present invention relates to antennas of electromagnetic radiation and more particularly to a transportable antenna system which is adapted to radiate electromagnetic energy efficiently from a very short radiator compared to the wavelength of the radiated energy. In military applications, the dimensions of portable ground based or vehicular high frequency antennas are necessarily a small fraction of the wavelength. It is well known that ground based antennas which are substantially smaller than \( \lambda/4 \) are usually inefficient electromagnetic radiators. In addition the required wide frequency range of interest in the present invention (2 to 30MHz) imposes serious practical limitations in tuning and effecting efficient power transfer from the transmitter to the antenna. For example, known prior art apparatus heretofore utilized a series whip antenna being in the order of 30 feet in length and generally mounted on a plate over the ground or on the side of a vehicle or other supporting means. This type of antenna although being portable, is physically not compatible for certain use, e.g. jungle environment because of the nature of the terrain. Secondly, this type of antenna by nature presents difficulty in being resonated over the desired operating frequency range.

One known type of transportable high frequency antenna system attempting to overcome the inherent difficulties in obtaining an electrically short antenna for operation in the range from 2 to 30MHz is taught for example in U.S. Pat. No. 3,510,872, J. H. Mulhaney, which utilizes a collapsible helical antenna element. A second type of electrically short antenna is disclosed in U.S. Pat. No. 3,209,358, R. A. Felsenfeld, which discloses, inter alia, a linear antenna having electronically controlled tuning means. In addition to ferrite core antennas for obtaining compactness, electrically short radiating antennas have also been achieved in the prior art by the use of inductively loaded folded monopole antennas such as taught in U.S. Pat. No. 3,103,011, E. W. Seeley.

SUMMARY OF THE INVENTION

The subject invention is directed to an improvement in high frequency antennas and briefly comprises a short inductively loaded vertical radiator element having a capacitive top termination coupled to one end, while the opposite end is coupled to a ground system through the series combination of remotely controlled reactance tuning means and energy feeding means. A tuning detector coupled to the feeding means is adapted to provide an output signal indicative of the resonant or non-resonant state of the antenna. This signal is then coupled to a control unit which is adapted to vary the reactance tuning means until resonance is achieved. When the antenna consists of a ground based system the ground system consists of a counterpoise comprising a number of radially oriented wires lying in the horizontal plane and suspended above the ground. In a vehicular configuration, the radially oriented wires acting as the counterpoise are deleted and the grounding system comprises the vehicle body itself. Also, in the ground based configuration, cable choke means are additionally included in the feeding means for suppressing radiation in the RF feed lines.

BRIF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an electrical schematic diagram illustrative of the land based embodiment of the subject invention; and FIG. 2 is a diagram illustrative of a typical plan view of the capacitive top terminations at one end of the radiating element shown in FIG. 1, as well as the counterpoise consisting of a number of radially oriented wires located at the other end; FIG. 3 is an electrical schematic diagram of a vehicular mounted embodiment of the subject invention; and FIG. 4 is a partial electrical schematic diagram illustrative of yet another embodiment of the subject invention.

DESCRIPTIONS OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and more particularly to FIG. 1, the radiating means consists of a relatively short inductively loaded vertical radiator element having a capacitive top termination 12 connected to the other extremity thereof and a counterpoise ground system 14 coupled to the other extremity by means of the series of combination of a frequency band select inductive reactance 16, a variable fine tuning capacitor 18, and antenna feed point means comprising s broadband transformer 20 having its secondary winding connected between the tuning capacitor 18 and the counterpoise 14.

The vertical radiating element 10 comprises a metal mast or wire supported by plastic or fiber glass tubing and typically having a height \( h \) = 6 feet for operation in the high frequency range (HF) of the electromagnetic spectrum of from 2 to 30MHz. The top termination 12 is comprised of a plurality of radially oriented wires or metal tubes 22 extending radially outwardly in a horizontal plane from the vertical central axis of the radiating element 10. The effect of the capacitive top termination is to increase radiation efficiency and reduce antenna reactance. A means for maintaining the radially oriented elements 22 in the horizontal plane is one of choice, depending upon the intended use. For example, if the elements 22 are comprised of wires, some form of insulating support, not shown, would be required. In vehicular installations, the top capacitance elements may also be required to be arranged to reduce wind resistance. In FIG. 2, the top capacitance elements 22 are shown arranged in a regularly spaced configuration 45° apart from one another. This is shown merely for sake of illustration and is not meant to be interpreted in a limiting sense, however.

Since the physical dimension of the radiating element 10 is only a small fraction of the wavelength, it acts over a broad frequency range as though it were a capacitance insofar as its circuit properties are concerned. Accordingly, a loading inductance 16 is required to achieve quarter wavelength (\( \lambda/4 \)) resonance at a given operating frequency. Since the inductance varies inversely, as the square of the frequency, for a frequency range of 2 to 30MHz the inductor 16 must have a range variation of 1:225. Accordingly, the inductance 16 is comprised of a multi-tapped inductor having selected
3 portions of the winding adapted to be shorted out by means of a shorting switch 24.

The operation, the inductive reactance 16 operates substantially as a fixed inductance for a selected frequency band in a plurality of overlapping plurality of in the high frequency (HF) range. Accordingly, the inductor 16 is adapted to be adjusted in steps to provide coarse tuning of the radiating element to a predetermined frequency band within the HF range. The variable capacitance 18 on the other hand adapted to provide a fine tuning adjustment. Thus resonance is obtained by means of the variable capacitance 18 in series with a substantially fixed inductor 16.

The counterpoise 14 is used to reduce ground losses in the ground based embodiment shown in FIG. 1, and consists of a plurality of radially oriented wires or other type elements 26 disposed in a horizontal plane just above the ground 28. The elements 24 are also shown regularly disposed in a radial fashion in FIG. 2 for purposes of illustration only. Experimentation has shown that in the counterpoise 14 preferably comprises at least sixteen wire elements 26, each approximately 13 feet long and suspended 12 inches above the ground 28 in order to effectively shield the antenna element 10 and stabilize its resistance to a relatively low value.

The antenna system resulting from the configuration shown in FIG. 1 exhibits a relatively high Q which makes remote controlled fine tuning of antenna resonance necessary due to the fact that the antenna reactance is sensitive to the presence of nearby objects. Accordingly, the band select inductance value of the inductor 16 is provided by means of an electrically controlled rotary selector 30 mechanically coupled to the switch 24 while the variable fine tuning capacitor 18 is controlled by means of an electrically operated reversible motor 32. Both the rotary selector 30 and the reversible motor 32 are operated by respective control signals applied thereto from a control unit 34 with the motor 32, at least operating in response to an electrical output signal from an antenna tuning state detector 36. This will be considered in greater detail subsequently.

Fine tuning of the antenna is preferably accomplished by means of the variable capacitor 18 in view of the following considerations. The antenna tuning range, within a given band, can be calculated from the approximate formula:

$$\frac{f_2}{f_1} = \sqrt{\frac{C_{min}}{C_{min}}} \times \frac{C_{max} + C_{min}}{C_{max} + C_{min}}$$  \hspace{1cm} (1)

wherein $f_2$ and $f_1$ are the upper and lower operating frequencies, respectively, $C_{max}$ and $C_{min}$ are the maximum and minimum capacitance of the variable fine tuning capacitor 18, and $C_{min}$ denotes the antenna capacitance. Typically $C_{min} = 50\mu F$, $C_{min} = 10\mu F$, and $C_{max} = 300\mu F$ which then results in a ratio of

$$\frac{f_2}{f_1} = 2.2$$  \hspace{1cm} (2)

Variable vacuum capacitors having the recited values for $C_{max}$ and $C_{min}$ are commercially available.

If on the other hand fine tuning by means of variable inductance were to be used, a relatively narrower tuning range would be achieved in most bands as exhibited by the formula:

$$\frac{f_2}{f_1} = 1.05$$  \hspace{1cm} (3)

would be obtained, which is substantially less than that obtainable with capacitance tuning. From the foregoing, the ratio ($f_2/f_1$) utilizing both capacitative and inductive fine tuning indicates that fewer bands are required to cover the entire HF range (2 to 30MHz) when the variable capacitor tuning method is employed. Obviously, since fewer bands are needed to cover the frequency range, and since the required capacitor type components are commercially available, capacitor fine tuning is highly preferable.

In the land based embodiment shown in FIG. 1, an RF source such as a transceiver 38 is coupled to the antenna feed point 40 by means of the matching transformer 20 by way of RF transmission line segments 42 and 44 and the tuning detector 36. The transmission line 44 is additionally configured to include a cable choke portion 46 which is shown in FIG. 1 in block diagramatic form, but in actuality, consists in having a portion of the transmission line 44 simply formed into a coil. Matching of the antenna to the feed line by means of the broadband transformer 20 is relatively easy, first since resonance is always established at the operating frequency, the corresponding antenna feed point impedance is resistive even though for example with 50ohm radio transceivers, the feed point impedance is usually less than 50ohms when the A/4 resonant mode is used. Secondly, in conjunction with the counterpoise 14, the antenna input impedance is relatively constant over a broad frequency range, e.g. 2 to 13MHz. At upper frequencies above 13MHz, when preferable, the matching transformer 20 may be unnecessary and therefore deleted. In such a case, the transmission line 42 would be connected directly to the antenna feed point 40 without incurring a substantial mismatch. Alternatively, the transformer 20 could be designed so as to achieve minimum VSWR over the entire HF range from 2 to 30MHz.

The impedance match between the antenna and transmission line 42 from the transceiver 38 is determined by the electrical characteristics of the broadband transformer 20 and the tuning state of the antenna radiating element 10. Assuming that the transformer introduces no reactances of its own, a “match” is obtained only when the antenna is non-reactive, i.e. in its resonant state. The tuning detector 36 which for example preferably comprises a radio frequency phase sensor, well known to those skilled in the art, is coupled to the antenna feed point by means of the broadband matching transformer 20 and the RF transmission line segment 42. A phase sensor is a device which is adapted to measure the phase relationship between the
radiating element's excitation voltage and the current and produces a DC output voltage which is proportional to the phase difference therebetween, with zero output from the detector indicating antenna resonance. An output signal from the sensor of a positive polarity for example, indicates that the antenna is in a non-resonant state and has a corresponding reactive impedance which is inductive while a negative polarity output is indicative of a non-resonant state wherein the corresponding reactive impedance is capacitive. The phase sensor accordingly must accurately monitor the tuning state of the antenna over the entire frequency range of from 2 to 30MHz.

The DC output signal from the phase sensor 36 is coupled to the control unit 34 by means of a shielded cable 48 which also includes a portion thereof configured into a cable choke portion 50 in the same manner as the cable choke portion 46. The remote control unit contains electrical circuitry e.g. a servo-system necessary to effect control of coarse and fine tuning, and includes the necessary voltage and power supplies as well as an antenna tuning state indicator or meter, manual controls and a source of primary power. The DC signal derived from the phase sensor 36 for example, is at least used to drive the reversible motor 32 mechanically coupled to the variable capacitor 18. When desirable this signal can also be used to initiate operation of the rotary selector. This is provided by means of a multiwire cable 52. The cable 52 also includes a portion thereof which is configured into a cable choke portion 54 in the same manner as the cable chokes 46 and 50. It should be pointed out that when desirable the separate cable chokes could be combined. The purpose of the cable chokes 46, 50 and 54 is to suppress feed line radiation and reduce ground losses. The cable choke 46 in the RF transmission line 44 is the most important and is located relatively close the the antenna for maximum effectiveness and provides a high impedance across its extremities, e.g. 5 kilohms at frequencies where feed line excitation is most troublesome. In the case of the subject antenna system, feed line excitation appears to be of concern in the frequency range of from 2 to 10MHz rather than at higher frequencies. This is explained by the fact that the frequencies above approximately 10MHz, the counterpoise 14 acts as a better ground. The cable chokes 46, 50 and 54 moreover become increasingly essential as the dimensions of the counterpoise 14 decrease.

Referring now to a vehicular installation, attention is directed to the FIG. 3. In such embodiment, the elements are exactly the same as shown and described with respect to the ground based embodiment shown in FIG. 1 with the exception that the cable chokes 46, 50 and 54 and the counterpoise 14 illustrated in FIG. 1 are now eliminated. This is due to the fact that the radiating element 10 is terminated in the vehicle body 56 which effectively acts as the counterpoise. In all other respects, the two embodiments are exactly alike.

Another embodiment of the subject invention adapted for either land or vehicular use is shown in FIG. 4. A land based configuration is shown for purposes of illustration since it discloses utilizing a counterpoise 14 as the "ground system". Whereas in the earlier embodiments shown in FIGS. 1 and 3, the coarse or band tuning is accomplished by means of a multiple tap single inductor 16 having a selected portion of the winding shorted by means of the rotary se-

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resonant state and has a corresponding reactive impedance which is inductive while a negative polarity output is indicative of a non-resonant state wherein the corresponding reactive impedance is capacitive. The phase sensor accordingly must accurately monitor the tuning state of the antenna over the entire frequency range of from 2 to 30MHz.

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ing capacitance 18 is adjusted closer to the value needed to establish antenna resonance, the RF power input to the antenna will increase. Correspondingly, the DC output signal of the sensor will also increase up to a point and then decrease as resonance is approached. At resonance, the phase sensor output signal from the tuning detector 36 will vanish indicating that the feed point current and voltage are in phase. At this point the tuning operation ceases and maximum power is delivered to the antenna.

The tuning detector 36 up to this point has been described in terms of a phase sensor. There are, however, several limitations associated with the use of phase information for control of antenna tuning. One disadvantage is that the error signal needed to initiate fine tuning is often very small when the antenna is initially detuned from resonance. Another is that the accuracy of the phase sensor is seriously impaired if the signal emitted by the transmitter has significant harmonic components. While proper operation can nevertheless be obtained by proper equipment design, another way to indicate antenna resonance is to utilize an indicator which produces a DC output proportional to reflected power. In such a case, resonance is indicated wherein reflected power is minimized, which is at the point of resonance. However, when the antenna is non-resonant, the reflected power measurement method cannot indicate whether the antenna is inductive or capacitive. Thus for optimum operation, both phase and reflected power sensors would be incorporated in the tuning detector 36 so as to eliminate ambiguities and poor sensitivity.

Furthermore, vehicular installations such as shown by the embodiment illustrated in FIG. 3 requires that the automatic tuning system be in continuous operation due to the motion of the antenna. In base installations, such as shown by the embodiment illustrated in FIG. 1 where the antenna is usually undisturbed, the antenna’s tuning system may, when desirable, be deactivated to conserve primary power except when the operating frequency is changed.

Other modifications and variations of the present invention are possible in light of the above teachings. For example, the antenna can be modified to achieve somewhat better electrical efficiency by locating the inductor 16 and the variable fine tuning capacitor 18 just beneath the top capacitance 12, i.e., at the top of the radiating element 10 rather than at the bottom. However, such an arrangement would be unattractive for vehicular use. Also, for installation in airborne vehicles such as helicopters, the antenna system would utilize the same type of tuning system but a modified top capacitance 12 acceptable to air frame designers would be necessary.

It should be pointed out that the present invention constitutes an improvement over prior art apparatus in a number of respects. For example, the top termination capacitance reduces antenna height and yields higher efficiency than if a single wire of the same height were used. Moreover, the tuning system covers the entire high frequency range (2 to 30 MHz) without complexity and lends itself to manual or automatic control. The tuning system, moreover, provides more efficient power transfer to the antenna than is available with present commercial couplers. Only two high Q reactors are used, one of which comprises a variable capacitor in place of a variable inductor commonly used hereto.

fore but which requires sliding or rolling contacts which are a source of erratic operation, noise and power loss. For the ground based installation, the isolated counterpoise in combination with the cable choke effectively shields the antenna against strong variations in the ground characteristics and decreases power losses. Even though its dimensions are modest, the counterpoise is usually a more efficient “ground system” than one of comparable size composed of wire radiating along the earth's surface or buried. In addition, there is theoretical evidence indicating that up to 98% of the total ground loss occurs within a radial distance of 0.05A from the antenna radiator axis in the low HF range which provides justification for the use of the counterpoise as set forth in the present specification.

Accordingly, having thus set forth what is at present considered to be the preferred embodiments of the subject invention,

I claim:

1. A tunable high frequency antenna system, typically but not restricted for use in the frequency range of from 2 to 30 MHz, comprising in combination:
   an electrically short, normally vertical radiating element having a physical length less than a quarter wavelength for the desired frequency of operation;
   a capacitive top termination coupled to the upper extremity of said radiating element;

   a first controlled electrical reactance connected in series to said radiating element comprising an inductor having a plurality of inductance taps, said first reactance being selectively adjustable in value to provide a coarse tuning of said radiating element to a predetermined frequency band within a selected frequency range comprised of a plurality of overlapped bands;

   a switch means coupled to said inductance taps for selectively connecting a portion of said inductance with said radiating element;

   a second controlled electrical reactance connected in series with said radiating element and said first reactance wherein said second reactance comprises a variable capacitance to provide a fine tuning of said radiating element within said predetermined frequency band;

   first conduit means for feeding a radio frequency signal to said radiating element including a broadband transformer having a secondary winding connected in series with said radiating element and said first and second reactances;

   a ground system connected in series with said first and second reactances, and said secondary winding;

   a second circuit means coupled to said first circuit means and being responsive to the resonance state of said radiating element to provide an electrical output signal indicative of said resonant state; and

   third circuit means coupled to said second circuit means and being responsive to said output signal provided thereby to generate a control signal to vary said first and second reactances in directions to affect resonance of said radiating element; and

   means controlled from said third circuit means for remotely operating said switch means coupled to said inductance taps for selectively shortening out a selected portion of said inductor.

2. The antenna system as defined by claim 1 and additionally including electrically operable driver means
responsive to said control signal for mechanically varying said capacitance.

3. The antenna system as defined by claim 1 wherein said ground system comprises a counterpoise located a predetermined distance above the ground.

4. The antenna system as defined by claim 3 wherein said counterpoise comprises a plurality of radially oriented wire conductors lying substantially in a horizontal plane and being suspended a predetermined distance above the ground.

5. The antenna system as defined by claim 3 wherein said first circuit means includes an RF transmission line, a portion of which comprises a cable choke for operating in combination with said counterpoise to suppress feed line current and ground losses.

6. The antenna system as defined by claim 1 wherein said first circuit means includes an RF transmission line and a primary winding coupled to said secondary winding and said primary winding being coupled to said radio frequency signal via said transmission line; and wherein said second circuit means comprises a tuning detector coupled to said primary winding of said matching transformer.

7. The antenna system as defined by claim 1 wherein said first circuit means includes:
   an RF transmission line, a primary winding coupled to said secondary winding and being coupled to said radio frequency signal by means of said transmission line; and
   wherein said second circuit means comprises a tuning detector including circuit means for being coupled between the secondary winding and said radiating element.

8. The antenna system as defined by claim 7 wherein said ground system comprises a counterpoise located a predetermined distance above the ground; and wherein said RF transmission line includes a cable choke portion therein for operating in combination with said counterpoise to suppress feed line current and ground losses.

9. The antenna system as defined by claim 8 wherein said second circuit means are coupled together by means of a transmission line a portion of which is configured as a cable choke; and wherein said third circuit means and said second reactance is coupled by means of an electrical cable, a portion of which comprises a cable choke.

10. The antenna system as defined by claim 1 wherein said ground system comprises a vehicle body.

11. The antenna tuning system as defined by claim 1 wherein said second circuit means comprises phase sensor apparatus adapted to measure the phase relationship between the excitation voltage and current of said radio frequency signal.

12. The antenna system as defined by claim 1 wherein said capacitive top termination comprises a plurality of elements extending radially outward from said radiating element in a plane substantially parallel to said ground system.

13. The antenna system as defined by claim 13 further including an electrically driven rotary selector switch coupled to said taps and being operable to select a selected portion of said inductor in response to another control signal from said third circuit means to effect coarse tuning of said radiating element.

14. The antenna system as defined by claim 13 wherein said second circuit means and said third circuit means are coupled together by means of an electrical transmission line, a portion of which is configured as a cable choke; and wherein said third circuit means and said second reactance is coupled by means of an electrical cable, a portion of which comprises a cable choke.

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