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Campbell

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[11] **3,909,830**

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[54] **TACTICAL HIGH FREQUENCY ANTENNA**

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[73] Assignee: **The United States of America as represented by the Secretary of the Army**, Washington, D.C.

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[52] **U.S. Cl.** **343/703**; 343/712; 343/745; 343/752

[51] **Int. Cl.**[2] **H01Q 1/32**; H01Q 9/18

[58] **Field of Search** 343/703, 750, 745, 752

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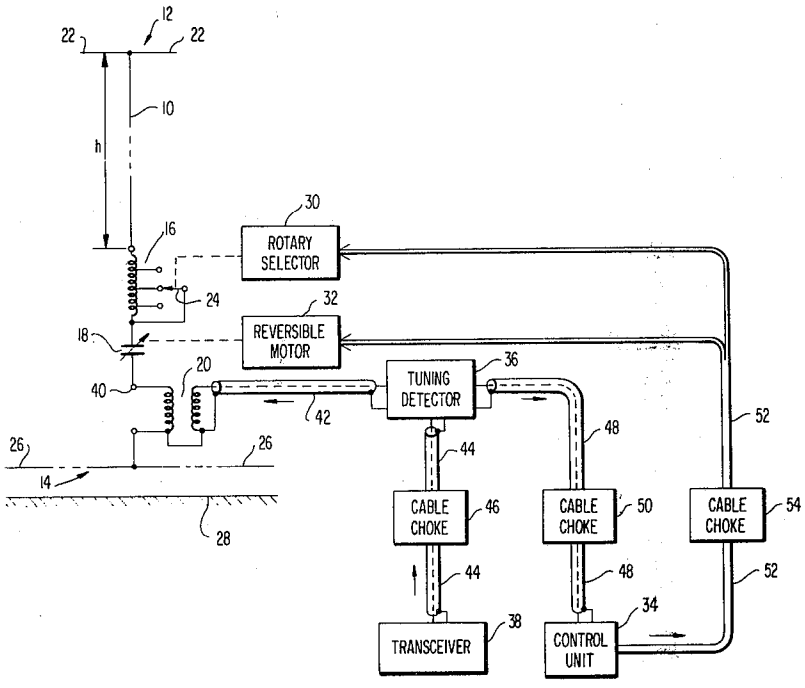
Primary Examiner—Eli Lieberman

Attorney, Agent, or Firm—Nathan Edelberg; Robert P. Gibson; Arthur L. Bowers

[57] **ABSTRACT**

An electrically short (less than λ/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 λ/4 resonance at a given operating frequency.

14 Claims, 4 Drawing Figures



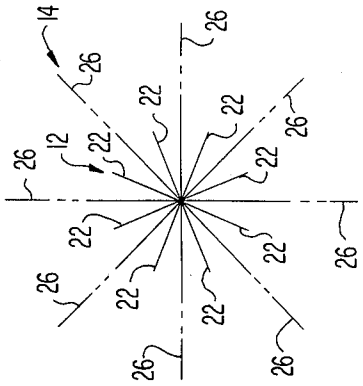

14
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FIG. 2

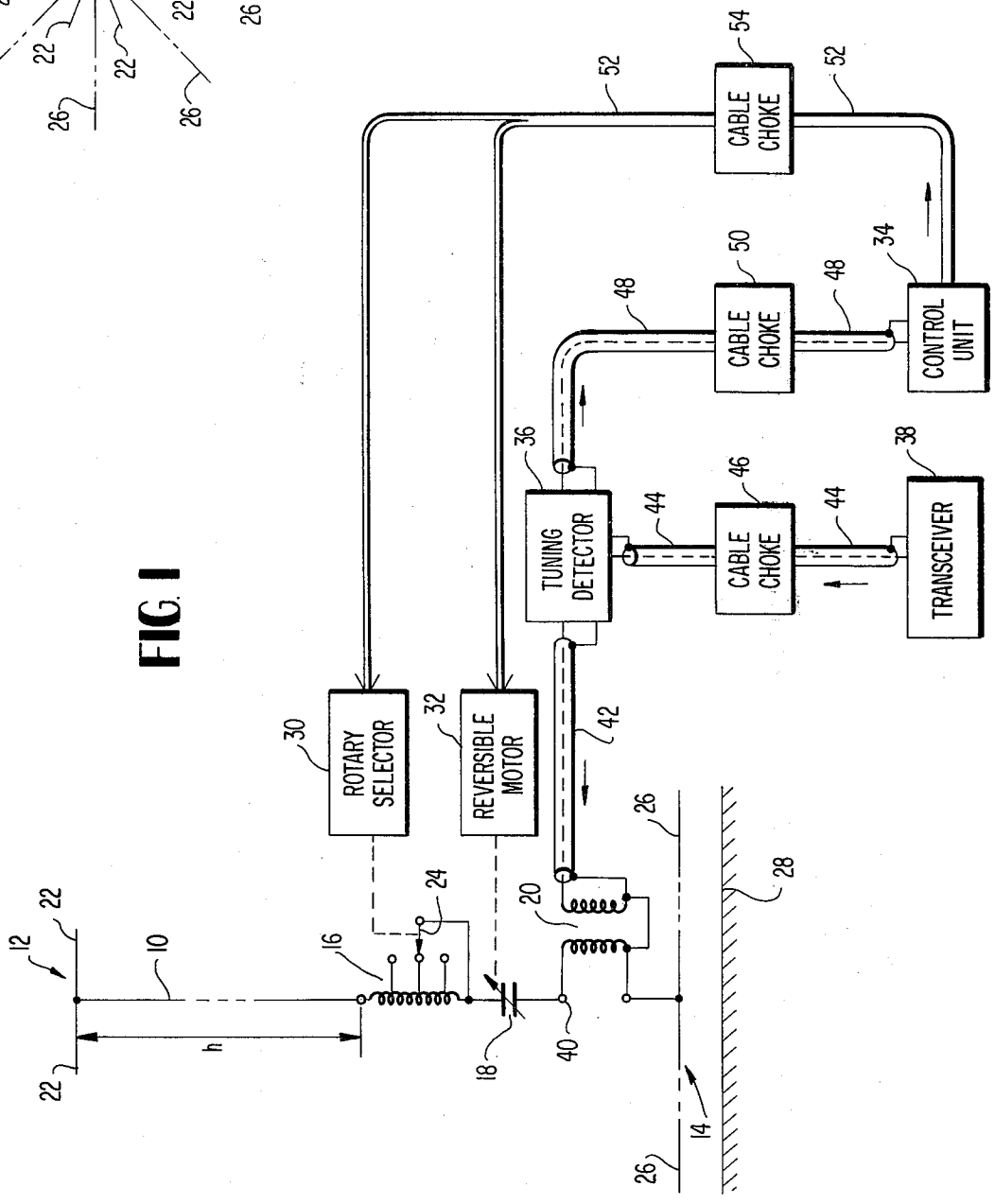

CABLE CHOKE
CABLE CHOKE
CONTROL UNIT
TUNING DETECTOR
CABLE CHOKE
TRANSCEIVER
ROTARY SELECTOR
REVERSIBLE MOTOR
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FIG. 1

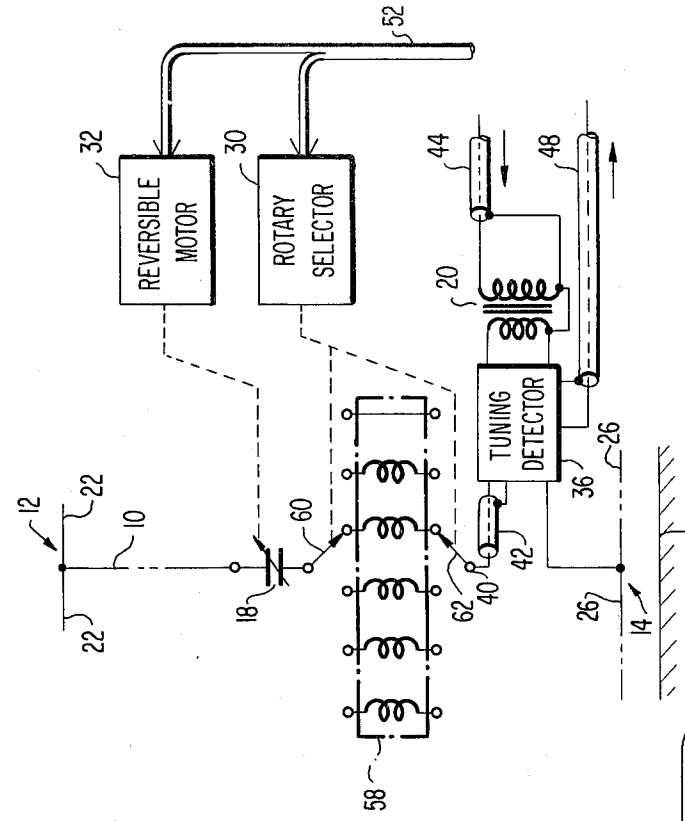

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REVERSIBLE MOTOR
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TUNING DETECTOR
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FIG. 4

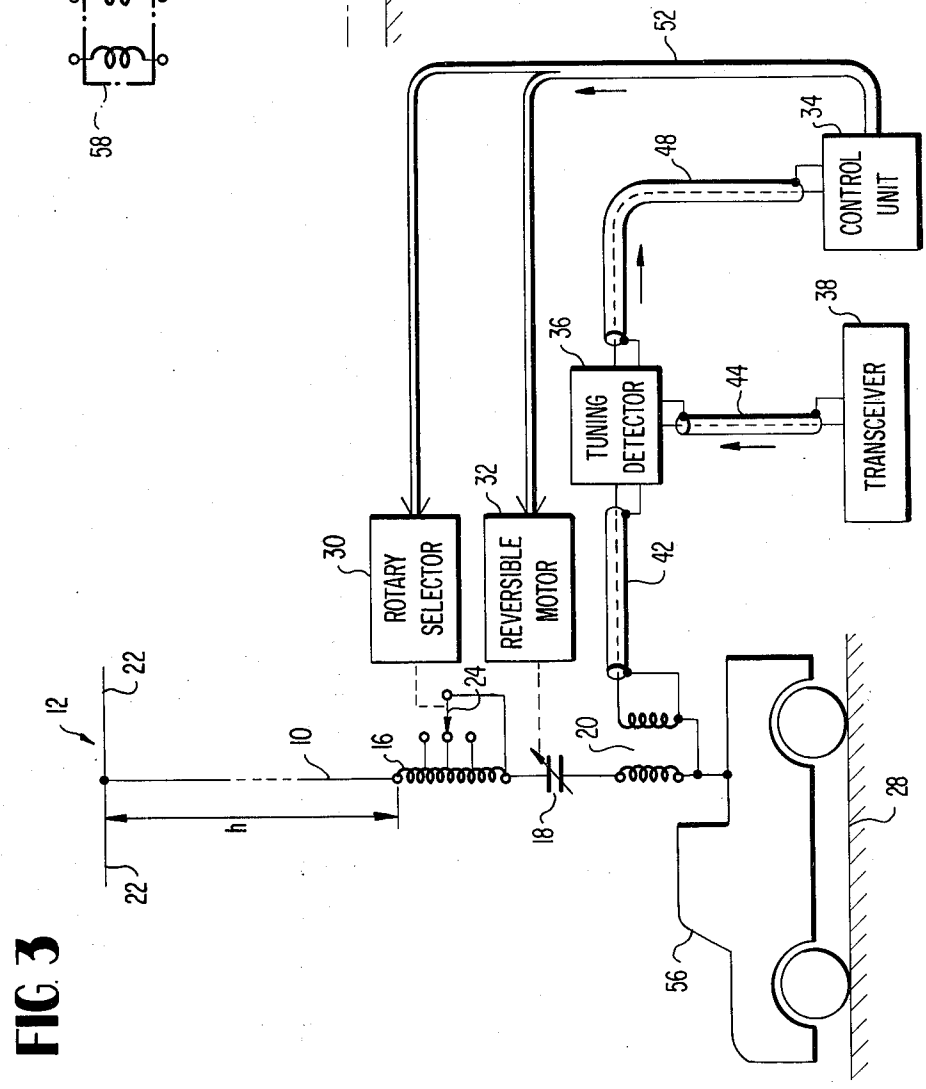

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FIG. 3

TACTICAL HIGH FREQUENCY ANTENNA

The invention described herein may be manufactured and used by or for the government for government 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. Felsenheld, 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 radiating 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.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an electrical schematic diagram illustrative of the land based embodiment of the subject invention;

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 **10** having a capacitive top termination **12** connected to the upper 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 capacitance **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 capacitor 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

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 pluralityof 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:

$$\frac{f_2}{f_1} \cong \sqrt{\left(\frac{C_{max}}{C_{min}}\right) \times \left(\frac{C_{ant} + C_{min}}{C_{ant} + C_{max}}\right)} \qquad (1)$$

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_{ant} denotes the antenna capacitance. Typically $C_{ant} = 50pF$, $C_{min} = 10pF$, and $C_{max} = 300pF$ which then results in a ratio of

$$\frac{f_2}{f_1} \cong 2.2.$$

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:

$$\frac{f_2}{f_1} \cong \sqrt{\frac{L_F + L_{max}}{L_F + L_{min}}} \qquad (2)$$

where f_2 and f_1 are the upper and lower operating frequencies, L_{max} and L_{min} is the inductance of the variable inductance utilized as the fine tuning element, and L_F denotes the fixed inductance, i.e. inductance of the element **16** shown in FIG. **1.** For typical values of $L_F = 100\mu H$, $L_{max} = 12\mu H$ and $L_{min} = 1\mu H$, a ratio of

$$\frac{f_2}{f_1} \cong 1.05$$

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 capicator 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 sourse 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 diagrammatic 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 broad band 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 λ/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. 5kilohms 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** decreases.

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 selector driven switch **24,** the present embodiment discloses the use of a plurality of inductors **58** selectively coupled individually in series with the fine tuning capacitor **18** and the vertical radiator element **10.** The selective interconnection is provided by means of a multiple position two section band selector switch including one section **60** which connects one end of the selected inductor to the variable capacitance **18** while the other section **62** connects the opposite end of the same selected inductor to the antenna feed point **40.** As in the other embodiments the switch position is mechanically controlled by the roatry selector **30.**

Also in the embodiment shown in FIG. **4,** the tuning detector **36** is located between the antenna and the broadband radio frequency transformer **20.** In other words their relative positions are reversed with respect to the antenna feedpoint **40** and RF source, i.e. the transceiver **38.**

The embodiment disclosed in FIG. **4** has several advantages over the two previous embodiments in that it is possible in some instances with this configurations to obtain more than one frequency at which resonance is indicated by the phase sensing type tuning detector **36** for a given setting of the fine tuning capacitor **18** and the band select setting of the inductor **16.** Although only one of the resonances constitutes the desired resonance frequency associated with the antenna, the "extraneous resonances" results from the relatively complicated capacitive and inductive coupling occuring between the various sections of the coarse tuning (band select) inductor **16.** In principle the extraneous resonances are not harmful as long as they can be distinguished from the desired antenna resonance and are somewhat separated in frequency. From a practical standpoint, however, it is desirable and in some applications essential to eliminate all extraneous resonances within the particular band of operation in order that the antenna can be resonated without ambiguity.

By utilizing separate tuning inductors for each selected band within the HF range, only one resonance frequency was observed in each band corresponding to the desired antenna resonance. All extraneous resonances occured at frequencies outside the operating band.

Secondly the stray reactances of the transformer **20** can in some instances cause faulty tuning when the transformer is connected between the phase sensing tuning detector **36** and the antenna. The problem is obviated when the tuning detector **36** is installed between the antenna and the transformer.

The advantage obtained by the configuration shown in FIG. **4** is that separate coarse tuning inductors facilitate the selection or setting of the various bands. Separate inductors also yield a lower power loss than a single tapped inductor, and more importantly, since only the desired antenna resonance is obtained in each band the use of separate inductors facilitates automatic tuning.

Under normal circumstances, the antenna radiating element **10** will be initially in the non-resonant state and thus will be badly matched to the transmitter portion of the transceiver **38.** Consequently, little power will be supplied to the non-resonant antenna and the DC error signal produced by the phase sensor **36** will be correspondingly small. The polarity of the phase sensor output signal determines of course whether to increase or decrease the tuning reactor. As the fine tun-

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, reasonance is indicated wherein reflected power is minimized, which is at the point of resonance. However, when the antenna is nonresonant, 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 30MHz) 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 heretofore 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 radials lying on 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 0.05λ 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 30MHz, 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 valve to provide a coarse tuning of said radiating element to a predetermined frequency band within a selected frequency range comprised of a plurality of overlapping 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;

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 effect resonance of said radiating element;

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 conduit circuit means and said third 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 **3** further including an electrically driven rotary selector switch coupled to said taps and being operable to short 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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