RADIO TELEPHONE WITH AUTOMATICALLY TUNED LOADED ANTENNA

Filed June 12, 1964 3 Sheets-Sheet 1

FIG. 1

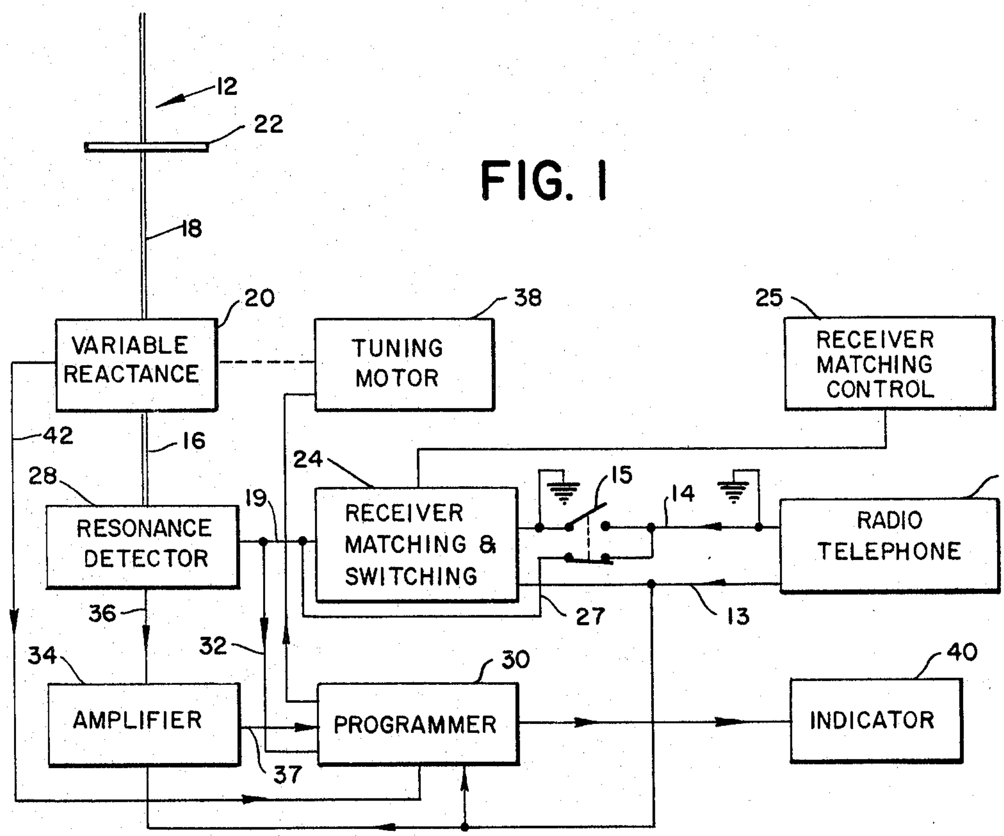
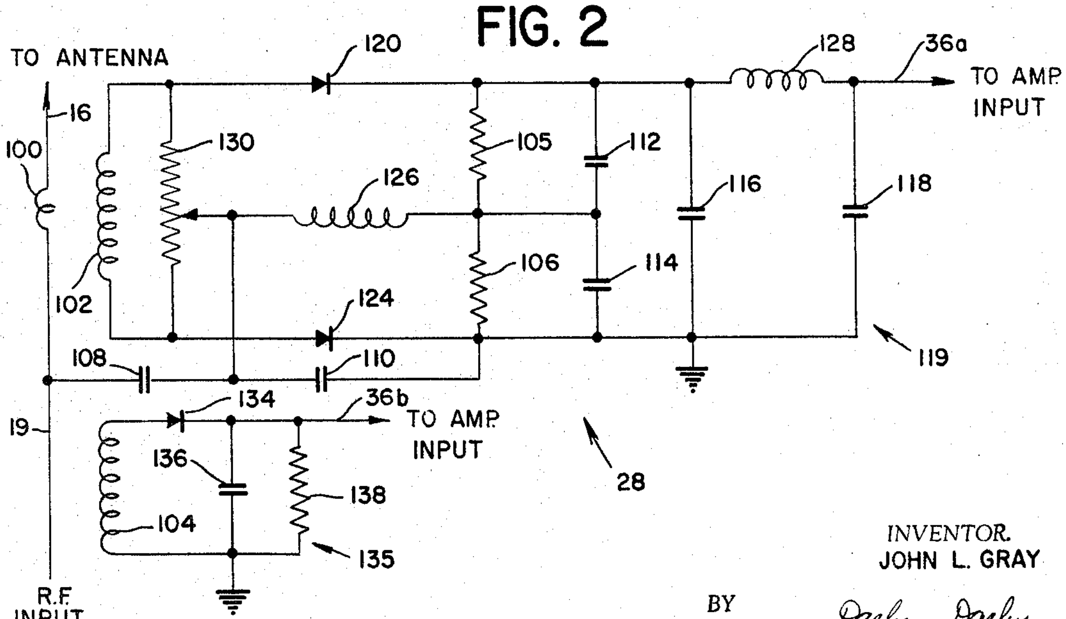


FIG. 2



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RADIO TELEPHONE WITH AUTOMATICALLY TUNED LOADED ANTENNA

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FIG. 2A

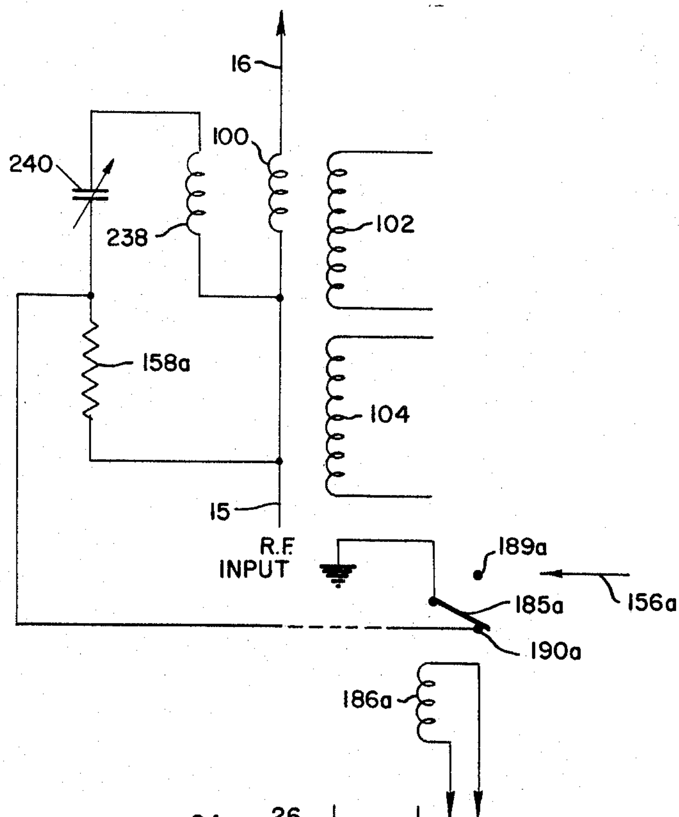
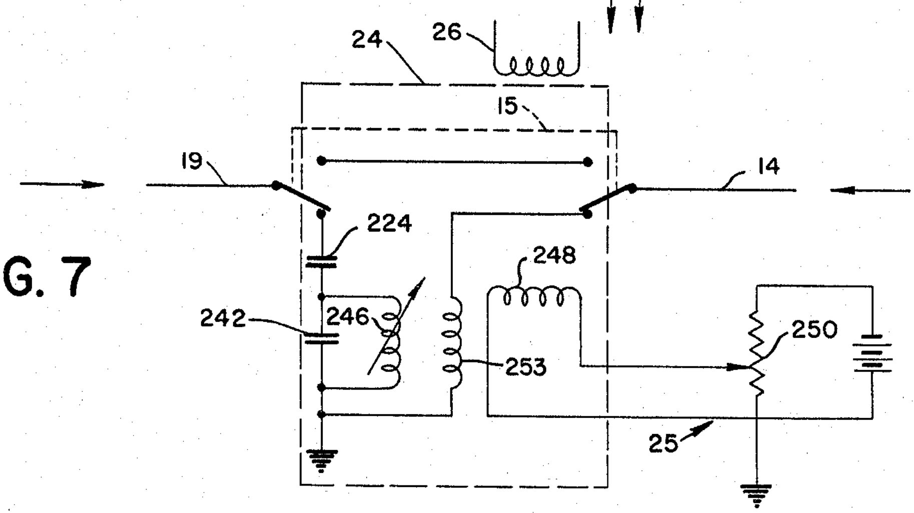


FIG. 7



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RADIO TELEPHONE WITH AUTOMATICALLY TUNED LOADED ANTENNA

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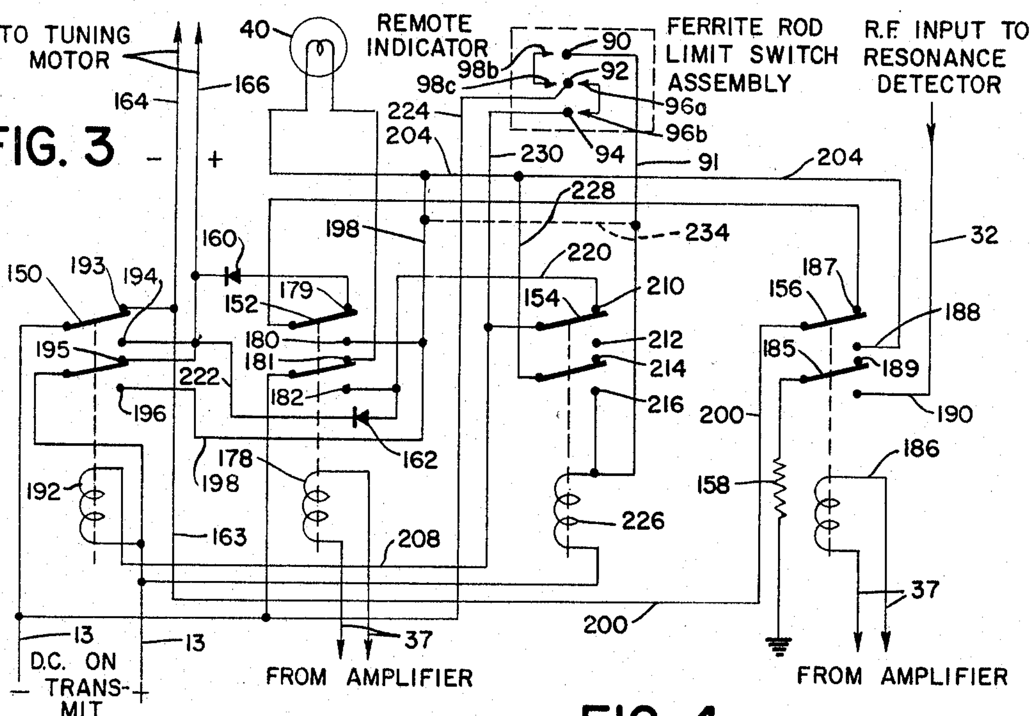


FIG. 3

FIG. 4

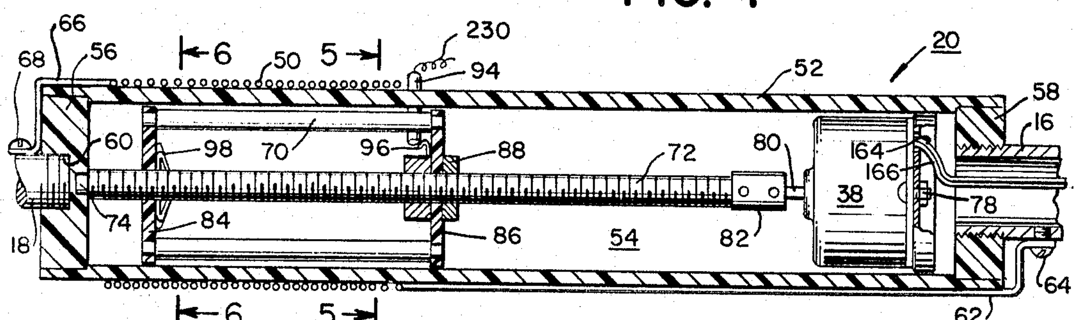


FIG. 6

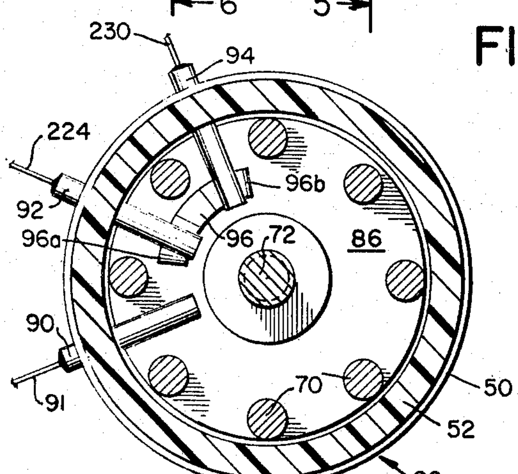
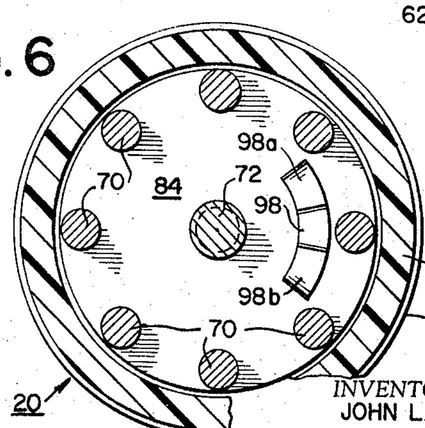


FIG. 5



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United States Patent Office 3,381,222
Patented Apr. 30, 1968

3,381,222

RADIO TELEPHONE WITH AUTOMATICALLY TUNED LOADED ANTENNA

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Filed June 12, 1964, Ser. No. 374,765
12 Claims. (Cl. 325—25)

ABSTRACT OF THE DISCLOSURE

An apparatus for automatically self-tuning a loaded antenna with a sensor coupled to the antenna circuit for sensing when the antenna is tuned for resonance to an RF signal source. A logic circuit responsive to signals from the sensor for controlling the movement of a loading coil in the antenna to place the antenna in resonance with the RF signal.

This invention relates to antennas and antenna systems, and more particularly it relates to antennas and antenna systems transmitting and receiving radio signals which incorporate adjustable inductance devices for "tuning" the antennas and antenna systems.

This invention is particularly useful where a single antenna system is used over a wide frequency range by unskilled personnel, and the antenna is located remotely from the transmitter or receiver.

The strength of the electromagnetic field radiated from a section of wire carrying radio frequency current primarily depends on the length of wire and the amount of current flowing. Other things being equal, the field strength is directly proportional to the current flowing. Hence, it is desirable to make the current flowing as large as possible considering the power available. It is well-known that the power radiated by an antenna operated at resonance is substantially increased over one not operated at resonance for a given power availability at a transmitter, and similarly the receptivity of a resonant antenna in receiving radio energy is increased.

In practice, especially in mobile work, it is often necessary to provide a single antenna, usually of fixed small physical length, which is capable of satisfactory operation over a broad band of frequencies. The antenna operates in such a manner that its impedance match with a transmission line at each of the frequencies is satisfactory for operability. This type of operation and construction is used often in aircraft, automotive vehicles, trucks, small boats or other moving conveyances, where for reasons of economy of space and weight, a single antenna system must be used.

In many instances these antennas of fixed length have a maximum dimension, which is small compared to the operating wave length, and have impedance characteristics which vary rapidly with frequency. Good operation is normally only achieved over a relatively narrow range of frequencies, if fixed matching networks and tuning elements are used. For use over a range of frequencies, these antennas require retuning of the matching circuit of the antenna system as the frequency of operation is changed.

The industry has long recognized the advantages of being able to exactly resonate an antenna to any frequency quickly over a certain range, and many attempts have been made to solve this problem. Antennas have been remotely tuned by switchable lumped reactances, sliding tapped inductions and physically changing the length of the antenna. While these methods have improved the matching and tuning, they have not solved the problem.

These advantages are especially significant for mobile operation in which physical limitations ordinarily require antenna length to be smaller than a quarter wave length of the wave length of the exciting energy. Also, mobile operation incurs constant change of environment, which continually changes the resonant characteristics of the antenna, and operation by relatively unskilled personnel.

One of the objects of this invention therefore is to provide an antenna capable of being automatically resonated over a band of frequencies.

Another object of the present invention is to provide an antenna system having a higher radiating efficiency over a wide band of frequency.

A further object of the present invention is to provide a single antenna capable of having its effective electrical length quickly and easily varied to offer maximum effectiveness for radiation of energy at two or more frequencies, without requiring a complex tuning or matching network to maintain a constant input impedance characteristic.

Another object is to provide an antenna system which can be adjusted for operation with a variety of transmitters and receivers operating at the same or different frequencies and which may be adjusted for operation remotely.

Still another object of the present invention is to provide an antenna system, which can be electrically changed to adapt to physical changes in environment and which automatically prevents damage to the equipment regardless of careless operation by the operator.

A still further object of the present invention is to provide an antenna system of relatively constant physical length, which may be made resonant automatically covering a range of frequencies and which is relatively simple and rugged in construction and is small and compact in size.

Other objects, features and advantages of the invention will become apparent upon reading the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a block diagram showing an antenna system in accordance with the present invention remotely coupled to a transmitter and receiver, which may operate on different frequencies;

FIGURE 2 is a schematic diagram of a circuit of the present invention for detecting whether an antenna is resonant or non-resonant with respect to a given signal;

FIGURE 2A is a modification of a portion of the circuit of FIGURE 2;

FIGURE 3 is a schematic diagram of a circuit in accordance with the present invention for automatically tuning the antenna during transmission;

FIGURE 4 shows a cross-sectional, side-elevational view of a variable reactance in accordance with the present invention;

FIGURE 5 is a cross-sectional view taken along line 5—5 of FIGURE 4;

FIGURE 6 is a cross-sectional view of the variable inductance taken along line 6—6 of FIGURE 4; and

FIGURE 7 is a schematic diagram of circuits for switching a receiving unit into and out of the antenna circuit.

Referring now to the drawings, FIGURE 1 diagrammatically shows a transmitting-receiving system in which radio signals from a transmitting and/or receiving apparatus 10, illustrated as a radio-telephone, are radiated or received by a remotely positioned antenna 12. Remotely positioned refers to a distance of about six feet or more. The following description will discuss the operation of the system for transmission until otherwise specified. The signals are fed from transmitter 10 to the antenna structure 12 through transmission lines or cables 14, which may be coaxial cables. The receiver, also designated as 10, may be operated on a frequency different from that used by the transmitter.

Antenna 12 is shown as being made up of a plurality of elongated, electrically conductive sections, which are designated as a base section or radiator 16 and an upper section or radiator 18. Additionally, as discussed below, interconnecting a resonance detector unit 28 and a receiver matching and switching unit 24 is an antenna section 19.

Physically interposed between antenna base portion 16 and antenna upper portion 18 is a variable reactance assembly 20, which, as explained in detail below, includes an inductive element or "loading coil" connected in series with antenna sections 16 and 18. Antenna 12, also illustratively shown, has a capacitive top loading element 22, which as illustrated, takes the form of a disc and is used for improving efficiency, and allowing antenna 12 to be resonated with less loading inductance and therefore less losses. The design of capacitive loading element 22 should be such as to offer the maximum capacity that is mechanically possible and not present a shorted conductive path to any of the magnetic flux generated by the loading coil in variable reactance assembly 20.

During transmission, a radio signal from radio-telephone unit 10 is carried by transmission line 14, which is preferably a coaxial line. Transmission line 14 is interconnecting radio-telephone unit 10 and a receiver matching and switching unit 24. Interconnected in line 14 is a switch or relay 15, one section of which in its closed position bypasses unit 24 via transmission line 27, when relay 15 is energized by a signal from radio-telephone unit 10 during transmission. The transmitted signal is fed directly into antenna section 19 via transmission line 27 and into lower radiator 16 via resonance detector unit 28. If antenna 12 is not at resonance with the frequency of the transmitted signal, a suitable load impedance 158, which, as shown, is in programmer unit 30, is placed in the output line via conductor 32. Since antenna 12 is normally initially detuned, it is not accepting any radio signals from transmitter 10 and dummy load impedance 158 in the output circuit prevents the output amplifier tubes and their modulator of transmitter 10 from exceeding their normal dissipation. In a manner as will be discussed hereinafter, resonance detector unit 28 detects that antenna 12 is not properly tuned and signals an amplifier circuit 34 via conductor 36. Preferably, amplifier circuit 34 comprises dual circuits, which are not shown. The signal transmitted by resonance detector unit 28 to amplifier circuit 34 varies in polarity in response to whether the tuning frequency of the antenna is above or below the freqency of the transmitted signal. For example, the signal transmitted from resonance detector unit 28 to amplifier circuit 34 can be made positive, if antenna 12 is tuned to a frequency above the exciting transmitted radio frequency and negative if the tuned frequency is below the frequency of the exciting transmitted radio frequency. Amplifier circuit 34 is normally in an ON condition and sending a signal, or signals where dual circuits are utilized, to programmer unit 30 via conductors 37 for adjusting the resonant frequency of antenna 12. When amplifier circuit 34 receives a signal of different polarity from resonance detector unit 28, amplifier circuit 34 signals programmer unit 30 via conductor 37, which varies the resonant frequency of antenna 12, as discussed hereinafter. Depending upon the signal received by programmer unit 30 from amplifier circuit 34, the direction of rotation of motor 38 is controlled to vary the inductance of reactance assembly 20, so as to tune antenna 12 towards resonance at the frequency of the transmitting signal. As antenna 12 approaches resonance, it begins to accept the radio frequency energy from transmitter 10. The acceptance of the transmitted signal by antenna 12 is also sensed by resonance detector unit 28, which signals programmer unit 30 via dual amplifier circuit 34 for removing the dummy load from line 32 and also begins the process to stop motor 38. Various modes of programming can be used to tune antenna 12 and maintain antenna 12 in tune, which will be discussed hereinafter. Advantageously, when antenna 12 is in tune, the operator is signalled in some manner, such as illuminating a signal light 40 to provide a simple visual indication to the operator, when antenna 12 is accepting maximum power. Of course, other signaling devices, such as a buzzer, could be used.

In order to prevent damage to the mechanism of the variable reactance assembly 20, some type of limit control must be utilized, which automatically triggers programmer unit 30 via line 42 to reverse the direction of motor 38.

If the frequency of the received signal differs from the frequency of the transmitted signal, the impedance of the received signals must be adjusted to the cable impedance to avoid attenuation. As shown in FIGURE 1, a separate receiver switching and matching unit 24 is used, which is remotely adjusted by unit 25.

As shown in FIGURE 7, receiver switching and matching unit 24 is in the antenna circuit only during reception. Relay switch 15 connects or bypasses unit 24 in accordance with signals received by coil 26. Antenna section 19 is coupled into a parallel-tuned tank circuit 242 via a coupling capacitor 224. The resonant frequency of tank circuit 242 is adjusted by means of a saturable reactor 246. The reactance of reactor 246 is remotely controlled by a tuning current in a coil 248, which current is adjusted by a pot 250. Transmission line 14 is coupled into tank circuit 242 by a link 253. The ratio of the turns of link 253 to the turns on the saturable reactor 246 is adjusted to give the best match over the band of frequencies to be covered.

During transmit operation, the separate, remotely controlled receiver switching and matching unit 24 is switched out of the antenna circuit by switch 15 being open when coil 26 is energized. The transmitted signal bypasses receiver switching and matching unit 24 and is fed directly into antenna section 19. For receive operation, the operator sets the receiver of the radio-telephone 10 to the desired frequency, and then adjusts pot 250 in the receiver matching control network 25 for maximum signal.

FIGURES 4, 5, and 6 show the details of variable reactance assembly 20. The lower end of upper radiator 18 is fixedly mounted to one end of variable reactance assembly 20. Similarly, the upper end of lower radiator 16 of antenna 12 is fixedly mounted to the other end of variable rectance assembly 20. Variable reactance assembly 20 comprises an elongated hollow coil form 52, preferably cylindrical in form, formed of insulating material and having a central passage 54 therethrough. At opposite ends of form 52 are end pieces 56 and 58 positioned transversely across passage 54. End piece 56 has a tapped opening 60 for attachment of the upper radiator 18, which has a cooperatively threaded stud for mating with threaded opening 60. Similarly, the top end of the lower or base radiator 16 is received within the corresponding end 58 of tubular form 52 in any convenient manner. Advantageously, base radiator 16 is hollow.

Mounted about coil form 52 is a coil 50. Coil 50 is advantageously a continuous conductor or a number of conductors connected in series, which is wound in either a single or a multiple layer formation in a conventional manner. Proper selection of the wire size and the number of turns per inch in the helix and the manner of winding will reduce the losses caused by eddy currents formed in the individual turns of the coil 50, as well as lower the capacitive coupling between adjacent turns. Coil 50 is electrically connected to the base section radiator 16 by means of a conductor 62, which is shown electrically connecting base radiator 16 by means of a screw 64. Similarly, coil 50 is electrically connected to the upper radiator by means of a conductor 66, which is connected to upper radiator 18 by a screw 68.

To increase the inductance of coil 50, a core of high permeability material is disposed within passage 54 and within and adjacent coil 50. To cover a wide range of power output transmitters, a series of spaced apart rods 70 is distributed about the inner diameter of coil 50, as seen best in FIGURES 5 and 6. For obtaining sufficient reactance change, a high permeability material is used, such as a ferromagnetic ceramic material, such as described by Snoeck in U.S. Patents 2,452,529, 2,452,530 and 2,452,531. This material maintains a high Q even when subjected to substantial magnetic saturation and also provides a wide range of inductance variation. To prevent individual rods 70 from being overheated at higher radio frequency power input into coil 50, it is necessary to place a shield about each of the rods to insure that the magnetic flux from coil 50 is evenly distributed between the several rods 70. In place of the individual shields about each of the rods, an electrically conductive member 72 mounted along the axis of symmetry of the rods 70 provides sufficient shielding to promote even distribution of the magnetic flux to the various rods 70 and thereby eliminating rod hot spots and lossess. Conductive member 72 may be made of brass, aluminum, copper and can also be silver-plated.

To vary the inductance of coil 50, rods 70 are withdrawn or introduced into coil 50 at a desired rate. It is observed that withdrawing or introducing rods 70 into coil 50 a predetermined amount, resonates antenna 12 for operation at the desired frequency. Therefore, the preselected introduction or withdrawing of rods 70 permits quick and simple adjustment of the reactance of coil 50, which varies the resonance of antenna 12 over a variety of frequency ranges.

Conductive member 72 is shown in the form of a cylinder and is threaded as seen best in FIGURE 4, and as discussed below operates as a shaft. End piece 56 of coil form 52 has an interiorly directed, centrally disposed opening 74 for rotatably receiving a reduced diameter end of member 72. Mounted within coil form 52 and adjacent the upper end of lower radiator 16 is reversible motor 38 with a suitable gear train for securing the desired output speed of rotation. Motor 38 and its gear train are shown as a single unit and are fixedly mounted within tubular form 52 in any convenient manner, such as shown by a bolt and nut 78. Advantageously, motor 38 is reversible and has its output shaft 80 rotate at a fixed speed determined by the gear train. Output shaft 80 is coupled to the upper end of member 72 by means of an insulated coupling 82. Rods 70 are mounted in any convenient manner on two end plates 84 and 86, which are made of insulated material. As shown, the ends of rods 70 are reduced in diameter and fitted into openings in the respective end plates 84 and 86. Attached to one of the rod end plates, illustratively shown as attached to end plate 86, is a threaded bushing 88. Threaded bushing 88 cooperatively engages threaded member 72 for moving rods 70 and end plates 84 and 86 in unison longitudinally along the interior of coil form 52. Extending through tubular form 52 and between adjoining rods 70 are a plurality of stop fingers, illustratively shown as three in number, 90, 92 and 94. Fingers 90, 92, and 94 prevent the rod assembly from rotating during longitudinal movement within passage 54. Hence, when motor 38 rotates threaded member 72 in one direction, rods 70 move into coil 50 and when motor 38 rotates in the opposite direction, rods 70 are withdrawn from coil 50. Fingers 90, 92 and 94 also limit the length of longitudinal movement of the assembly of rods 70 to prevent damage by the movement of the assembly of rods 70 exceeding the length of coil form 52. As shown in FIGURE 4, attached to the interior surface of end plate 86 is a conductive sheet 96, which is positioned to have portions 96*a* and 96*b* engage fingers 92 and 94, respectively, when fully traversed, so that rods 70 are fully inserted within coil 50, as shown in FIGURE 4. Fingers 92 and 94 are electrically connected by means of sheet 96. Similarly, attached to the interior surface of end plate 84 is a conductive sheet 98, which is positioned to have portions 98*a* and 98*b* contact fingers 90 and 92, respectively, when the assembly of rods 70 is fully traversed to the left, as shown in FIGURE 4. Fingers 90 and 92 are electrically connected by means of electrical conductive sheet 98. Advantageously, the electrical conductors 91, 224 and 230 for fingers 90, 92 and 94, respectively, and electrical conductors 164 and 166 for motor 38, are carried within the interior of antenna section 16. When corresponding fingers 90, 92 and 94 make contact with their corresponding conductive sheets 96 or 98, a signal is sent to reverse direction of motor 38 in a manner which will be discussed below.

The schematic circuit diagram of the resonance detector unit 28 is shown in FIGURE 2. Resonance detector unit 28 signals when antenna 12 is in condition to accept efficiently the radio frequency signal. Antenna 12 is both transformer and capacity-coupled to resonance detector unit 28. The primary coil 100 of the R.F. transformer is coupled to antenna 12 and the R.F. source from radio-telephone 10. Primary coil 100 is coupled to two transformer secondary windings 102 and 104. The circuit composed of coils 100 and 102, and resistors 105, 106 and 130, capacitors 108, 110, 112, 114, 116 and 118, and diodes 120 and 124, and choke coils 126 and 128, form a conventional phase detector circuit with R.F. current filtering in the output circuit. This circuit is hereinafter designated as resistive load detector circuit 119. An L.C. filter is composed of capacitors 116 and 118 and coil 128. When antenna 12 is resistive and drawing current, the output across capacitor 116 will be 0. Capacitors 108 and 110 form a capacitive network divider and feed capacitively coupled R.F. voltage to the resistor-diode network formed of resistors 105 and 106 and diodes 120, and 124, to provide a voltage in phase with the antenna R.F. voltage. Depending upon the polarity of coil 100 with respect to coil 102, the voltage across capacitor 116 will be of one polarity when antenna 12 has a capacitive reactance (i.e., the antenna is tuned to a frequency above the exciting radio frequency) and the polarity of the voltage will be reversed when antenna 12 has an inductive reactance (i.e., the antenna is tuned below the exciting radio frequency).

Resistor 130 has an adjustable tap which is used to offset the null or zero output in the L.C. output filter shown, so that the system ceases to tune when antenna 12 is accepting maximum power.

The circuit shown in FIGURE 2 composed of coil 100 and coil 104, diode 134, capacitor 136 and resistor 138, produces a positive output voltage signal when R.F. current is accepted by antenna 12 through coil 100. This circuit is hereinafter designated current detector circuit 135. The output signals of resonance detector unit 28 are coupled to amplifier unit 34 via conductors 36*a* and 36*b*. Conductors 36*a* and 36*b* may each be connected to a separate amplifier circuit.

Amplifier unit 34 is a conventional D.C. amplifier, and is preferably a transistorized DC amplifier, such as found in the Transistor Manual, sixth edition, published by General Electric Company; RCA Transistor Manual, Technical Series SC–10; and Silicon Zener Diode and Rectifier Handbook, second edition, published by Motorola, Inc. Amplifier unit 34 amplifies the output signals of resonance detector unit 28 received via conductors 36*a* and 36*b*, and feeds these amplified signals into programmer unit 30.

The schematic wiring diagram of programmer unit 30 is shown in FIGURE 3. Programmer unit 30 is electrically coupled to amplifier unit 34, resonance detector unit 28 and the limit switch assembly of control rods 70, as shown in FIGURE 4. As shown in FIGURE 3, programmer unit 30 contains four relays, 150, 152, 154 and 156, which advantageously each is a double-pole, double-throw type, and is shown in its unenergized state. Relay 150 operates to control the direction of rotation of motor 38, which controls the position of rods **70** in variable reactance assembly **20**. Once relay **150** is energized, it remains energized for as long as the transmit signal from radio-telephone unit **10** continues or until relay **154** is energized.

Relay **152** operates to turn off the tuning motor **38**. Relay **152** is controlled by the output signal of amplifier unit **34**, which in turn receives a signal from resonance detector **28** when antenna **12** is resistive, or is tuned to the transmitted signal. When relay **152** is energized, it forces relay **150** to latch, unless relay **154** is energized or closed.

Relay **154** is used to unlatch relay **150** and thereby reverse the direction of rotation of tuning motor **38** when the appropriate limit switch contact **98** is made with corresponding fingers **90** and **92**. Relay **154** remains energized for as long as relay **152** is energized.

Relay **156** operates to prevent relay **152** from shutting off tuning motor **38** unless relay **156** is deenergized. Relay **156** also places a dummy load, shown as resistor **158**, across the R.F. output line to protect the transmitter during tune-up of antenna **12** and releases the dummy load resistor **158** when deenergized. Relay **156** is normally energized by an output signal from dual amplifier unit **34**, which in turn receives an output signal from resonance detector unit **28** when antenna **12** begins drawing current. When antenna **12** begins drawing current, amplifier circuit **34** signals relay **156** to shut off so as to remove the dummy load resistor **158** from the R.F. output circuit and allows relay **152** to shut off the tuning motor **38**.

Diode **160** is interposed between conductor **166** and contact **179** of relay **152** to give tuning motor **38** dynamic braking when it is shut off by relay **152**. Diode **162** prevents momentary shorting of the supply energizing current when relay **150** is being energized by the closure of relay **152**. Indicator **40** is energized when relay **150** is energized and relay **152** is deenergized, which indicates the tune-up of antenna **12**.

Motor **38** is electrically connected to programmer unit **30** by conductors **164** and **166**, which are carried within lower radiator **16**, as shown in FIGURE 4. When both relay **150** and relay **152** are energized, motor **38** receives a signal via conductors **164** and **166**, so as to rotate member **72** in a direction to withdraw rods **70** from within the reactance coil **50** and thereby raise the resonant frequency of antenna **12**.

Generally the operation of the antenna system of the present invention is as follows:

Prior to the antenna system of the present invention, receiving an initial signal from radio-telephone unit **10**, relays **150**, **152**, **154** and **156** in programmer unit **30** are in their unenergized condition, as shown in FIGURE 3. An initial signal from radio-telephone unit **10** is sent to programmer unit **30** via conductor line **13**. Advantageously, this signal is a D.C. signal, which is readily available during the transmit cycle of radio-telephone unit **10**. When this initial signal is received by programmer unit **30**, relay **150** is unlatched and tuning motor **38** of the variable reactance assembly **20** begins rotation in a direction to introduce tuning rods **70** into coil **50** for lowering the resonance of antenna **12**. However, simultaneously amplifier unit **34** is actuated by this initial signal via line **13**, and energizes relays **152** and **156** via conductors **37**. Signals from amplifier unit **34** via conductors **37** energizes coil **178** of relay **152**, thereby closing contacts **180** and **182**. Similarly, amplifier unit **34** energizes coil **186** of relay **156** via line **37** and closes contacts **188** and **190**.

When relay **152** is closed, contact **182** is closed, which energizes coil **192** of relay **150** for completing the circuit via contact **210** of relay **154** and conductor **220**, thereby closing relay **150**, which closes contacts **194** and **196**. Closing of relay **150** reverses the polarity of the voltage applied to motor **38** via conductors **164** and **166**, and thereby reversing its direction and causing variable reactance assembly **20** to tune the antenna upward in frequency. When relay **150** is deenergized and an initial D.C. signal is applied via conductor line **13**, conductor **164** to motor **38**, is negative as shown and conductor **166** is positive as shown. Energizing relay **150** closes contact **194** making conductor **166** negative and closes contact **196** making conductor **164** positive via conductors **198** and **204**, through contact **188** of relay **156** to conductor **200**. Since relay **156** is energized by the output of amplifier unit **34**, dummy load resistor **158** is in the R.F. output circuit via transmission line **32** and contact **190**. Contacts **194** and **196** of relay **150** are connected when relay **156** is energized in the manner described above with respect to making conductor **164** positive.

Relay **150** remains latched while relay **152** is energized, since the circuit of coil **192** of relay **150** is completed from line **13** through coil **192** via conductor **208** through contact **210** of relay **154**, via conductor **220** through contact **182** of relay **152** to the opposite polarity. With relay **150** latched, motor **38** continues to rotate in the same direction until control rods **70** are fully withdrawn. When control rod assembly **72** is fully withdrawn from coil **50**, conductive sheet **98** on end plate **84** makes contact with fingers **90** and **92**. Finger **92**, as shown in FIGURE 3, is connected to negative potential via line **224**, which grounds finger **90**. Finger **90** is connected to coil **226** of relay **154** for completing the circuit of coil **226** and thereby energizing coil **226** and closing relay **154**. When relay **154** closes, it deenergizes relay **150** by breaking of contact **210**. When relay **150** is deenergized, the polarity of motor **38** is reversed, causing motor **38** to reverse direction and introduce slug assembly **70** into coil **50**. Coil **226** of relay **154** continues to be energized and thereby relay **154** is closed through contact **216** of relay **154**, via conductors **228** and **204**, through contact **188** of relay **156**, via conductors **200** and **163**, through contact **193** of relay **150** to negative. Motor **38** will continue to rotate in this direction until control rods **70** are fully within coil **50** and sheet **96** makes contact with fingers **92** and **94**, as shown in FIGURE 5. When this occurs, finger **94** is grounded and completes the circuit of coil **192** of relay **150** via conductor **208** for causing a current to pass through coil **192** and thereby energize relay **150**, which changes the polarity supplied to motor **38** via conductors **164** and **166**, which reverses the direction of rotation of motor **38** for withdrawing control rods **70** from coil **50**. The closing of relay **150** breaks contact **193** which in turn breaks the circuit of coil **226**, which unlatches relay **154**.

Control rods **70** continue to oscillate between sheets **96** and **98** until an R.F. signal is received.

When a radio frequency signal, higher in frequency than the antenna resonant frequency, is attempted to be transmitted via antenna **12**, antenna **12** appears as an inductive load to resonance detector unit **28**. The output across capacitor **116** of the phase detector circuit of resonance detector unit **28** is negative and since there is no antenna current, the output from the current detector circuit **135** of resonance detector unit **28** is 0. A zero current and a negative phase signal output from resonance detector unit **28** causes amplifier **34** to conduct, and programmer unit **30** is actuated in a manner similar to that described above, with no R.F. signal applied. The initial actuating signal from radio-telephone unit **10** via line **13** energizes relay **150** and the outputs of amplifier **34** energize relays **152** and **156**. With the relays in this condition, motor **38** is rotated in a direction to remove control rods **70** from coil **50**, which raises the resonant frequency of antenna **12**. As the resonant frequency of antenna **12** approaches the frequency of the R.F. signal, antenna **12** begins drawing current. Current flowing in antenna **12** causes the current detector circuit **135** of resonance detector unit **28** to transmit a positive signal to the circuit of amplifier **34** coupled to coil **186** of relay **156**, which breaks the output signal from amplifier **34** and deenergizes relay **156**. The opening of relay **156** removes dummy load resistor **158** from the R.F. output conductor 32 allowing radio-telephone unit 10 to apply full power output to antenna 12. Further, the opening of relay 156 places relay 152 in condition to stop motor 38. Motor 38 continues to rotate in the same direction even when relay 156 opens. As the resonant frequency of antenna 12 increases, the output signal of resistive-load detector circuit 119 of resonance detector unit 28 becomes less negative in phase and then becomes positive. A positive signal received by amplifier 34 from the resistive load detector circuit 119 of resonance detector unit 28 cuts off the output signal of amplifier 34 applied to relay 152 and thereby deenergizes coil 178 of relay 152. The opening of relay 152 turns off motor 38 by breaking contact 180 of relay 152 and places dynamic braking diode 160 across motor 38 through contact 179. Simultaneously, indicator 40 is energized by reason of contact 181 of relay 152. In the present operation of this unit, relays 152, 154 and 156 are deenergized and only relay 150 remains energized. As discussed above, variable resistor 130 of resonance detector unit 28 is adjusted so that motor 38 and control rods 70 stop when antenna 12 is accepting maximum power.

When a radio frequency signal having a lower frequency than the resonant frequency of antenna 12 is transmitted by radio-telephone unit 10 and an initial signal is applied via line 13, antenna 12 appears as a capacitive load to resonance detector unit 28. The output of the resistive load detector circuit 119 of resonance detector unit 28 is positive. Applying the positive signal from resistive load detector circuit 119 to amplifier 34 via conductor 36*a*, breaks the output signal of amplifier 34 coupled to coil 178 of relay 152 of programmer unit 30. No current flows in antenna 12 so the current detector circuit 135 is zero. Amplifier 34 receiving no signal from current detector circuit 135 sends a signal to coil 186 of relay 156. Thus, relays 150, 152 and 154 of programmer unit 30 remain open. Since relay 156 is energized, dummy load resistor 158 is placed in the output circuit of radio-telephone unit 10. The polarity of the signal applied to motor 38 directs control rods 70 into reactance coil 50, which decreases the resonant frequency of antenna 12. As the resonant frequency of antenna 12 approaches that of the frequency of the transmitting signal, antenna 12 begins to accept current, which causes current detector circuit 135 of resonance detector unit 28 to transmit a positive signal to amplifier unit 34 via conductor 36*b*, which cuts off the signal from amplifier unit 34 to coil 186 of relay 156, thereby deenergizing coil 186. Opening of relay 156 removes dummy load resistor 158 from the RF output line, which allows antenna 12 to receive all of the output signal from radio-telephone unit 10 and gives control to relay 152 to shut off motor 38. As the resonant frequency of antenna 12 is reduced, it becomes closer to the frequency of the transmitted signal, causing the phase of the output signal of the resistive load detector circuit 119 of resonance detector unit 28 to become less positive until the output signal ceases to be positive and becomes essentially zero, when the resonant frequency of antenna 12 is equal to the frequency of the transmitted signal. When the output signal from resistive load detector circuit 119 is essentially zero, a circuit in amplifier unit 34 coupled to coil 178 of relay 152 is biased on and begins to conduct and thereby energizing coil 178 of relay 152 and closing relay 152. As discussed in the above examples, relay 150 is then latched and the sequence described above occurs.

If for any reason the transmission of the R.F. signal ceases, and then continued on the same frequency, none of relays 150, 152, 154 and 156 close, causing motor 38 to tune antenna 12 to lower frequencies. The procedures described above occur, which causes a recycling of resonant frequency of antenna 12 until the right frequency is obtained.

If diode 160 in the circuit of programmer unit 30, shown in FIGURE 3, is disconnected, and a connection is made between contact 180 of relay 152 and contact 216 of relay 154, shown by dashed line 234, a continual sensing of the resonant frequency of antenna 12 is provided, so that the resonant frequency of antenna 12 is corrected throughout the transmission of an R.F. signal from radio-telephone unit 10. Operation is similar to that described above, except motor 38 is not cut off as described above at the tuned frequency. Instead of motor 38 being cut off when relay 152 is deenergized, conductor 234 connecting contact 180 of relay 152 to contact 216 of relay 154 grounds relay 154 causing it to close. The closing of relay 154 unlatches relay 150 making tuning motor 38 lower or reduce the resonant frequency of antenna 12. This reduction in the resonant antenna frequency continues until the resistive load detector circuit 119 of resonance detector unit 28 produces a signal to close relay 152, which in turn closes relay 150 and releases relay 154, so that a signal is transmitted to motor 38 reversing its direction so as to tune the resonant frequency of antenna 12 upward in frequency until relay 152 opens, and the process is repeated.

If the antenna 12 is close to the radio-telephone unit 10, i.e., about 6 feet, it is sometimes desirable to eliminate a non-radiating transmission line altogether. In this case receiver matching and switching unit 24, relay 15, transmission line 14 and bypass line 27 is eliminated and horizontal antenna section 19 will go directly to the radio-telephone unit 10. This approach has application in marine mobile operations, and eliminate the problem of antenna matching and tuning when both identical and different frequencies are used for transmission and reception. If a low impedance transmission line, such as coaxial cable, is used between resonance detector unit 28 and radio-telephone unit 10, and the same frequency for transmitting and receiving is used, antenna 12 can be tuned for both receiving and transmission by transmitting a signal. With these requirements, receiver matching and switching unit 24 and receiver matching control unit 25 can be eliminated and horizontal antenna section 19 will connect directly to radio-telephone unit 10 via transmission line 14. However, this procedure requires the transmission of a signal, so as to properly tune the set both for transmission and receiving.

Occasionally, where the resonance detector unit 28 is located remote from the variable reactance assembly 20, stray capacitance of the antenna circuit becomes appreciable. This occurs when the physical dimensions of the antenna is large. If the stray capacitive reactance in the antenna circuit is appreciable to resonance detector unit 28, the resonance detector unit 28 will be actuated in the same sense that it would be when the radio frequency signal being transmitted is at a lower frequency than the antenna resonant frequency. In this situation antenna 12 may be unintentionally tuned away from the frequency of the transmitted signal. This normally is not critical, since control rods 70 move in and out of coil 50 until an end stop conducting sheet 96 or 98 contacts fingers 92 and 94, or 90 and 92, respectively, for reversing the direction of movement of control rods 70, which movement continues until the resonance frequency of antenna 12 matches the transmit or receive frequency.

To avoid this occasional problem, a corrective circuit is shown in FIGURE 2A, where a coil 238 is added to primary coil 100 of resonance detector unit 28. Coil 238 is identical to primary coil 100 and connected so that its polarity is opposite and equal to the polarity across coil 100. Coil 238 is coupled to a variable capacitor 240 and through relay 156*a* to ground, when switch 185*a* of relay 156*a* makes connection with contact 190*a*, which occurs when coil 186*a* is energized in a manner similar to coil 186 of relay 156. Since, as shown in FIGURE 3, dummy load resistor 158 is coupled to switch 185 of relay 156, a dummy load resistor 158*a* is added to relay 156*a*, as shown, and operates in a similar manner as dummy load 158, as described above. Variable capacitor 240 is adjusted so that is capacitive reactance is equal to the stray capacity of the antenna circuit, so as to cancel the effect of the stray capacitance in the circuit, insofar as the resonance detector unit 28 is concerned. When the current detector circuit 135 of the resonance detector unit 28 senses that antenna 12 is drawing current, coil 186*a* is deenergized which removes dummy load resistor 158*a* from the R.F. output circuit, in the same manner as described above.

While the control rods 70 were shown to be fully within coil 50 in their maximum IN position, if desired, coil 50 can be lengthened, so as to be longer than the maximum inward position of the control rods 70. This will provide a more restricted frequency band than described above, with less stray capacity introduced into coil 50 of FIGURE 4.

Further, while a plurality of control rods 70 were shown, a solid slug or tube may be used. However, because of the range of power intended to be handled by the present invention, the use of a plurality of rods provides more flexibility. With the larger power R.F. outputs, the use of rods materially decreases the weight and cost of the variable reactance assembly as compared to the use of a solid or cylindrical core.

In the various arrangements shown, additional circuit elements may be used where required. For example, to transfer the receiving energy from the antenna to the receiver, various approaches may be used. A saturable reactor in series with the center portion of antenna 12 could be switched into the circuit on receive, which reactance can be remotely controlled by a tuning circuit, which can be adjusted by the variable resistor 130 of the resonance detector circuit 28 shown in FIGURE 2. Additionally, the energy from antenna 12 is coupled to the transmission line to the receiver by means of a parallel tuned tank through a coupling capacitor. The resonant frequency of this tank can be adjusted by means of a saturable reactor, similar to that mentioned above. The transmission line is coupled into the tank circuit by means of a link which can be varied to the turns of the tank to provide the best match over the band of frequencies contemplated. Various alternative elements, such as a broad-band matching transformer, can be coupled into these circuits to provide the necessary impedance matching.

While the apparatus of the present invention was shown varying the inductance of the antenna, similar apparatus can be used to vary capacitive reactance. If a variable capacitor were substituted for the variable inductor illustrated, and it were coupled to the antenna sections, the reactance of the antenna would also vary. This would be readily available if the antenna were made inductive so that varying capacitance would change the reactance.

Further, the antenna was shown vertically oriented, but could be horizontally oriented as well.

Also, the flux shield or flux equalizer 72 was shown mounted coaxially within coil 50. However, shield 72 could be offset sometimes from the coil axis and perform satisfactorily.

Various remotely controllable antenna tuning systems have been described and from this description it would be apparent that antenna tuning systems embodying the present invention are well-adapted to attain the ends and objects set forth herein and that the various embodiments of the invention shown herein can be modified so as to produce operating characteristics best suited to the needs of each particular use.

While the principles of this invention have been described with respect to specific embodiments, it is to be understood that this description is made only by way of example and not as a limitation to the scope of the invention as set forth in the objects thereof and in the accompanying claims.

What is claimed is:

1. An antenna system tunable over a broad range of frequencies for use with a source of RF energy, comprising an antenna having at least a first and a second conductive section, a variable reactance member interposed between and coupled to said first and second sections, said antenna having its electrical length changeable in response to varying the reactance of said reactance member, means coupling said RF source to said antenna, means coupled to said antenna for detecting resonance of said antenna with said RF source, said detecting means coupling containing stray capacitance, means producing a counter reactance to said stray capacitance, said counter reactance coupled to said detecting means, so that said detecting means is substantially responsive only to antenna reactance, and means responsive to said detector means for varying the reactance of said reactance member to change the electrical length of said antenna so as to tune said antenna to receive maximum RF power from said RF source.

2. An antenna system tunable over a broad range of frequencies for use with a source of RF energy, comprising a antenna having at least a first and a second conductive section, a variable reactance, member interposed between and coupled to said first and second sections, said antenna having its electrical length changeable in response to varying the reactance of said reactance member, means coupling said RF source to said antenna, means coupled to said antenna detecting said antenna beginning to accept current from said RF source, said detector means including means nullifying stray capacitance of said antenna conductive sections between said detecting means and said variable reactance member, an RF power-absorbing load adapted to be coupled to said RF source for receiving said RF energy, switching means adapted to couple and uncouple said load to said RF source and said stray capacitance nullifying means, said switching means responsive to said detecting means for uncoupling said load and said stray capacitance nullifying means from said RF source when said antenna begins to accept current from said RF source.

3. An antenna tuning system comprising an antenna unit having a first and a second conductive section, a source of radio frequency energy signal for energizing said antenna, an energy transmission line extending between said source and said antenna, and adjustable inductive reactance member interposed between and coupled to said sections of said antenna, said inductive reactance member having a coil electrically coupled to each of said antenna sections and a core of permeable material adapted to be moved into and out of said coil to vary the inductive reactance of said member, means for moving said core into and out of said coil for controlling the impedance relationship between said antenna and said radio frequency signal, a detection unit coupled to said antenna for sensing the resonance of said antenna with said radio frequency signal, switching means coupled to said detector unit for actuating said core moving means for moving said core with respect to said coil for varying the reactance of said reactance member to tune said antenna to the frequency of said radio frequency signal, and means for reversing direction of movement of said core automatically upon movement of said core a predetermined distance.

4. An antenna tuning system comprising an antenna unit having a first and a second conductive section, a source of RF energy coupled to said antenna for energizing said antenna, an adjustable inductive reactance member interposed between and coupled to said sections of said antenna, said inductive reactance having a coil electrically coupled to each of said antenna sections and a plurality of spaced apart rods of permeable material adapted to be moved into and out of said coil for varying the reactance of said antenna, a member made of electrically conductive material coaxially aligned within said coil, means coupled to said rods for moving said rods into and out of said coil, a detection unit coupled to said antenna for sensing the resonance of said antenna with said RF source, said means being adapted to sense the power

received by said antenna from said RF source, switching means coupled to said detector unit for actuating said rod moving means for moving said rods with respect to said coil for varying the reactance of said reactance member to tune said antenna to the frequency of said RF signal, and means for reversing direction of movement of said rods automatically upon movement of said rods a predetermined distance.

5. An antenna tuning system comprising an antenna unit having a plurality of conductive sections, a source of radio frequency energy adapted to be coupled to said antenna for energizing said antenna, a power absorbing load coupled to said radio frequency source, an adjustable inductive reactance member interposed between and coupled to a pair of consecutive sections of said antenna, said inductive reactance having a coil electrically coupled to each of said pair of antenna sections and a movable core of permeable material adapted to be moved into and out of said coil for altering the electrical length of said antenna, means moving said core into and out of said coil, a detection unit coupled to said antenna and adapted to send predetermined signals in response to power received by said antenna, switching means responsive to signals from said detector unit for actuating said core moving means for moving said core with respect to said coil and varying the reactance of said reactance member, second switching means responsive to signals from said detection unit for uncoupling said power absorbing load from said radio frequency source, and means for reversing direction of said core moving means automatically upon predetermined core movement, said core being moved with respect to said coil until said antenna is at resonance frequency.

6. An antenna tuning system comprising an antenna unit having a plurality of conductive sections, a source of radio frequency energy adapted to be coupled to said antenna for energizing said antenna, a power absorbing load coupled to said radio frequency source, an adjustable inductive reactance member interposed between and coupled to a pair of consecutive sections of said antenna, said inductive reactance having a coil electrically coupled to each of said pair of antenna sections and a movable core of permeable material adapted to be moved into and out of said coil for altering the electrical length of said antenna, means moving said core into and out of said coil, a coil connected to said antenna, a detection unit coupled to said coil and adapted to send predetermined signals in response to power received by said antenna, said detecting unit including a coil coupled to said last-mentioned coil and having equal and opposite electrical characteristics thereto, said detecting coil coupled to a variable capacitor for nullifying the effect of stray capacitance in said antenna conductive sections between said inductive member and said detecting unit, switching means responsive to signals from said detector unit for actuating said core moving means for moving said core with respect to said coil and varying the reactance of said reactance member, second switching means responsive to signals from said detection unit for uncoupling said power absorbing load from said radio frequency source, and means for reversing direction of said core moving means automatically upon predetermined core movement, said core being moved with respect to said coil until said antenna is at resonance frequency.

7. An antenna tuning system comprising an antenna unit having at least a pair of conductive sections, a source of RF energy for energizing said antenna, a receiver of RF energy from said antenna, an energy transmission line connecting said antenna to said receiver, means for coupling said RF source to said antenna, impedance matching means coupling said antenna and said receiver, first switching means responsive to a predetermined signal for connecting said receiver to said impedance matching means and disconnecting said receiver from said impedance matching means in response to cessation of said predetermined signal, an adjustable inductive reactance member interposed between and coupled to said pair of sections of said antenna, said inductive reactance having a coil electrically coupled to each of said pair of antenna sections and a movable core of permeable material adapted to be moved into and out of said coil for varying the reactance of said antenna, a member made of electrically conductive material coaxially aligned within said coil, means coupled to said core for moving said core into and out of said coil for controlling the impedance relationship between said antenna and said RF source, detection means coupled to said antenna and adapted to sense the power received by said antenna from said RF source, second switching means responsive to said detection means for actuating said core moving means for moving said core with respect to said coil for varying the reactance of said reactance member to tune said antenna to the frequency of said RF signal, and means for reversing direction of movement of said core automatically upon predetermined core movement.

8. An antenna system tunable over a broad range of frequencies for use with a source of RF energy and a receiver of RF energy, comprising an antenna having at least a pair of conductive sections, a variable reactance member interposed between and coupled to said pair of antenna sections, said antenna having its electrical length changeable in response to varying the reactance of said reactance member, means coupling said receiver of RF energy to said antenna, said means including impedance matching means, said coupling means being adjustable for providing maximum transfer of signal from said antenna to said receiver, switching means responsive to a predetermined signal from said RF source for uncoupling said receiver impedance matching means from said antenna and coupling said RF source to said antenna, means coupled to said antenna adapted to detect said antenna having a resistive load so as to receive a maximum power from said RF source, said detecting means giving predetermined output signals in response to the resonance frequency of said antenna being above or below said RF of said source, and means responsive to said signals of said detecting means for varying the reactance of said reactance member to change the electrical length of said antenna so as to tune said antenna to the frequency of said RF source.

9. An antenna tuning system comprising an antenna unit having at least a pair of conductive sections, a source of RF frequency coupled to said antenna for energizing said antenna, a conductor wound in a coil interposed between said pair of antenna sections and electrically coupled to each, a threaded cylinder rotatably and coaxially mounted within said coil and made of electrically conductive material, a plurality of rods movable parallel to the axis of said coil and into and out of said coil, said rods being spaced apart and made of a permeable material, a pair of end plates each affixed to corresponding ends of said rods, said rods and said pair of end plates forming an assembly, means carried by one of said end plates threadedly engaging said threaded cylinder so that rotation of said cylinder in one direction moves said rod assembly logitudinally in one direction and reversing rotation of said cylinder reverses direction of said rod assembly, a reversible electrical motor coupled to said threaded cylinder, a plurality of fingers generally radially disposed between said rods an intersecting the path of travel of said end plates, the axis of said fingers lying in a plane transverse to the axis of travel of said rods, means carried by each of said end plates for electrically connecting a pair of said fingers at the end of travel of said rod assembly, detecting means coupled to said antenna for sensing resonance in said antenna and adapted to sense the power received by said antenna from said RF source, switching means responsive to said detecting means for selectively actuating said motor for moving said rods in relation to said

coil for adjusting the tuned frequency of said antenna towards the frequency of said RF source, said switching means reversing the direction of said motor in response to a pair of fingers being electrically connected by one of said means carried by one of said end plates.

10. An antenna tuning system comprising an antenna unit having an upper and a lower conductive section, a source of RF frequency coupled to said antenna for energizing said antenna, a conductor wound in a coil interposed between said upper and lower antenna sections and electrically coupled to each, a threaded cylinder rotatably and coaxially mounted within said coil and made of electrically conductive material, a plurality of rods movable parallel to the axis of said coil and into and out of said coil, said rods being spaced apart and made of a permeable material, a pair of end plates each affixed to corresponding ends of said rods, said rods and said pair of end plates forming an assembly, means carried by one of said end plates threadedly engaging said threaded cylinder so that rotation of said cylinder in one direction moves said rod assembly longitudinally in one direction and reversing rotation of said cylinder reverses direction of said rod assembly, a reversible electrical motor coupled to said threaded cylinder, a plurality of fingers generally radially disposed between said rods and intersecting the path of travel of said end plates, the axis of said fingers lying in a plane transverse to the axis travel of said rods, means carried by each of said end plates for electrically connecting a pair of said fingers at the end of travel of said rod assembly, detecting means coupled to said antenna for sensing resonance of said antenna and adapted to sense the power received by said antenna from said RF source, a RF power absorbing load coupled to said RF source for receiving said energy, switching means responsive to said detecting means for selectively actuating said motor for moving said rods in relation to said coil for adjusting the tuned frequency of said antenna towards the frequency of said RF source, and maintaining said rods in position with respect to said coil for maintaining said antenna at substantial resonance during transmission, said switching means reversing the direction of said motor in response to a pair of fingers being electrically connected by one of said means carried by one of said end plates, and second switching means adapted to couple and uncouple said power-absorbing load to said RF source, said second switching means responsive to said detecting means for uncoupling said power-absorbing load from said RF source when said antenna is accepting current from said RF source.

11. A variable reactance assembly, comprising a hollow elongated cylinder formed of an insulating material, a coil of wire wound circumferentially on said cylinder, a plurality of rods made of permeable material spaced apart in predetermined relation within said cylinder, a threaded cylinder made of electrically conductive material rotatably and coaxially mounted within said cylinder, a pair of end plates each affixed to corresponding ends of said rods, means carried by one of said end plates threadably engaging said threaded cylinder, so that rotation of said threaded cylinder moves said rods longitudinally, means carried by said cylinder for rotating said threaded cylinder in opposite directions, and means electrically coupled to said last-mentioned means for limiting longitudinal movement of said rods by reversing rotation of said means.

12. An antenna system tunable over a broad range of frequencies for use with a source of RF energy, comprising an antenna having at least a first and a second conductive section, a variable reactance member interposed between and coupled to said first and second sections, said antenna having its electrical length changeable in response to varying the reactance of said reactance member, means coupling said RF source to said antenna, means coupled to said antenna detecting said antenna accepting current from said RF source, means nullifying stray capacitance of said antenna conductive sections between said detecting means and said variable reactance member, an RF power-absorbing load adapted to be coupled to said RF source for receiving said RF energy, switching means adapted to couple and uncouple said load to said RF source, and said stray capacitance nullifying means, said switching means responsive to said detecting means for uncoupling said load from said RF source when said antenna accepts current from said RF source.

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