Jan. 14, 1958 W. E. PATTERSON 2,820,222

ANTENNA TUNER

Filed May 4, 1954 2 Sheets-Sheet 1

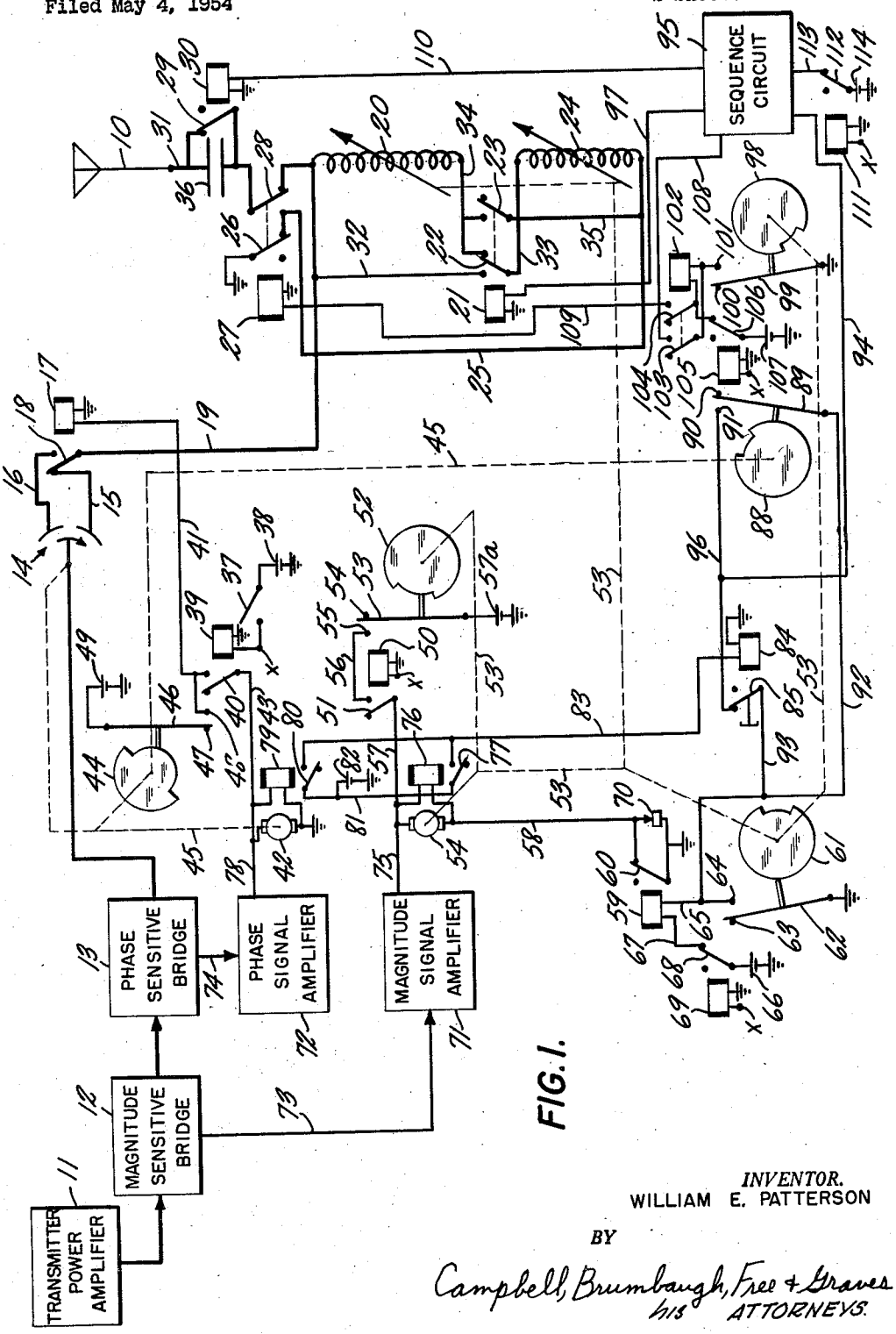


FIG. 1.

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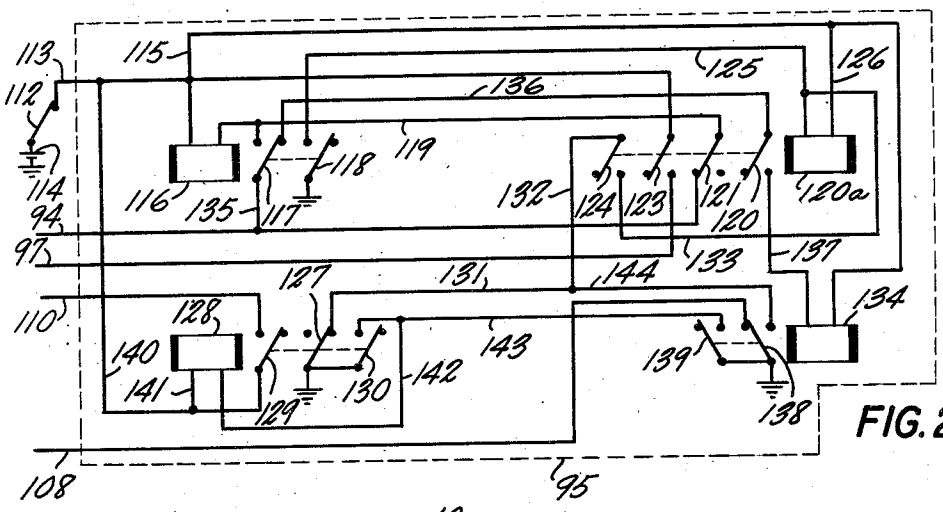


FIG. 2.

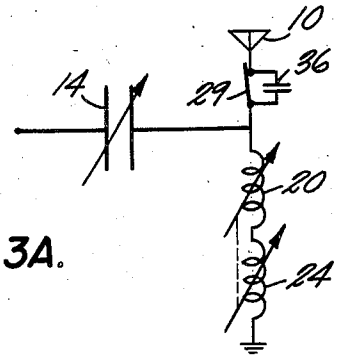


FIG. 3A.

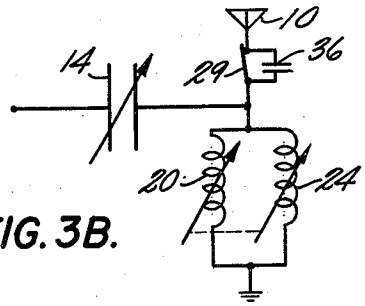


FIG. 3B.

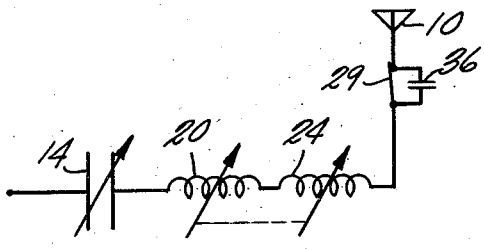


FIG. 3C.

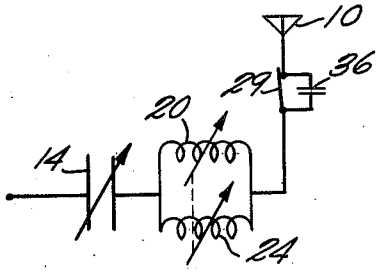


FIG. 3D.

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Application May 4, 1954, Serial No. 427,472

30 Claims. (Cl. 343—861)

This invention relates to impedance matching circuits and has particular reference to methods and apparatus for automatically tuning an antenna to a radio transmitter.

In the coupling of energy from a first impedance to a second impedance, it is well known that such impedances must be matched for efficient operation. A typical example in which such matching is important occurs in the transmission of electro-magnetic signals. Thus, an antenna must be properly tuned to a transmitter if maximum electrical efficiency is to be realized. Various arrangements for performing this function have been employed including manually tuned circuits between the transmitter and the anntenna and various automatic circuits relying, in some instances, on information other than the R.-F. signals from the transmitter. The problem becomes particularly acute where the transmitter operates on a great number of different frequencies which necessitates the retuning of the antenna whenever the transmitter is rechanneled. Further, various weather conditions can change the antenna characteristics to detune the antenna while the transmitter is operating on a single channel.

An example wherein the above-outlined problems have been particularly difficult to overcome occurs in aircraft radio transmitters wherein a large number of channels are utilized. In switching between channels, it is greatly desirable that the antenna be matched to the transmitter within as short a time as possible after such rechanneling. Further, it is necessary that the antenna be continuously tuned to the transmitter during operation thereof to accommodate changes in the antenna characteristics due to the change from ground to airborne operation or to climatic conditions such as rain, ice, heat and cold.

The present invention provides an antenna tuner that satisfies the above-outlined conditions in radio transmission. Sensing circuitry is provided between the transmitter output and the antenna to generate signals indicative of the impedance mismatch therebetween. Such signals are supplied to circuits which adjust tuning elements in attempting to tune the antenna to the transmitter. Further circuitry responsive to the adjustment of the tuning elements selectively arranges the tuning elements in the proper relation by the actuation of switching means to permit their adjustment to tune the antenna to the transmitter.

These and further advantages of the invention will be more readily understood when the following description is read in connection with the accompanying drawings in which:

Figure 1 is a schematic circuit diagram partially in block form of an antenna tuner constructed in accordance with the present invention;

Figure 2 is a schematic circuit diagram of one form of a sequence circuit that may be employed in the tuner illustrated in Figure 1; and

Figures 3A, 3B, 3C and 3D are schematic circuit diagrams illustrating the various relationships between the

tuning elements and the antenna that may be necessary to match an antenna to a transmitter.

Referring to an illustrative embodiment of the invention in greater detail with particular reference to Figure 1, an antenna **10** must be matched to the output impedance of a transmitter power amplifier **11** in order to provide for efficient operation of a multi-channel radio transmitter (not shown). For clarity, the signal path from the transmitter power amplifier **11** to the antenna **10** is designated by heavy connecting lines to distinguish it from the control circuits.

Inserted in the output of the amplifier **11** are a magnitude sensitive bridge **12** and a phase sensitive bridge **13**, both bridges being of conventional design. The magnitude sensitive bridge **12** is constructed so that it responds with zero signal when it looks into a predetermined magnitude of impedance while the phase sensitive bridge **13** sends out zero signal when it looks into a resonant condition which is, of course, zero phase angle.

From the phase sensitive bridge **13**, the R.-F. signals are coupled through a variable condenser **14** joined by conduits **15** and **16** to the front and back contacts of a relay **17** actuating an armature **18**. The condenser **14** may comprise any conventional variable condenser and is shown herein as having high and low sections connected to the conduits **15** and **16**, respectively. The particular condenser illustrated is an air condenser constructed so that the rotor thereof makes one revolution while the capacity is varied from the minimum value to the maximum value. After passing through its maximum value, the capacity of the condenser **14** will abruptly switch to its minimum value. An example of such a condenser may be found in the Patent No. 1,631,360 to Clark. It will be understood that other variable condensers may be substituted in the circuit.

The R.-F. signals are next coupled by a conduit **19** to the upper end of a variable inductance **20**. As shown in Figure 1, the lower end of the inductance **20** is joined by a conduit **34** to a back and a front contact of a relay **21** actuating armatures **22** and **23**. When deenergized, the armature **22** joins the back contact of the relay **21** through a conduit **33** to the upper end of a second variable inductance **24**, the lower end of the inductance **24** being tied to ground through a conduit **25** and an armature **26** actuated by a relay **27**.

The upper end of the inductance **20** is also connected through an armature **28** of the relay **27** and an armature **29** of a relay **30** to a conduit **31** leading to the antenna **10**. Thus, it will be apparent from inspection that Figure 1 shows the variable condenser **14** and the variable inductances **20** and **24** connected in circuit with the antenna **10** as illustrated in Figure 3A.

In certain instances, as explained in detail hereinafter, it is desirable to connect the variable inductances **20** and **24** in parallel relation. This may be accomplished by the energization of the relay **21** which joins the upper ends of the inductances **20** and **24** through a conduit **32** and the conduit **33** and the armature **22**. Similarly, the lower ends of the inductances **20** and **24** are joined by the conduit **34**, the armature **23** and a conduit **35** so that the resultant circuit is as shown in Figure 3B.

In other circumstances, it is desirable to insert the inductances **20** and **24** in series between the source of R. F. signals and the antenna **10**. This may be achieved by the energization of the relay **27** to disconnect the upper end of the inductance **20** from the antenna **10** and join the lower end of the inductance **24** through the conductor **25** and the armature **28** to the antenna **10**. This arrangement of circuit elements is shown in Figure 3C. Of course, while the variable inductances **20** and **24** are in series relation with the antenna **10** and the source of

R. F. signals, the relay 21 may be energized to place the inductances 20 and 24 in parallel relation as shown in Figure 3D.

It is necessary to render the antenna 10 more capacitive under certain conditions. Therefore, a condenser 36 may be selectively inserted between the inductances 20 and 24 and the antenna 10 by the energization of the relay 30.

At this time, it may be well to point out that the variable inductances 20 and 24 are preferably of the variometer type, a variable inductance that is well known and comprises a pair of concentrically mounted coils rotatable with respect to each other. In this instance, the rotating coils of a pair of variometers are mechanically joined together so that the inductances 20 and 24 are effectively ganged and adjusted as a unit. Since it is desirable to provide a large range of inductance in order to tune a wide variety of antennas to a radio transmitter, two variometers are preferably employed in the antenna tuner. Thus, while in parallel the variable inductances 20 and 24 may be adjusted from a low minimum value through a certain range and while in series, they may be adjusted through another range to a high maximum value. Of course, if such an extended range is not necessary, a single variometer could be employed. Further, other variable inductances may be substituted for the variometers within the scope of the present invention.

In matching the antenna 10 to the amplifier 11, it is preferable to commence the automatic tuning operation with the tuning elements connected in a predetermined manner and adjusted to a predetermined value range or point. Thus, it has been found preferable to initially employ the circuit arrangement illustrated in Figure 3A. However, it may be that the tuning elements are in any of the other arrangements illustrated in Figures 3B, 3C and 3D or that the condenser 14 and the inductances 20 and 24 are not within the predetermined range which, in this instance, is any point near the maximum capacitance and inductance of the tuning elements, respectively. Therefore, provision must be made for setting up the circuit as illustrated in Figure 3A before the automatic tuning is initiated.

Circuit means for connecting the tuning elements as illustrated in Figure 3A include a plurality of relay actuated switches controlled by a switch 37 which connects a D. C. source 38 to a terminal X. The switch 37 may be closed automatically in response to rechanneling of the associated radio transmitter (not shown) in which event it will be opened upon completion of such rechanneling. Alternatively, the switch 37 may be manually actuated. Terminal X, in turn, is joined to a plurality of relays for actuating the plurality of switches as will be indicated in detail below, the actual connections between only one terminal X and a relay being shown for simplicity. Of course, it will be understood that a single relay carrying a plurality of contacts may be employed to accomplish the same function performed by the plurality of relays disclosed.

Considering the setup or homing operation in detail, the closure of the switch 37 energizes a relay 39 which swings its armature 40 to a front contact thereof connected to the relay 17 through a conductor 41. This initiates the adjustment of the variable condenser 14 to a point in its maximum capacity range.

A grounded reversible D. C. motor 42 is tied to the armature 40 by a conductor 43 and drives a cam 44 through a conventional mechanical linkage 45. The cam 44 is provided with a raised segment over 180 degrees and actuates a following armature 46 between a pair of contacts 47 and 48, the last-mentioned contact being connected to the front contact of the relay 39. A D. C. source 49 is joined to the armature 46 so that its engagement with the contact 48 results in the source 49 energizing the relay 17 and the motor 42 during the interval the armature 40 engages the front contact of the relay 39. The variable condenser 14 and the cam 44 are orientated on the mechanical linkage 45 so that the armature 46 will engage the contact 48 as long as the variable condenser 14 is in its minimum capacity range. Therefore, it will be apparent that the motor 42 will be energized by the source 49, assuming the relay 39 to be energized, while the condenser is being driven through its minimum capacity range.

However, the armature 46 is disengaged from the contact 48 when the condenser 14 reaches its maximum capacity range and this results in the deenergization of the motor 42 and the relay 17. Thus, the armature 18 will engage the conduit 15 leading to the maximum capacity section of the condenser 14 and the variable condenser 14 will stand in its maximum capacity range. In this manner, the condenser 14 is prepared for the automatic operation of the tuning circiuts.

It is also necessary to connect the variable inductances 20 and 24 in the relation shown in Figure 3A with respect to the antenna 10 and to drive them to a point in their maximum range. The manner of obtaining the proper connections will be explained in the description of the control circuits. In order to accomplish the latter function of adjusting the variable inductances 20 and 24 to a predetermined maximum range, a relay 50 actuating an armature 51 is energized through the switch 37 and the terminal X. When the armature 51 engages the front contact of the relay 50, it conditions circuit means for adjusting the inductances 20 and 24 to their maximum range. These circuit means include a cam 52 joined by a mechanical linkage 53 to a D.-C. motor 54, the cam 52 being provided with an approximately 70 degree cut away portion, for example, this angle not being critical. An armature 53 follows the cam 52 and swings between contacts 54 and 55, the latter contact being joined through a conductor 56 to the front contact of the relay 50. The mechanical linkage 53 also drives the variable inductances 20 and 24, the cam 52 and variable inductances 20 and 24 being orientated thereon so that the armature 53 engages the contact 54 when these tuning elements are in the desired maximum range.

The armature 53 is energized by a source of D.-C. potential 57*a*. It will be evident that when the cam 52 actuates the armature 53 into engagement with the contact 55 and the relay 50 is energized, the motor 54 will be energized by the D.-C. source 57*a* through the armature 53, the conductor 56, the armature 51, conductors 57 and 58 to the back contact of a relay 59, and a grounded armature 60 of the relay 59. The motor 54 will continue to rotate until the armature 53 encounters the cut away portion of the cam 52 which breaks the energizing circuit. At this point, the variable inductances 20 and 24 will be in the desired maximum range.

As mentioned above, variometers are preferably employed for the variable inductances 20 and 24 and due to their nature, certain circuit arrangements must be employed therewith. Thus, it is well understood that the variometer inductance will vary from a maximum to a minimum to a maximum in 360 degrees relative rotation of the coils. However, for the purposes of the present invention, it is preferable to tune the antenna 10 while varying the inductance through a single cycle. In other words, only 180 degrees rotation of the variometers is utilized.

To provide this mode of operation, a cam 61 with a following armature 62 swinging between contacts 63 and 64 is driven by the mechanical linkage 53 from the motor 54. The contact 64 is joined through a conductor 65 to the relay 59, the other side of the relay 59 being connected to a D.-C. source 66 through a conductor 67 and an armature 68 of a relay 69, this last-mentioned relay being joined to the terminal X and energized when the switch 37 is closed. A cut away portion on the cam 61 is oriented so that the armature 62 swings to the contact 64 when the variometers are at minimum inductance. This

action energizes the relay 59 and disengages the armature 60 from the back contact thereof. Thus, a rectifier 70 normally in parallel with the armature 60 is inserted in series with the motor 54. The polarity of the rectifier 70 is chosen to preclude current flow in a direction through the motor 54 to cause further rotation of the variometers 20 and 24 in the same direction which would, of course, be utilizing the other 180 degrees rotation of the variometers. It will be evident that as soon as the motor 54 is rotated toward the maximum position on the desired side of the variometers 20 and 24, the relay 59 will be deenergized and the motor 54 will once again be grounded through the armature 60. Obviously, this arrangement could be eliminated if another type of variable inductance was employed. Further, the rectifier 70 and bypass 60 could be inserted in any other suitable position in the motor circuit.

It will be understood that the invention is not limited to the particular homing arrangement described above. Other similar homing means may be employed to adjust the tuning elements to a maximum range, to any other desired range or to any desired point. In addition, such homing means may be omitted from the tuner in certain instances.

To adjust the condenser 14 and the inductances 20 and 24 to attempt to tune the antenna 10 to the amplifier 11 while the circuit elements are connected as shown in Figure 3A, the output signals from both the magnitude sensitive bridge 12 and the phase sensitive bridge 13, which are conventionally D.-C. signals, are converted to A.-C. signals in any convenient manner such as by chopping in a vibrator (not shown) and passing through capacitors (not shown). The A.-C. signals are then fed to amplifiers 71 and 72 by conductors 73 and 74, respectively.

The output signals from the magnitude signal amplifier 71 are reconverted in any conventional manner, such as by further contacts on the chopping vibrator, to corresponding D.-C. potentials which are applied through a conductor 75 to the D.-C. drive motor 54, the other terminal of the drive motor normally being grounded through the conductor 58 and the armature 60. A relay 76 actuating an armature 77 is also connected across the motor 54.

The phase signal amplifier 72 applies error signals through a conductor 78 to the grounded D.-C. drive motor 42, a relay 79 having an armature 80 being connected across the motor 42. The armature 80 is joined to the armature 77 by a conductor 81 which is tied to a positive source of potential 82. The front contacts of the relays 76 and 79 are also joined by a conductor 83 which leads to a slow release relay 84 provided with an armature 85.

It should be noted that the signal from the magnitude sensitive bridge 12 may result in a positive or negative D.-C. voltage across the motor 54 according to whether the impedance the bridge 12 sees is too great or too small. Therefore, the motor 54 will respond in either direction to adjust the variable inductances 20 and 24 to attempt to remove the mismatch. The same is true for the phase sensitive bridge 13, the motor 42 adjusting the variable condenser 14 in a direction determined by the leading or lagging phase angle seen by the bridge 13.

Assuming that the switch 37 has been closed either manually or automatically in response to rechanneling of the radio transmitter, the tuning elements will preferably be arranged as illustrated in Figure 3A due to the deenergized condition of the relays 21 and 27 resulting from the operation of circuits to be described hereinafter. In addition, the condenser 14 and the variable inductances 20 and 24 will have been driven to their maximum ranges. Accordingly, opening the switch 37 results in an attempt to match the antenna 10 to the output impedance of the transmitter power amplifier 11. Thus, the magnitude sensitive bridge will respond with a D.-C. error signal of a positive or negative polarity if it looks into an impedance

magnitude different than the output impedance of the amplifier 11 for which it has been set. It will be assumed for the moment that the error signal causes the motor 54 to drive the inductances 20 and 24 toward their minimum value.

It may be, of course, that before the inductances 20 and 24 reach their minimum value, the impedance of the antenna 10 and the amplifier 11 will be matched. However, if this does not occur and the variable inductances 20 and 24 are driven to their minimum value, the armature 62 following the cam 61 will enter the cut away portion therein and engage the contact 64 to prevent further adjustment of the inductances 20 and 24 in the same physical direction.

Turning next to the phase sensitive bridge 13, it is set to generate error signals if it does not look into a resonant condition, i. e., zero phase angle. Thus, assuming a leading or lagging phase angle condition, an error signal will be generated to cause the motor 42 to rotate in either direction to vary the capacity of the condenser 14. It may be that with the circuit arrangement shown in Figure 3A, a resonant condition will be obtained and the motor 42 deenergized due to a lack of error signal. However, it will be assumed for the moment that during the tuning operation, the condenser 14 is driven through its maximum capacity after the inductances 20 and 24 have been driven to their minimum value. At this point, provision has been made to switch the tuning elements. This function is achieved by driving a cam 88 by the motor 42, a following armature 89 swinging between contacts 90 and 91 and being tied by a conductor 92 and the conductor 93 to the relay 59. In addition, the armature 89 is joined by the conductor 94 and a conductor 95 to the armature 85 of the relay 84.

The cut away portion of the cam 88 is oriented thereon so that the armature 89 drops therein and engages the contact 91 when the condenser 14 has reached its maximum value. As assumed above, the inductances 20 and 24 have been driven to their minimum value causing the armature 62 to engage the contact 64. Accordingly, a conductor 94 leading to a sequence circuit 95, which will be examined in detail hereinafter, is grounded through the series contacts 91 and 64. It should be noted that the back contact of the relay 84, connected to the contact 91 through a conductor 96, will not engage the armature 85 at this time. Thus, the slow release relay 84 will be energized through the armature 80 by the D.-C. source 82 since the motor 42 continues to drive the condenser 14 in response to error signals from the amplifier 72.

The grounding pulse furnished to the sequence circuit 95 on the conductor 94 will result in the energization of a conductor 97 leading from the sequence circuit 95 to the relay 21 which, when energized, will connect the variable inductances 20 and 24 in parallel relation as shown in Figure 3B.

By placing the inductances 20 and 24 in parallel, a much lower value of inductance will be inserted between the antenna 10 and ground. In many instances, this arrangement will permit the impedance of the antenna 10 to be matched to the transmitter output. However, in the event that the antenna characteristics are such that the parallel combination of the variable inductances 20 and 24 remains at or is again driven to the minimum value thereof by the motor 54, provision is made to insert the condenser 36 in series therewith to render the antenna 10 capacitive. This operation will be explained in detail hereinafter.

Returning to the condition of the antenna tuner immediately after the interval in which the switch 37 was opened, it will be recalled that the tuning elements are arranged as shown in Figure 3A and have been driven to predetermined maximum value ranges. In the operation above, it was assumed that the inductances 20 and 24 were driven to their minimum value in attempting to tune the antenna 10 while the condenser 14 was driven through

its maximum value. It will next be assumed that the error signal from the magnitude sensitive bridge 12 causes the motor 54 to vary the inductances 20 and 24 towards their maximum value in attempting to tune the antenna 10. This operation may result in the matching of the antenna 10 to the amplifier 11 or the inductances 20 and 24 may be driven until they reach their maximum value. At that point, provision is made for further shifting the connections of the tuning elements, such function being performed by a cam 98 cooperating with an armature follower 99 swinging between contacts 100 and 101.

The armature 99 is grounded while the contact 101 is tied to a relay 102 actuating a pair of armatures 103 and 104 connected to the terminals thereof. The relay 102 is also connected to the back contact of a relay 105, energized by the switch 37 and actuating an armature 106 which is joined to a D.-C. source 107. The cam 98 is provided with a cut away portion which is orientated to cause the armature 99 to engage the contact 101 when the inductances 20 and 24 are driven by the motor 54 to their maximum value, the cam 98 also being driven by the mechanical linkage 53. Thus, the armature 99 in engaging the contact 101 provides a ground so that the relay 102 may be energized by the D.-C. source 107 if the relay 105 is deenergized. This results in the engagement of the armature 103 with a front contact of the relay 102 that is joined by a conductor 108 to the sequence circuit 95, the conductor 108 being grounded through contacts in the sequence circuit 95. Accordingly, the relay 102 is effectively locked in position irrespective of further rotation of the cam 98. In addition, the armature 104 engages another front contact of the relay 102 to complete an energizing circuit for the relay 27 from the source 107 through the armature 106, the armature 104 and conductor 109. Thus, the relay 27 actuates the armature 26 to place the variable inductances 20 and 24 in series with the antenna 10 as shown in Figure 3C.

With the series arrangement illustrated in Figure 3C, it will usually be necessary to reduce the inductance of the tuning elements 20 and 24 to tune the antenna 10 to the amplifier 11. This is achieved when error signals from the bridge 12 rotate the motor 54 in the proper direction to reduce the value of the inductances 20 and 24. If necessary to further reduce such inductance, the variable inductances 20 and 24 may be inserted in the circuit in parallel as shown in Figure 3D. This would occur if the inductances 20 and 24 were driven to their minimum value and the condenser 14 driven through its maximum value or additional circuits actuated as explained in detail hereinafter.

Returning to the first-described operation of the tuning circuits, it will be recalled that when the inductances 20 and 24 are driven to their minimum value, they are placed in a parallel circuit relation as shown in Figure 3B when the condenser 14 is driven through its maximum value. In certain instances, the motor 54 will continue to receive error signals from the magnitude sensitive bridge attempting to further reduce the value of the inductance because the value of the inductances 20 and 24 in parallel will still be too great at their absolute minimum value to properly tune the antenna 10 to the amplifier 11 as far as the magnitude of impedance is concerned. Accordingly, provision has been made to render the antenna 10 somewhat capacitive at this point in order to require a greater value of inductance between the antenna 10 and ground to properly match the antenna 10 to the amplifier 11.

It will be remembered that when the armature 62 engaged the contact 64 and the armature 89 engaged the contact 91, a grounding pulse was furnished through the conductor 94 to the sequence circuit 95 causing the paralleling of the variable inductances 20 and 24. However, if the motor 54 permits the variable inductances 20 and 24 to remain at their minimum value or if it returns them to their minimum value, and the motor 42 again drives the condenser 14 through its maximum value, a further grounding pulse will be furnished to the sequence circuit 95 through the conductor 94 for the same reason it was previously furnished. However, at this time the relay 30 will be energized by a conductor 110 and the armature 29 will be disengaged from its front contact to place the condenser 36 in series with the antenna 10. At the same time as this occurs, the conductor 108 will be removed from ground to deenergize the relay 102 if it had previously been grounded. In addition, the conductor 97 will be deenergized resulting in the reconnection of the inductances 20 and 24 in series. Thus, the tuning elements will be returned to the circuit arrangement shown in Figure 3A with the switch 29 open.

With the last-mentioned circuit, the variable inductances 20 and 24 may be driven to their minimum value and thereby switched to the parallel relation illustrated in Figure 3B or may be driven to their maximum value and switched to the series relation illustrated in Figure 3C, the condenser 36 at all times remaining in series with the antenna 10 since the switch 29 is open. In this manner, it has been found that a transmitter power amplifier may be matched to antennas having widely differing characteristics.

In the operation of the tuning circuits shown in Figure 1, a grounding pulse is furnished to the sequence circuit 95 through the conductor 94 when the series connected armatures 62 and 89 engage their respective contacts 64 and 91. However, there may be instances when the inductances 20 and 24 will be driven to their minimum value to cause the armature 62 to engage the contact 64 but the condenser 14 will be adjusted to provide a resonant condition. Accordingly, the armature 89 will not engage the contact 91.

It will be obvious that under such circumstances, although the phase angle will be zero to provide a resonant condition, the impedance magnitude will not be properly matched and inefficient operation will result. Accordingly, further circuitry is provided to preclude such a condition, such circuitry including the slow release relay 84 operating in response to the relays 76 and 79 across the motors 54 and 42, respectively. Thus, since the variable inductances will be at their minimum value, the armature 62 will engage the contact 64 to energize the relay 59 and actuate the armature 60 to insert the rectifier 70 in series with the motor to prevent further actuation of the variable inductances 20 and 24 in the same physical direction. This action will preclude any significant voltage across the motor 54 so that the relay 76 will be deenergized and the armature 77 will drop out. Of course, the armature 80 is already resting on the back contact of the relay 79 since the condenser 14 is tuned to resonance resulting in the deenergization of the motor 42. After a short time interval, the slow release relay 84 will open to place the armature 85 in contact with the conductor 96 which effectively places this switch in series with the contact 64 and armature 62 to provide a grounding pulse to the conductor 94 leading to the sequence circuit 95. Accordingly, the sequence circuit 95 will perform in the same manner as when the armature 89 engages the contact 91. Further, this same mode of operation may occur when it is necessary for the condenser 36 to be placed in series with the antenna 10 due to the variable inductances 20 and 24 being driven to their minimum value in parallel relation. It should be understood that the capacity range through which the condenser 14 may be varied is great enough to tune any antennas that will normally be encountered to resonance, assuming that the impedance magnitude between the antenna and R.-F. source are suitably matched.

In order to better understand the operation of the tuning circuits described above, it might be helpful to describe a typical circuit that may be employed in the sequence circuit 95. Therefore, reference is made to Figure 2 wherein circuitry is shown which may be used in the sequence circuit 95. Before proceeding with a description of these

circuits, it should be pointed out that a relay **111**, provided with an armature **112** and having its back contact joined by a conductor **113** to the sequence circuit **95**, is energized by being joined to the terminal X. The armature **112** is also joined to a source of D.-C. potential **114**. Thus, when the switch **37** is closed, the sequence circuit **95** is cleared by the deenergization of the conductor **113**.

Proceeding with the description of Figure 2, the sequence circuit **95** is indicated in broken outline and is shown in its initial cleared condition, i. e., the condition in which it is found immediately after the switch **37** has recycled and the tuning circuits are prepared to match the antenna **10** to the amplifier **11**.

A grounding pulse on the conductor **94** will complete a circuit from the D.-C. source **114** through the armature **112**, the conductor **113**, a conductor **115**, a relay **116** actuating armatures **117** and **118**, a conductor **119**, an armature **121** of a relay **120***a* actuating armatures **120** to **124**, inclusive, and the conductor **94** thereby energizing the relay **116**. The armature **117** in swinging to its front contact furnishes a holding circuit for the relay **116** while the conductor **94** is grounded. The grounded armature **118** in engaging its front contact energizes the relay **120***a* through a conductor **125**, the other terminal of the relay **120***a* being connected by a conductor **126** to the conductor **115**. The relay **120***a* is locked in through a circuit extending from ground through an armature **127** of a relay **128** provided with further armatures **129** and **130**, conductors **131** and **132**, the armature **124** and the conductor **133**. Also, the actuation of the armature **123** to its front contact applies the potential of the D.-C. source **114** to the conductor **97** through the switch **112**, the conductor **113** and the armature **123**.

When the conductor **94** is disconnected from ground, the relay **116** will be deenergized. When the next grounding pulse is applied to the conductor **94**, a further energizing circuit will be completed through a conductor **135**, the armature **117**, a conductor **136**, the armature **120**, a conductor **137**, a relay **134**, the conductor **115**, the conductor **113**, the armature **112** to the source **114**. Grounded armatures **138** and **139** of the relay **134** will be actuated to engage their front contacts, and this will remove a ground from the conductor **108** which had previously held the relay **102** energized. When the relay **134** is energized, the relay **128** will also be excited through a circuit including the source **114**, the armature **112**, the conductor **113**, a conductor **140**, a conductor **141**, the relay **128**, a conductor **142**, a conductor **143** and the armature **139** to ground. It should also be noted that when the armature **138** engages the front contact of the relay **134**, the relay **120***a* is grounded through the conductor **133**, the armature **124**, the conductor **132**, the conductor **144** and the armature **138**.

The energized relay **128** is locked in by virtue of the grounded armature **130** engaging the front contact joined to the conductor **142**. Furthermore, the armature **129** engages a front contact to supply the positive potential of the D.-C. source **114** to the conductor **110** through the armature **112**, the conductors **113** and **140**, and the armature **129**. It will be evident that when the switch **112** is opened, the sequence circuit **95** will return to its initial condition so that the tuning elements will be connected as shown in Figure 3A. Thus, closing the switch **37** not only causes the motors **42** and **54** to drive their associated tuning elements to a predetermined maximum range as described above but also connects the tuning elements in a predetermined arrangement with respect to the antenna **10**.

In examining the above-described circuitry, it will be apparent that the transfer from the series to the parallel connection of the variable inductances **20** and **24** is irreversible in the sense that the grounding pulse on the conductor **94** energizes the relay **120***a* which remains locked in until the sequence circuit **95** is cleared or the condenser **36** is connected in series with the antenna **10**. However, if the motor **54** drives the parallel connected inductances **20** and **24** to their maximum value without tuning the antenna **10**, the circuit will be shifted to Figure 3D in order to complete the tuning function. This will rarely occur. However, it is obvious that the series to parallel switching could be made reversible if desired.

Provision has been made to prevent driving the variometers, if employed for the variable inductances **20** and **24**, beyond their minimum value to preclude operation thereof over more than 180 degrees of rotation. It has been found unnecessary to provide for such a function at the maximum value of the inductances **20** and **24** since their transfer to the circuit of Figure 3C will cause them to be driven toward their minimum value if their initial maximum value is of sufficient magnitude. However, if desired, similar provisions may be made to prevent the variometers, if employed, from being driven beyond their maximum value in order to permit the insertion of further tuning elements in the circuit.

While the sequence tuning circuit has been described as comprising the four interconnected relays **116**, **120***a*, **128** and **134**, it will be understood that it acts as a stepping switch which could be substituted therefor if desired. Further, it may be preferable in certain instances to initially connect the tuning elements in one of the other arrangements illustrated in Figures 3B, 3C or 3D instead of that shown in Figure 3A. In this event, the remainder of the circuits would be modified accordingly.

To aid in appreciating the advantages of the above-described invention, some typical values of capacity and inductance that have been found useful in the tuning elements will be set forth below. It will be understood, of course, that the invention is not limited to these illustrative values.

The variable condenser **14** may be continuously variable over 360 degrees from 16 to 650 micro-microfarads. The variable inductances, preferably variometers, may be variable from 1 to 20 microhenries, this range including both their series and parallel connections in the circuit. The series of condenser **36** may have a value of 75 micro-microfarads.

It has been found that an antenna tuner utilizing tuning elements with the above values will match a 52 ohm resistive load over the frequency range from 3 to 18.5 megacycles to the grounded type antennas normally employed on aircraft of the following types:

Lockheed Constellation
Douglas DC–4
Boeing 377
Douglas DC–6B

To gain an appreciation of the different antenna characteristics which the antenna tuner must accommodate, the impedances of several antennas at 10 megacycles on the aforementioned aircraft will be listed:

Lockheed Constellation	60–j225
Douglas DC–4	150–j800
Boeing 377	37+j15
Douglas DC–6B	11+j209

Another advantage afforded by the antenna tuner resides in the fact that any time R.-F. signals are being radiated by the antenna **10**, the magnitude sensitive bridge **12** and the phase sensitive bridge **13** will furnish error signals in order to drive the motors **54** and **42** to correct for any changes in the antenna characteristics. Thus, the antenna will often have to be tuned after a plane has left the ground. Further, where ice forms on the antenna, for example, its characteristics may be changed to such a degree that inefficient operation would result unless the antenna tuner automatically corrected for the mismatch.

It will be understood that the above-described embodiments of the invention are illustrative only and modifications thereof will occur to those skilled in the art. For example, various types of variable condensers could be

employed in place of the one shown in Figure 1 and, for example, "Increductors," a form of saturable reactor, could be employed for the variable inductances. In this latter case, the means for varying the inductance may comprise vacuum tubes driven directly by the error signals from the bridge 12. Therefore, the invention is not to be limited to the specific apparatus disclosed herein but is to be defined by the appended claims.

I claim:

1. Apparatus for tuning a second impedance to a first impedance comprising first tuning means series connected between said first impedance and said second impedance, means responsive to the phase angle mismatch between the first impedance and the second impedance for adjusting said first tuning means in a direction to eliminate the phase angle mismatch, second tuning means coupled to said second impedance, means responsive to the magnitude of the impedance mismatch between said first impedance and said second impedance for adjusting said second tuning means in a direction to eliminate the impedance magnitude mismatch, and control means responsive to the adjustment of said first and second tuning means for selectively inserting said second tuning means between said second impedance and ground or between said first tuning means and said second impedance.

2. Apparatus for matching a second impedance to a first impedance comprising variable capacity means series connected between said first impedance and said second impedance, means responsive to the phase angle mismatch between the first impedance and the second impedance for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said second impedance, means responsive to the magnitude of the impedance mismatch between said first impedance and said second impedance for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, and control means responsive to the adjustment of said capacity means and said inductance means for selectively inserting said inductance between said second impedance and ground or between said capacity means and said second impedance.

3. Apparatus for matching a second impedance to a first impedance comprising variable capacity means series connected between said first impedance and said second impedance, means responsive to the phase angle mismatch between the first impedance and the second impedance for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said second impedance, means responsive to the impedance mismatch between said first impedance and said second impedance for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, a condenser adapted to be connected in series with said second impedance, and control means responsive to the adjustment of said capacity means and said inductance means for selectively connecting said inductance means between said second impedance and ground or between said capacity means and said second impedance and for selectively connecting said condenser directly to said second impedance in series with said capacity means.

4. Apparatus for tuning an antenna to a source of radio frequency energy comprising first tuning means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said first tuning means in a direction to eliminate the phase angle mismatch, second tuning means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said second tuning means in a direction to eliminate the impedance magnitude mismatch, and control means responsive to the adjustment of said first and second tuning means for selectively inserting said second tuning means between said antenna and ground or between said first tuning means and said antenna.

5. Apparatus for tuning an antenna to a source of radio frequency energy comprising first tuning means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said first tuning means in a direction to eliminate the phase angle mismatch, second tuning means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said second tuning means in a direction to eliminate the impedance magnitude mismatch between said source and said antenna, third tuning means adapted to be connected in series with said antenna, and control means responsive to the adjustment of said first and second tuning means for selectively inserting said second tuning means between said antenna and ground or between said first tuning means and said antenna and for selectively connecting said third tuning means directly to said antenna in series with said first tuning means.

6. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, and control means responsive to the adjustment of said capacity means and said inductance means for selectively inserting said inductance means between said antenna and ground or between said capacity means and said antenna.

7. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said variable inductance means in a direction to eliminate the impedance magnitude mismatch, a condenser adapted to be connected in series with said antenna, and control means responsive to the adjustment of said capacity means and said inductance means for selectively inserting said inductance means between said antenna and ground or between said capacity means and said antenna and for selectively connecting said condenser directly to said antenna in series with said capacity means.

8. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, first control means for initially inserting said inductance means between said antenna and ground, and second control means responsive to the adjustment of said capacity means and said inductance means in a predetermined manner for inserting said inductance means between said capacity means and said antenna.

9. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, first control means for initially inserting said inductance means between said antenna and ground, and second control means rendered operative upon the adjustment of said inductance means to a predetermined maximum value thereof for inserting said inductance means between said capacity means and said antenna.

10. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, variable inductance means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, a condenser adapted to be connected in series with said antenna, first control means responsive to the adjustment of said capacity means and said inductance means for selectively inserting said inductance means between said antenna and ground or between said capacity means and said antenna, and second control means responsive to the adjustment of said inductance means to a predetermined minimum value thereof for connecting said condenser directly to said antenna in series with said capacity means.

11. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, said capacity adjusting means being deactuated upon substantial elimination of the phase angle mismatch, two variable inductances coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductances in a direction to eliminate the impedance magnitude mismatch, first control means for initially connecting said inductances in series relation with respect to each other and between said antenna and ground, and second control means responsive to the adjustment of said inductances to a predetermined minimum value thereof for connecting said inductances in parallel relation with respect to each other.

12. Apparatus as defined in claim 11 wherein said second control means includes means operative upon the adjustment of said variable inductances to the predetermined minimum value thereof and the adjustment of said variable capacity means to a predetermined maximum value thereof or upon the deactuation of said capacity adjusting means and the adjustment of said variable inductance means to the prdetermined minimum value for connecting said inductances in parallel relation with respect to each other.

13. Apparatus as defined in claim 12 wherein said inductances comprise variometers.

14. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, said capacity adjusting means being deactuated upon substantial eliminiation of the phase angle mismatch, two variable inductances coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductances in a direction to eliminate the impedance magnitude mismatch, first control means for initially connecting said inductances in series relation with respect to each other and for selectively connecting said inductances between said antenna and ground or between said antenna and said capacity means, a condenser adapted to be connected in series with said antenna, and second control means operative upon the adjustment of said inductances to a first predetermined minimum value thereof for connecting said inductances in parallel relation with respect to each other, said second control means being operative upon the further adjustment of said inductances in parallel to a second predetermined minimum value thereof for connecting said condenser directly to said antenna in series with said capacity means.

15. Apparatus as defined in claim 14 wherein said second control means includes means operative upon the connection of said condenser to said antenna for connecting said inductances in series relation to each other between said antenna and ground.

16. Apparatus as defined in claim 14 wherein said second control means includes means operative upon the adjustment of said variable inductances to the first or second predetermined minimum value thereof and the adjustment of said variable capacity means to a predetermined maximum value thereof or upon the deactuation of said capacity adjusting means and the adjustment of said variable inductance means to the predetermined minimum value for rendering said second control means operative.

17. Apparatus as defined in claim 16 wherein said inductances comprise variometers.

18. Apparatus as defined in claim 17 wherein means are provided to limit the operation of said variometers to substantially 180 degrees rotation thereof.

19. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, said capacity adjusting means being deactuated upon substantial elimination of the phase angle mismatch, variable inductance means coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductance means in a direction to eliminate the impedance magnitude mismatch, first control means for initially inserting said inductance means between said antenna and ground, a condenser adapted to be connected in series with said antenna, and second control means operative upon the adjustment of said inductance means to a predetermined minimum value thereof and the adjustment of said variable capacity means to a predetermined maximum value thereof for connecting said condenser directly to said antenna in series with said capacity means, said second control means being operative upon the adjustment of said inductance means to a predetermined maximum value thereof for inserting said inductance means between said capacity means and said antenna.

20. Apparatus are defined in claim 19 wherein said second control means are also operative upon the adjustment of said inductance means to the predetermined minimum value and the deactuation of said capacity adjusting means for connecting said condenser directly to said antenna in series with said capacity means.

21. Apparatus as defined in claim 20 wherein said second control means includes means operative upon the

connection of said condenser to said antenna for inserting said inductance means between said antenna and ground.

22. Apparatus for tuning an antenna to a source of radio frequency energy comprising variable capacity means series connected between said source and said antenna, means responsive to the phase angle mismatch between the output impedance of said source and the impedance of said antenna for adjusting said capacity means in a direction to eliminate the phase angle mismatch, said capacity adjusting means being deactuated upon elimination of the phase angle mismatch, two variable inductances coupled to said antenna, means responsive to the magnitude of the impedance mismatch between said source and said antenna for adjusting said inductances in a direction to eliminate the impedance magnitude mismatch, first control means for initially connecting said inductances in series relation with respect to each other and between said antenna and ground, a condenser adapted to be connected in series with said antenna, and second control means operative upon the adjustment of said inductances to a first predetermined minimum value thereof and the adjustment of said variable capacity means to a predetermined maximum value thereof for connecting said inductances in a parallel relation with respect to each other, said second control means operative upon the further adjustment of said inductances to a second predetermined minimum value thereof and the adjustment of said variable capacity means to the predetermined maximum value thereof for connecting said condenser directly to said antenna in series with said capacity means, said second control means being operative upon the adjustment of said inductances to a predetermined maximum value thereof for connecting said inductances between said capacity means and said antenna.

23. Apparatus as defined in claim 22 wherein said second control means includes means operative upon the connection of said condenser to said antenna for connecting said inductances in series relation to each other between said antenna and ground.

24. Apparatus as defined in claim 22 wherein said second control means are also operative upon the adjustment of said inductances to the first or second predetermined minimum value thereof and the deactuation of said capacity adjusting means.

25. Apparatus as defined in claim 24 wherein said inductances comprise variometers.

26. Apparatus as defined in claim 25 wherein means are provided to limit the operation of said variometers over 180 degrees rotation thereof.

27. A method for matching a second impedance to a first impedance comprising the steps of inserting variable capacity means in series between said first and said second impedances, coupling variable inductance means to said second impedance, adjusting the variable capacity means to eliminate the phase angle mismatch between the first and second impedances, adjusting the variable inductance means to eliminate the impedance magnitude mismatch between the first and second impedances, and selectively inserting the variable inductance means between the second impedance and ground or between the variable capacity means and the second impedance in accordance with the adjustment of the variable capacity means and the variable inductance means.

28. A method for matching a second impedance to a first impedance comprising the steps of inserting variable capacity means in series between said first and second impedances, coupling variable inductance means to said second impedance, adjusting the variable capacity means to eliminate the phase angle mismatch between the first and second impedances, adjusting the variable inductance means to eliminate the impedance magnitude mismatch between the first and second impedances, selectively inserting the variable inductance means between the second impedance and ground or between the variable capacity means and the second impedance in accordance with the adjustment of the variable capacity means and the variable inductance means, and selectively connecting a condenser directly to the second impedance in series with the capacity means in accordance with the adjustment of the variable capacity means and the variable inductance means.

29. A method for tuning an antenna to a source of radio frequency energy comprising the steps of inserting variable capacity means in series between the source and the antenna, coupling variable inductance means to the antenna, adjusting the variable capacity means to eliminate the phase angle mismatch between the output impedance of the source and the impedance of the antenna, adjusting the variable inductance means to eliminate the impedance magnitude mismatch between the source and the antenna, and selectively inserting the variable inductance means between the antenna and the ground or between the variable capacity means and the antenna in accordance with the adjustment of the variable capacity means and the variable inductance means.

30. A method for tuning an antenna to a source of radio frequency energy comprising the steps of inserting variable capacity means in series between the source and the antenna, coupling variable inductance means to the antenna, adjusting the variable capacity means to eliminate the phase angle mismatch between the source and the antenna, adjusting the variable inductance means to eliminate the impedance magnitude mismatch between the source and the antenna, selectively inserting the variable inductance means between the antenna and the ground or between the variable capacity means and the antenna in accordance with the adjustment of the variable capacity means and the variable inductance means, and selectively connecting a condenser directly to the antenna in series with the capacity means in accordance with the adjustment of the variable capacity means and the variable inductance means.

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