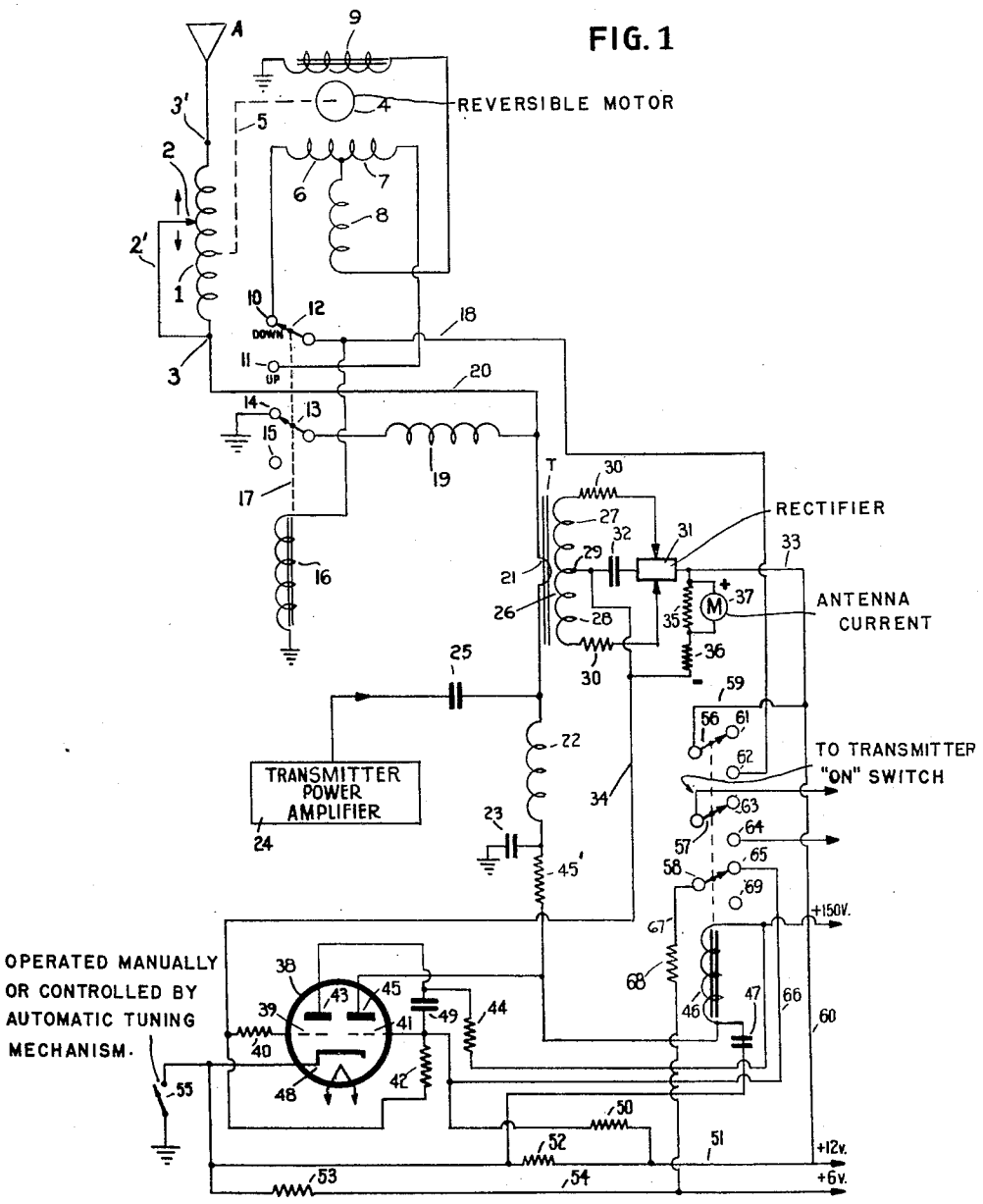
Feb. 21, 1950 W. B. MORRISON 2,498,340

ANTENNA TUNING CONTROL SYSTEM

Filed March 23, 1945 3 Sheets-Sheet 1

FIG. 1



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ANTENNA TUNING CONTROL SYSTEM

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FIG. 4.

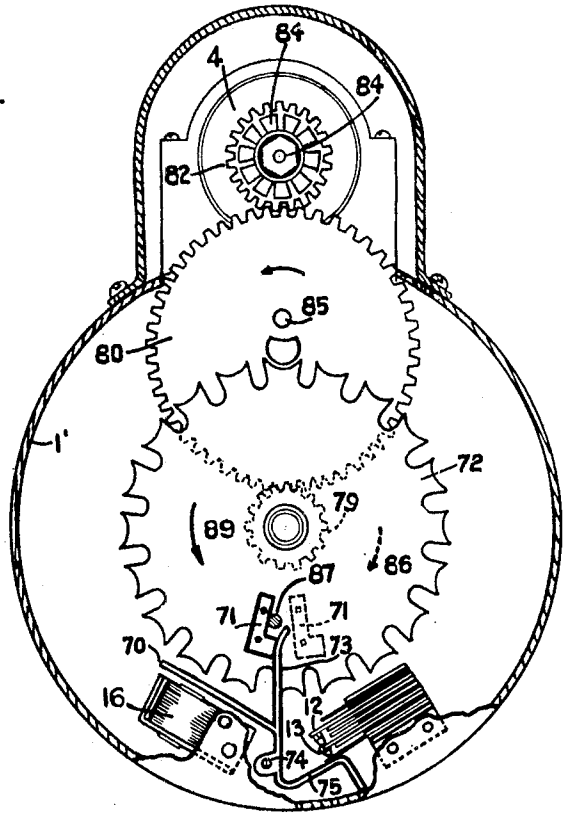


FIG. 2a.

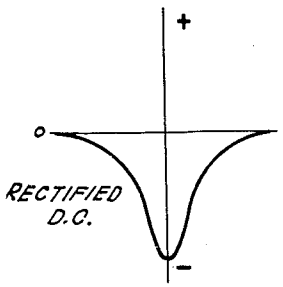


FIG. 2b.

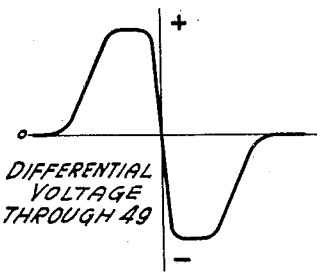
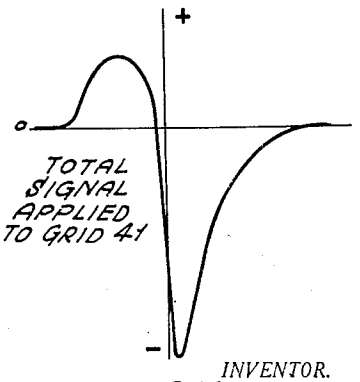


FIG. 2c.



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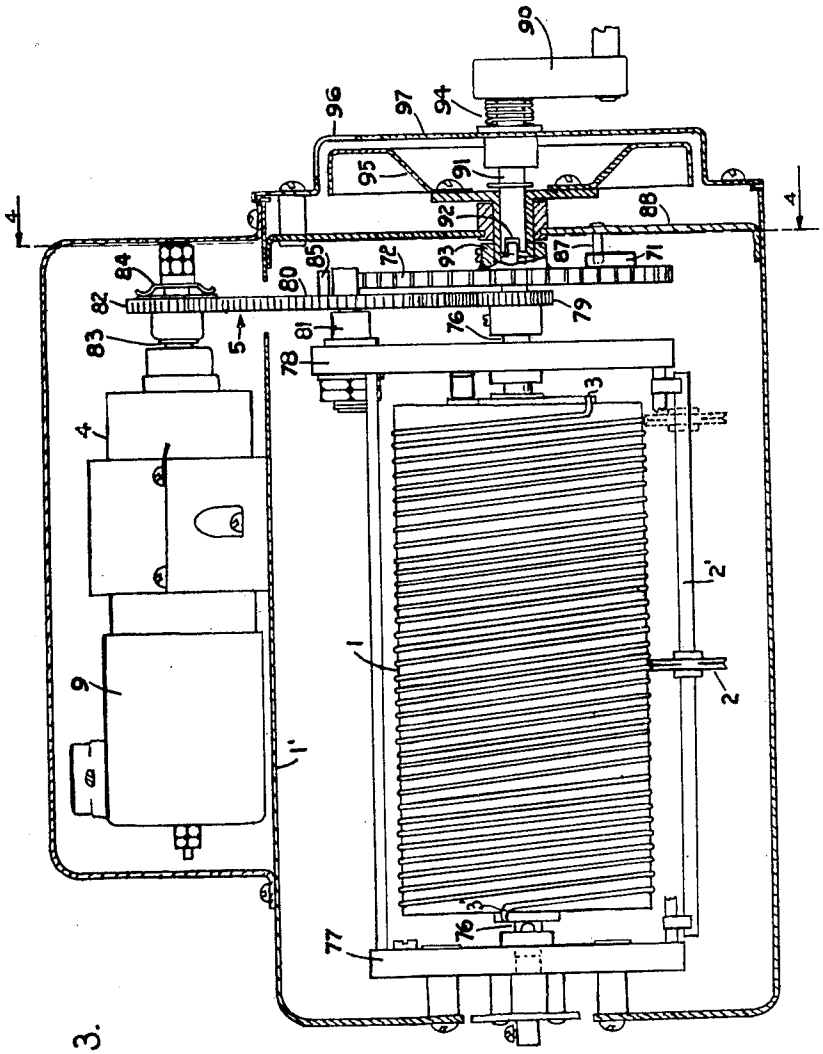


FIG. 3.

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Patented Feb. 21, 1950

2,498,340

UNITED STATES PATENT OFFICE

2,498,340

ANTENNA TUNING CONTROL SYSTEM

William B. Morrison, Verdun, Quebec, Canada, assignor, by mesne assignments, to Radio Corporation of America, New York, N. Y., a corporation of Delaware

Application March 23, 1945, Serial No. 584,393
In Canada January 22, 1945

5 Claims. (Cl. 250—17)

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My present invention relates to an antenna tuning control system, and more particularly to a control system for automatically adjusting the inductance of an antenna tuning coil to a value such that the antenna circuit will be in exact resonance at a selected operating frequency of a transmitter or receiver to which the antenna circuit is coupled.

Although the invention may find general application in systems where it is desired to provide for the automatic adjustment of a tunable device in response to a transmitted or received radio signal, the invention as disclosed herein is applied to a transmitter-receiver set utilized in a two-way communication system which is described and claimed in an application, Serial No. 584,392, filed concurrently herewith, by John C. E. Mitchell and the present applicant, which application is now U. S. Patent No. 2,433,290, granted Dec. 23, 1947.

In the operation of a transmitter designed to operate on any one of a plurality of carrier frequencies, or a transmitter-receiver set for two-way communication, such as described in the above-mentioned application, it is often necessary to change over from one operating frequency or carrier to another, and frequently at short notice. It is therefore advantageous and desirable that the antenna circuit, in addition to the tunable circuits of the transmitter-receiver set, be tuned to exact resonance, and as quickly as possible.

Accordingly, it is one of the main objects of my invention to provide automatically-operated means for adjusting the tuning of the antenna circuit of a transmitter to exact resonance at the transmitted frequency.

Another object of the invention is to provide means automatically operated in response to antenna current for adjusting the tuning of the antenna circuit.

A still further object of the invention is to provide, as the antenna tuning means, a rotary inductance coil which is motor-operated, in response to antenna current, to a position such that it tunes the antenna circuit to resonance, suitable control means being provided to cause substantially instantaneous stoppage of the motor at the resonant-adjusted position of the coil.

A more specific object of my invention is to provide a rotary tuning coil for the antenna circuit, a reversible motor for rotating the coil first in one direction and then in the other to vary its inductance, antenna-current responsive means, and a control circuit operated by the latter means for deenergizing the motor at the instant the coil is rotated to a position where

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it provides the requisite inductance to tune the antenna circuit to resonance.

The novel features characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, as to its organization, circuit arrangement and mode of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawing, in which:

Fig. 1 is a schematic circuit diagram of the antenna tuning control system in accordance with the invention,

Figs. 2*a*, 2*b* and 2*c* are certain voltage curves which will serve to explain certain aspects of the invention,

Fig. 3 is a view in elevation and partly in section of the antenna tuning coil and the elements associated therewith, including the driving motor, and

Fig. 4 is a sectional view of Fig. 3 taken on the line 4—4 of Fig. 3.

Referring to Fig. 1, the antenna tuning coil, which is of the rotary type, is shown at 1. A variable tap 2 is electrically connected by a conductive connection 2′ to the coil at one end 3, the opposite end 3′ being connected to the antenna A. As shown in Fig. 3, tap 2 is in the form of a roller and the conductive connection 2′ is in the form of a rod along which the roller is adapted to slide in the axial direction. A reversible motor indicated at 4 is adapted, when energized, to rotate the coil through suitable reduction gearing represented by the dash line 5. Rotation of the coil causes the variable tap or roller to travel up or down as viewed in Fig. 1, or to the left or right as viewed in Fig. 3, in contact with the coil turns, depending upon the direction of motor travel, thereby introducing a varying amount of coil inductance into the antenna circuit.

The motor is provided with a pair of reversing windings 6 and 7, to the common terminal of which there is connected the motor field winding 8 in series with a brake coil 9 which is grounded at one end. The other terminals of windings 6 and 7 are connected, respectively, to switch contacts 10 and 11 with which there is adapted to cooperate a movable switch arm 12. A second switch arm 13 is movable between a grounded contact 14 and a blank contact 15, and a relay coil 16 is adapted, when energized, to actuate both switch arms 12 and 13 in unison from their normal upper positions, as shown, to their lower positions by means represented diagrammatically

by the dash line 17. The relay coil 16 is grounded at one end and is connected at its other end to a conductor 18 which in turn is connected to the switch arm 12. A radio frequency choke 19 is connected between the switch arm 13 and a conductor 20 leading from the low end 3 of the tuning coil.

Connected to the antenna lead 20 is the primary winding 21 of a transformer T, and in series therewith is a coil 22 which together with a shunt condenser 23 constitute a radio frequency antenna filter. The block at 24 represents the power amplifier of the transmitter and is the same as that designated 24 in the application above mentioned. The power amplifier output is fed to the antenna circuit through a coupling condenser 25 (corresponding to the condenser designated 41 in said application), the condenser being connected to the junction between transformer primary 21 and the choke 22.

The transformer T is provided with a secondary winding 26 divided into two sections 27 and 28 by a tap 29, the outer ends of the coil sections being connected, respectively, through resistances 30 of suitable values to the contacts of a dry-disc rectifier 31. The coil sections 27 and 28 are so proportioned that together with the distributed capacity of the circuit including the rectifier they resonate at approximately 3 and 6 mc. However, by means of the resistances 30 the current-frequency curve is sufficiently flattened to provide a substantially uniform output from the rectifier over the operating range of the transmitter of 2 to 8 mc.

Connected between the tap 29 and the rectifier 31 is a radio frequency bypass condenser 32, and connected between a conductor 33 from the output electrode of the rectifier and a conductor 34 leading from the tap 29 are the rectifier load resistors 35 and 36. A meter 37 for indicating antenna current is shunted across the portion 35.

A discharge tube for controlling the operation of the motor 4 in response to the antenna current is shown at 38. Although this tube is shown as a twin-triode, the type used being a "6J6," separate tubes or a twin tube of a different type having similar characteristics may be used instead. The lead 34 which is the negative side of the rectifier output is connected to the grid 39 of the first tube section through a coupling resistor 40 and also to the grid 41 of the second tube section through a coupling resistor 42. The plate 43 of the first section is connected through a load resistor 44 to a source of potential represented by +150 v. and the plate 45 of the second section is connected through a relay coil 46 to the same potential source. The plate 45 is also connected to the low end of choke 22 by way of a resistor 45'. Condenser 47 is a bypass condenser for the plate circuit of the second tube section, being connected between the low potential side of relay coil 46 and cathode 48 of the tube, and condenser 49 is a coupling condenser which serves to couple the plate circuit of the first tube section to the grid 41 of the second section. A resistor 50 is connected from grid 41 to a +12 v. conductor 51 to which cathode 48 is also connected through a resistor 52, and a second cathode resistor 53 is connected to a +6 v. conductor 54. The cathode of the control tube is adapted to be connected to ground through a switch 55 which may be constituted as a push-button for manual operation or for the particular application herein disclosed be controlled by automatic tuning mechanism.

The relay coil 46 is adapted, upon being energized, to actuate a gang of switch arms indicated at 56, 57 and 58. The switch arm 56 is connected by way of a conductor 59 to lead 33 and by way of a conductor 60 to the +12 v. conductor 51, the lead 33 from the rectifier also being connected to conductor 60. The upper contact 61 of switch 56 is blank while the lower contact 62 has connected to it the conductor 18 which leads from the motor-reversing switch arm 12. The upper contact 63 of switch 57 is blank, there being connected to the lower contact 64 and to the switch arm 57 a pair of conductors which lead to the transmitter "on" switch (not shown). The upper contact 65 of switch 58 is connected to grid 41 of the second tube section by way of a conductor 66, and the switch arm itself is connected to the +6 v. conductor 54 by way of a conductor 67 which includes a resistor 68, the lower contact 69 of switch 58 being blank.

Tube 38 controls the current through the relay coil 46 which in turn, actuates or pulls-in the three switch arms, 56, 57 and 58 when it is energized. The relay coil is thus energized when the tube is in a conducting condition and is non-energized when the tube is biased to cut-off. The conducting condition of the tube is controlled as follows: Antenna current through transformer T is fed to the rectifier 31, there being developed across the load resistors 35 and 36 a D. C. potential which varies directly as the R. F. current fed into the antenna from the power amplifier 24 of the transmitter. Thus, when the antenna circuit including its coil 1 passes through resonance, a negative D. C. voltage of the form shown in Fig. 2*a* is obtained. This negative voltage is applied to the grid 39 of the first section of the tube through resistor 40, being amplified approximately twenty times in this section of the tube, and is then coupled to the grid 41 of the second tube section through the coupling condenser 49. As the voltage induced on one plate of a condenser varies as the rate of change of voltage on the other plate, the voltage appearing on grid 41 through condenser 49 is the differential of the resonance curve shown in Fig. 2*a*. The differential voltage curve as the antenna coil passes through resonance is shown in Fig. 2*b*. In addition, some of the D. C. resonance voltage from the rectifier output is fed to grid 41 through resistor 42. The relative amplitudes of these two voltages on grid 41 are as shown in Figs. 2*a* and 2*b* and the resulting voltage is the sum of these voltages shown in Fig. 2*c*. The above action results in a sharp increase in negative voltage with great enough amplitude to produce plate current cut-off in the tube at the instant the antenna coil reaches the point at which resonance for the antenna circuit is obtained.

The tuning-coil driving motor 4 is a D. C. motor of the reversible type. Power to the motor is switched on by the switch arm 56 when actuated to its lower contact 62 by the relay 46 and thus the motor runs only when the relay 46 is energized. When the tuning-up cycle is started, the motor will always rotate the coil to the point of maximum inductance, that is, in a direction such that tap or roller 2 travels towards the coil end 3. This is so because at the beginning of the cycle the position of switch 12 is as shown in the drawing in contact with the upper contact 10, thereby completing the motor circuit through the field winding 6 which is effective to rotate the motor in the above-designated direction. This precaution is nec-

essary in order to prevent the relay throwing out or becoming deenergized on an harmonic of the desired frequency. This is accomplished by causing a residual current to flow through the coil of relay 46 by tying the resistor 45' to ground when the antenna coil is tuned down to maximum inductance, the ground connection being completed through coils 22 and 19 and the closed position of switch 13 as shown. When the coil reaches the end of its travel, the direction of motor operation is reversed and the ground connection for resistor 45' is broken at 14 in a manner to be described in connection with Fig. 4. Switch 12 is brought down to its contact 11 to complete the motor circuit through the other field winding 7, thereby rotating the tuning coil in the opposite direction to cause the tap or roller 2 to recede from the maximum inductance position at coil end 3 so that the inductance in the antenna circuit is gradually diminished.

Although the relay coil 16 is energized during the time the motor circuit is energized, the switches 12 and 13 which are adapted to be controlled thereby are not actuated to their low contacts, the reason being that normally the relay armature 70 (Fig. 4) is spaced a sufficient distance from the pole of the relay so as not to be attracted thereto in the presence of current through the relay. However, when the tuning coil reaches the end of its travel, an actuator 71 carried by a motor-driven Geneva gear 72 strikes an arm 73 attached to or formed integral with the armature 70 which is pivoted at 74 to urge the armature towards the relay pole. The energized relay will therefore hold the armature in attracted position. Formed integrally with or otherwise attached to the armature is a member 75 which, in the attracted position of the armature, actuates the switch arms 12 and 13 to the lower contacts, as seen in Fig. 1. As mentioned previously, this causes the motor to reverse its direction of operation, thereby rotating the antenna coil so that its effective inductance is reduced, and causes also the ground connection for resistor 45' to be broken at contact 14. Although actuator 71 is withdrawn from the arm 73 by movement of the gear 72 in the opposite direction, relay 16 holds its armature 70 in attracted position, and switches 12 and 13 will be closed while the antenna tuning coil tunes back up. The switches will pull back to their positions as shown in Fig. 1 when the tuning adjustment is completed and the motor voltage is shut off at contact 62 upon the opening of switch 56.

The control relay 46 is normally in a non-energized state. To initiate operation of the control tube it is necessary that the cathode 48 of the tube be grounded. This is accomplished by the closure of switch 55 which may be performed manually, or, when used in connetion with a system such as described in the above-mentioned application which is adapted for automatic tuning, the switch may be arranged for closure automatically at a proper point in the sequence of automatic tuning operations.

The manner of operation of the control tube is as follows: With the control switch 55 open, the cathode 48 is 12 volts positive, being connected to the +12 v. conductor 51 through the resistor 52; and the grid 41 is at 6 volts positive, being connected to the +6 v. conductor 54 by way of conductors 66, 67 and resistor 68. The grid is therefore 6 volts negative with respect to the cathode and is sufficient to bias the second section of the tube to plate current cut-off. As a consequence the relay coil 46 is deenergized, and the motor is inoperative by reason of switch arm 56 being on its upper contact 61.

Upon the closure of switch 55, the cathode is connected to ground, grid 41 still remaining at +6 volts. There will result, therefore, an instantaneous high plate current through the tube to cause energization of relay 46 which in turn will pull-in the several switches 56, 57 and 58. Power to the motor will then be applied through switch 56 closed on contact 62, and the +6 volt connection to grid 41 will be broken at contact 65. There will, however, be applied to the grid a bias of +12 volts through the resistor 50 which is large enough (1 megohm) to limit the grid current to a safe value. With the cathode still at ground potential (switch 55 remaining closed up to this point, it being only necessary that switch 55 be closed for a fraction of a second) and the grid being at +12 volts, the relay continues to be energized. With the opening of switch 55 at this time by the removal of the finger or otherwise, the cathode is brought back to +12 volts, and since the grid is also at +12 volts, the tube operates, or is conductive, with zero grid bias, and the relay coil 46 continues to be energized by the normal plate current of the tube. In the meantime the motor has begun to drive the tuning coil 1 to its maximum inductance position whereat the motor reversal occurs as previously explained.

At the point of resonance of the antenna circuit, there occurs a sharp increase in the negative bias on grid 41, as explained above in connection with the curve of Fig. 2c. As a consequence the plate current of the tube cuts off and the control relay coil is deenergized, opening the motor energizing circuit at contact 62. By means of the brake coil 9 which is deenergized simultaneously with the motor, a mechanical brake device (not shown), but which may be of any suitable construction, is released to brake the motor.

The motor drive for the rotary tuning coil 1 may be seen from the constructional views shown in Figs. 3 and 4. The coil is enclosed in a cylindrical case 1' and is mounted on a shaft 76 which is journalled at its opposite ends in a pair of side members 77 and 78. The shaft end at the right has affixed to it a pinion 79 which meshes with a gear 80 mounted on a stud shaft 81 supported from the member 78. Geared to gear 80 is a driving pinion 82 freely mounted on the motor shaft 83 and is adapted to be driven thereby through a friction clutch plate 84 which avoids placing on the manual drive, later to be described, an unduly heavy load due to the motor armature and the brake mechanism. The gear train 82, 80 and 79 constitute the reduction gearing which has been indicated in Fig. 1 by the dash line 5.

The gear 80 is provided with a drive pin 85 for the Geneva cam or gear 72 which is freely mounted on the right-hand end of the coil shaft. The gear 72 is designed to make one complete revolution for the time it takes the roller 2 to travel on its conductive rod 2' from one end of the coil to the other.

In the direction of rotation of the gear 72, as indicated by the dotted arrow 86, the roller 2 will approach the coil end 3, that is, to the right as seen in Fig. 3. The actuator 71 is shown dotted in Fig. 4 at a position just prior to the roller reaching this limit of travel. With the next stepping movement of the Geneva gear 72, the actuator will rock the armature 70 towards the holding relay 16 and also throw the switches 12 and 13 to their opposite contacts as heretofore

explained. A stop pin 87, carried by an end cover plate 88, serves to limit further travel of actuator 71 and gear 72. The motor having thus reversed its direction of operation, the gear will rotate in the opposite direction, or as indicated by the solid arrow 89. If the coil does not pass through resonance, gear 72 will be rotated to said opposite limit of its travel, the actuator 71 being indicated at that position in full lines, where it is in contact with the stop pin 87. Just prior to reaching this limiting position, 71 coacts with arm 73 to withdraw the armature 70 from relay 16 and releases the pressure of member 75 on switch arms 12 and 13 to cause their return to the position shown in Fig. 1. The cycle will then start anew and continue to operate until a tuning position corresponding to the transmitted carrier is located, or until the transmitter is shut down.

For tuning the antenna coil manually there is provided a hand wheel or crank 90 at the end of a shaft 91 which is provided at its other end with a transverse slot 92 adapted to receive a similarly shaped extension 93 on the coil shaft 76. Normally parts 92 and 93 are disengaged due to the action of a coil spring 94. When it is desired to manually adjust the tuning coil, crank 90 is pressed in to permit engagement between the female portion of shaft 91, and the male portion of shaft 76. The crank is then rotated until the antenna circuit is tuned to resonance, which condition will be indicated by the maximum deflection of the tuning meter 37 (see Fig. 1).

In manual operation the coupling between the driving shaft 91 and the driven shaft 76 is direct. The gear 80, however, is rotated through pinion 79 to provide rotation of a calibrated antenna tuning dial 95, which dial is directly coupled to gear 72. The calibrations of dial 95 are viewable through an opening 96 formed in a cover plate 97.

While I have shown a particular embodiment of my invention, it will, of course, be understood that I do not wish to be limited thereto, since various modifications may be made in the circuit arrangement, in the instrumentalities, and in the mechanical construction employed without departing from the spirit and scope of my invention as set forth in the appended claims, and I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim is:

1. In a circuit arrangement comprising an oscillatory circuit having a component thereof variable in opposite directions over a predetermined range of mechanical movement to tune said oscillatory circuit over a prearranged frequency spectrum, a control system operative upon application of alternating currents to said oscillatory circuit to vary said component to tune said oscillatory circuit substantially to resonance with said alternating currents, said control system including a power operated device, means controlled by said power operated device to vary said component in one direction to one extremity of said range of movement and thereupon to vary said component in the other direction toward the other extremity of said range of movement, a control circuit associated with said power operated device to cease said variation of said component in said other direction at a position of said component at which resonance of said oscillatory circuit with said alternating currents is obtained, said control circuit comprising means to derive a unidirectional voltage proportional to said alternating currents, said voltage increasing rapidly as resonance is approached to a maximum at resonance and decreasing in complementary manner after resonance is passed, an electron discharge system having at least a cathode element, a control element and an anode element, a relay having the actuating winding thereof connected to said anode element and having an armature coupled in circuit with said power operated device to render the same operable when said electron discharge system is conducting, and means to render said electron discharge system conducting to initiate said variation of said component by said power operated device, the improvement comprising a network to which a portion of said voltage is applied to derive a bi-directional voltage increasing rapidly in one direction as resonance is approached, reversing and passing through zero at resonance, and reversing and decreasing in complementary manner after resonance is passed, means to combine said voltages to produce a resultant voltage increasing rapidly in one direction only as resonance is passed, and means to apply said resultant voltage to said control element of said electron discharge system to block the same when said component is at a position tuning said oscillatory circuit substantially to resonance with said alternating currents, thereby to deenergize said relay and cause cessation of said variation of said component.

2. In a circuit arrangement comprising an oscillatory circuit having a component thereof variable over a predetermined range of mechanical movement to tune said oscillatory circuit over a prearranged frequency spectrum, a control system operative upon application of alternating currents to said oscillatory circuit to vary said component to tune said oscillatory circuit substantially to resonance with said alternating currents, said control system including a power operated device arranged to vary said element from one extremity toward the other extremity of said range of movement, a control circuit associated with said power operated device to cease said variation at a position of said component at which resonance of said oscillatory circuit with said alternating currents is obtained, said control circuit comprising means to derive a unidirectional voltage proportional to said alternating currents, said voltage increasing rapidly as resonance is approached to a maximum at resonance and decreasing in corresponding manner after resonance is passed, an electron discharge system having at least a cathode element, a control element and an anode element, a relay having the actuating winding thereof connected to said anode element and having an armature coupled in circuit with said power operated device to render the same operable when said electron discharge system is conducting, and means to render said electron discharge conducting to initiate said variation of said element by said power operated device, the improvement comprising a network to which a portion of said voltage is applied to derive a bi-directional voltage increasing rapidly in one direction as resonance is approached, reversing and passing through zero at resonance, and reversing and decreasing in corresponding manner after resonance is passed, means to combine said voltages to produce a resultant voltage increasing rapidly in one direction only as resonance is passed, and means to apply said resultant voltage to said control element of said electron discharge system to block the same when said component is

at a position tuning said oscillatory circuit substantially to resonance with said alternating currents, thereby to deenergize said relay and cause cessation of said variation of said component.

3. In a circuit arrangement comprising an oscillatory circuit having a tuning component reversibly variable over a predetermined range of mechanical movement to tune said oscillatory circuit over a prearranged frequency spectrum, a control system operative upon application of alternating currents to said oscillatory circuit to adjust said component to tune said oscillatory circuit substantially to resonance with said alternating currents, said control system including a reversible motor, mechanical linkage under the control of said motor to drive said component in one direction to one extremity of said range of movement and thereupon to drive said component in the opposite direction toward the other extremity of said range of movement, a control circuit electrically associated with said motor to cease said adjustment at a position of said component at which resonance of said oscillatory circuit with said alternating currents is obtained, said control circuit comprising a rectifier coupled to said oscillatory circuit to derive a unidirectional voltage proportional to the alternating current therein, an electron discharge system having at least a cathode element, a control grid and an anode, a relay having the actuating winding thereof connected to said anode and having an armature coupled in circuit with said power operated device to render the same operable when said electron discharge system is conducting, and a switch arranged to alter the bias on said electron discharge system to render the same conducting to drive said component in said one direction by said motor, a differentiating network coupled to said rectifier to derive a bi-directional voltage increasing rapidly in one direction as resonance is approached, reversing and passing through zero at resonance, and reversing and decreasing in corresponding manner after resonance is passed, means to combine said voltages to produce a resultant voltage increasing rapidly in one direction only as resonance is passed, and means to apply said resultant voltage to the control grid of said electron discharge system to block the same when said component is adjusted to tune said oscillatory circuit substantially to resonance with said alternating current, thereby to deenergize said relay and halt the progress of said motor.

4. In a circuit arrangement comprising an oscillatory circuit having a tuning component reversibly variable over a predetermined range of mechanical movement to tune said oscillatory circuit over a prearranged frequency spectrum, a control system operative upon application of alternating currents to said oscillatory circuit to adjust said component to tune said oscillatory circuit substantially to resonance with said alternating currents, said control system including a reversible motor, mechanical linkage under the control of said motor to drive said component in one direction to one extremity of said range of movement and thereupon to drive said component in the opposite direction toward the other extremity of said range of movement, a control circuit electrically associated with said motor to cease said adjustment at a position of said component at which resonance of said oscillatory circuit with said alternating currents is obtained, said control circuit comprising a transformer coupled to said oscillatory circuit, a rectifier coupled to said transformer to derive a unidirectional voltage proportional to the alternating current therein, an electron discharge system having at least a cathode element, a control grid and an anode, a relay having the actuating winding thereof connected to said anode and having an armature coupled in circuit with said power operated device to render the same operable when said electron discharge system is conducting, and a switch arranged to alter the bias on said electron discharge system to render the same conducting to drive said component in said one direction by said motor, an amplifying electron discharge system coupled to said rectifier and a differentiating network to derive a differential voltage, means to combine said voltages to produce a resultant voltage increasing rapidly in one direction only as resonance is passed, and means to apply said resultant voltage to the control grid of said electron discharge system to block the same when said component is adjusted to tune said oscillatory circuit substantially to resonance with said alternating current, thereby to deenergize said relay and halt the progress of said motor.

5. A control system for tuning an oscillatory circuit having a component variable over a predetermined range of mechanical movement to tune said oscillatory circuit over a prearranged frequency spectrum, including a power device to drive said component over said range of movement, and a control circuit to interrupt said power device upon said component reaching a position at which said oscillatory circuit is tuned to resonance with a signal applied thereto, said control circuit comprising means to derive a voltage proportional to the current flowing in said oscillatory circuit, said voltage having a waveform rising to a maximum at the frequency at which resonance is obtained, means to alter the waveform of said voltage to produce a potential having a waveform having an intermediate value at the frequency at which resonance is obtained, electron discharge means coupled to control said power device and biased to maintain said power device normally operative, and means to apply said potential to said electron discharge means to block the same when said potential attains said intermediate value thereby to render said power device inoperative.

WM. B. MORRISON.

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