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AUTOMATIC FREQUENCY CONTROL
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9 Claims. (Cl. 250—20)

My present invention relates to automatic frequency control circuits, and more particularly to an automatic frequency control circuit especially adapted for superheterodyne receivers.

There has been disclosed by S. W. Seeley in application Serial No. 45,413 filed October 17, 1935, an automatic frequency control circuit which employs a discriminator network for deriving a direct current voltage from I. F. signal energy, the voltage depending in magnitude and polarity upon the sign and amount of frequency departure of the I. F. energy from its assigned operating value. The derived direct current voltage is used to control the gain of a control tube; the plate and grid circuits of the control tube being connected to the oscillator tank circuit to produce an effective inductive effect across the latter. Variation of the gain of the control tube then results in a change in frequency of the oscillator tank circuit.

One of the main objects of my present invention is to provide a frequency control circuit for the tank circuit of an oscillator tube, which frequency control circuit includes a tube whose output circuit is operatively associated with the tank circuit so as to reflect a predetermined reactance across the tank circuit; and there being at least two reactances of opposite sign in the oscillator output circuit whereby voltages may be developed across the two reactances, and means being utilized to control in a predetermined manner the impression of the voltages developed across the two reactances upon the input circuit of the frequency control tube.

Another important object of the invention may be stated to reside in the provision of an automatic frequency control arrangement for a superheterodyne receiver, which arrangement employs a discriminator network, a frequency control tube of constant gain, means including reactances of opposite sign, and devices for controlling the electrical effect of the reactances on the frequency control tube output current thereby regulating the frequency adjustment of the local oscillator tank circuit.

Yet another object of my invention is to provide an automatic frequency control arrangement for securing accurate tuning in a superheterodyne receiver, and which arrangement differs from arrangements known in the prior art in that the frequency control tube has a constant gain, but its frequency control effect on the oscillator tank circuit is regulated by selectively controlling the electrical effect of a pair of reactances of

opposite sign, and which reactances are in the local oscillator output circuit.

Still other objects of my invention are to improve generally automatic frequency control arrangements for superheterodyne receivers, and more especially to provide such control circuits for accurate tuning of superheterodyne receivers, and which control circuits are not only reliable and efficient in operation, but are economically manufactured and assembled in radio receivers.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically a circuit organization whereby my invention may be carried into effect.

Referring to the accompanying drawing, it will be noted that only those networks of the superheterodyne receiver are shown which are essential to an understanding of the invention. The receiver, in general, will comprise the usual signal collector followed by one, or more, stages of tunable radio frequency amplification; the receiver range may cover 550 to 1500 k. c. or the receiver may be of the all-wave type. The amplified signals will be fed to a first detector, or mixer, which is provided with a tunable input circuit 2. Local oscillations are impressed on the first detector by a local oscillator of the tunable type. The oscillator tube is denoted by the numeral 3; it may be a pentagrid tube of the 6A7 type. A tunable tank circuit 4 is connected between the grid 5 and cathode 6, the grid 5 being connected to the high alternating potential side of tank circuit 4 through a direct current blocking condenser 7. The cathode 6 is grounded through the resistor 8, the latter being shunted by a radio frequency bypass condenser 9; the low alternating potential side of the tank circuit being at ground potential.

The resistor 10 connects the grid 5 to the cathode side of resistor 8, and resistor 10 acts to bias the grid 5 negatively upon oscillation production, due to grid rectification. The grid 11 is connected to a source of proper positive potential (+B) through the coil 12; the latter being magnetically coupled to the tank circuit coil 13. The variable condenser 14 is arranged to have its rotors mechanically uni-controlled with the rotors of the variable condensers of the signal circuits.

The dotted line represents the mechanical uni-

control tuning device which simultaneously adjusts the positions of the rotors of condensers 16 and 14. Those skilled in the art are fully aware of the need for varying the signal circuits (as circuit 2) and tank circuit 4 through respectively different frequency ranges; the usual padder condensers may be employed in the tank circuit to maintain the I. F. constant in value. The I. F. energy may be given a frequency value chosen from a range of 75 to 465 k. c. The plate 17 of oscillator tube 3 is connected to a source of proper positive potential (+B) through resistor 18; the grid 19, disposed between a pair of positive screen grids, is grounded so that it assumes a potential which is negative with respect to the cathode by the voltage drop across resistor 8. This grid 19 is negative so it will not draw current. The local oscillations are impressed on the first detector in any desired manner; for example, the oscillations may be taken off from the grid side of condenser 7. It will be seen, therefore, that the electrode 11 functions as the plate of the oscillator section of tube 3; the electrodes 11 and 5 are reactively coupled to provide the oscillations.

The I. F. output of the first detector is transmitted through one, or more, I. F. amplifiers 20. The amplified I. F. energy is demodulated by the second detector (not shown); the detected energy is utilized by one, or more, audio amplifiers followed by a reproducer. It will be fully understood that the output circuit of the first detector 1 is resonated to the operating I. F.; and that the input and output circuits of the I. F. amplifiers, as well as the input circuit of the second detector, are similarly resonated.

The automatic frequency control circuit for the local oscillator derives its signal energy from any desired point in the I. F. transmission network. For example, I. F. energy may be tapped off from the high alternating potential side of the last I. F. transformer; and the I. F. energy may be amplified by an auxiliary I. F. amplifier 21. The I. F. tuned output circuit 22 of the latter is relatively loosely coupled to the tuned circuit 23, the latter being resonated to the operating I. F. The circuit elements associated with the circuit 23 provide the AFC discriminator.

The point *a* of circuit 22 is connected to the midpoint *b* of circuit 23 through a blocking condenser 26. The points *c* and *d* of circuit 23 are connected to the anodes 25' and 24' respectively of diodes 25 and 24. Between the anode and cathode of diode 25 is connected a resistor 27; and a second resistor 28 is connected between the anode and cathode of diode 24. The magnitudes of resistors 27 and 28 are equal; hence they may be provided by the equal sections of a single resistor, since the junction of the two resistors is connected to point *b* of the coil of circuit 23 by means of connection 29. One terminal of resistor 28 is grounded; the other terminal *e* is the point from which the AFC bias is taken off. The I. F. bypass condenser 30 is shunted across resistors 27—28. The voltage at point *e*, with respect to ground, will be either positive or negative, depending on the sign of the signal frequency departure from the operating I. F.

It is believed that only a general explanation need be given of the functioning of the discriminator network, since the details thereof have been disclosed in the aforementioned Seeley application. Assuming a relatively large magnitude for the condenser 26, the points *a* and *b* are at the same potential. The phase of point *a* with re-

spect to ground potential is zero when the I. F. energy impressed on circuit 22 is at the operating I. F.; at resonance there is no phase shift in circuit 22. The point *b* is, therefore, at zero phase. The current in circuit 22 induces a voltage in circuit 23, and the induced voltage is distributed equally about the midpoint *b*. At a given instant point *c* is as much positive as *d* is negative. The voltages impressed on the two rectifiers are, therefore, equal, although opposite in phase.

The rectified outputs of the discriminator depend only on the magnitudes, and hence the voltage drops across resistors 27 and 28 will be equal. Since the two rectifiers are in series opposition, the potential at point *e*, with respect to ground, will be zero when the frequency of the signals impressed on circuits 22 and 23 is equal to the resonant frequency thereof. If, now, the signal frequency departs from the operating I. F., there will occur a phase shift of substantially 90° in the circuit. The voltages induced in the two halves of the coil of secondary circuit 23 are still equal in magnitude and opposite in phase with respect to point *b*.

The voltage drop across circuit 22 is now added vectorially to the induced voltages. Thus, the potential at one side of the secondary, say point *c*, will be the sum of the induced voltage (*bc*) and the voltage across circuit 22. The potential at point *d* will be equal to the difference between the drop across circuit 22 and the voltage induced in *bd*. It follows that the input voltage of one rectifier, diode 25 in the assumed case, is much greater than that of the other. The voltage drop across resistor 27 will be greater than that across resistor 28; point *e* will, accordingly, be positive with respect to ground.

When the signal energy departs off the operating I. F. to the opposite direction, the same explanation leads to the conclusion that point *e* will be negative with respect to ground. It will, therefore, be seen that point *e* has a polarity dependent on the direction of frequency shift of the I. F. energy. The magnitude of the potential at *e* depends on the amount of the shift. The potential at *e* is used to vary the frequency of the tank circuit 4. This is accomplished by employing the potential at point *e* to vary the conductivity of diodes 40 and 41. The point *e* is connected to the anode 42 of diode 40 through a path including the filter resistor 43 and lead 44 (designated as the AFC lead). The resistor 43 suppresses all pulsating components in the AFC bias.

The diode 40 has its anode 42 connected to the plate 17 of oscillator tube 3 through blocking condenser 45. Between the anode and cathode of diode 40 is connected condenser 46; resistor 47, shunted across the condenser 46, has a high resistance and provides a direct current path for the diode 40 when the latter becomes conductive. The anode 50 of diode 41 is grounded; the cathodes of diodes 40 and 41 being connected in common.

The coil 48 is connected in shunt between the cathode and anode of diode 41; the coil 48 having one terminal thereof connected to the cathode side of condenser 46, and the other terminal of the coil being connected to ground through the condenser 51. The resistor 49, of large value, is connected to ground from the junction of condenser 46 and resistor 47. The resistor 49 functions as a direct current path for the diode 41. It will be observed that the plate 17 of tube 3 is connected to ground through a path which includes condenser 45, condenser 46, coil 48 and

condenser 51 in series. The cathodes of diodes 40 and 41 are connected to the junction of resistors 47 and 49.

The frequency control tube 60 may be of the pentode type, and the first grid 61 thereof is connected to the anode 42 of diode 40 through a path which includes the lead 62 and the condenser 63. The plate 64 is connected to a source of proper positive potential (+B) through a path which includes the coil 65, and it will be noted that coils 65 and 13 are magnetically coupled. The screen grid of tube 60 is connected to the plate potential source through a resistor 66. The grounded grid bias network 67 provides the normal operating bias for grid 61 by virtue of the connection of lead 62 to ground through the grid leak resistor 68.

The function of tube 60 is to reflect, or simulate, across the tank circuit 4 a reactance of proper sign with respect to a desired shift in local oscillator frequency. In contra-distinction to the arrangement disclosed in the aforesaid Seeley application, the gain of tube 60 is not varied. The tube operates at a constant gain; what is regulated by the potential developed at point *e* is the sign of the reactance across which oscillator output voltage is developed for impression on the grid 61 of control tube 60.

When the potential of point *e* is positive, the diode 40 is rendered conductive. The condenser 46 is short-circuited when diode 40 becomes conductive. Hence, the oscillator output current develops an alternating current voltage across coil 48; the voltage is impressed on the grid 61. Since the plate circuit of tube 60 is inductively coupled to the tank circuit 4, and the voltage impressed on grid 61 is developed across an inductance, there is simulated across tank circuit 4 a negative capacity. On the other hand, when the point *e* is negative in potential the diode 41 is conductive and short-circuits the coil 48. The oscillator output voltage developed across condenser 46 is impressed on the grid 61, and a negative inductance is reflected across the tank circuit 4.

The current at anode 17 will be in phase with the voltage of grid 5, and will have a magnitude proportional to the transconductance effect at grid 5 on anode 17. This current will flow through condenser 45 and either condenser 46 and diode 41, or diode 40 and inductance 48, depending upon whether the potential of conductor 44 is positive or negative. If conductor 44 is negative, diode 41 short-circuits inductance 48, so that the R. F. potential appearing on grid 61 is that across capacity 46, which lags the voltage at grid 5 by approximately 90°. By virtue of the transconductance of tube 60, quadrature current flows in winding 65. The mutual inductance between coils 65 and 13 causes this current to appear in the tank circuit in phase aiding, or opposing, the current through winding 13, and depending upon the relative direction of winding of coils 65 and 13. The effect, then, is the same as if the reactance of coil 13 were varied, the effect being an increase in inductance if the current from tube 60 appearing in coil 13 is opposite in phase with that due to oscillations generated in coil 13 by tube 3 and feedback winding 12; and the effect is that of a decrease in inductance of coil 13 when the two currents therein are in phase with each other.

The change in effective inductance of coil 13 therefore acts to vary the oscillation frequency of circuit 4. If the potential of lead 44 is positive,

diode 40 short-circuits condenser 46 causing the current from anode 17 to flow through coil 48 thereby producing phase relations differing by 180° from those occurring when lead 44 has a negative potential, and causing the oscillation frequency of circuit 4 to change in the opposite direction from that when lead 44 is negative. It is then seen that variation of the polarity of lead 44 produces a variation of oscillation frequency of circuit 4, the direction of frequency variation for a given polarity depending upon whether the mutual inductance of coils 65 and 13 be series-aiding or series-opposing.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances in the output circuit of the oscillator tube, a control tube provided with an input circuit and having an output circuit reactively coupled to said tank circuit to reflect a desired reactance across the tank circuit, and connection means for selectively impressing voltage developed across either of said pair of reactances upon the control tube input circuit.

2. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances in the output circuit of the oscillator tube, a control tube provided with an input circuit and having an output circuit reactively coupled to said tank circuit to reflect a desired reactance across the tank circuit, and connection means for alternately impressing voltage developed across either of said pair of reactances upon the control tube input circuit, and said pair of reactances being of opposite sign.

3. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances in the output circuit of the oscillator tube, a control tube provided with an input circuit and having an output circuit reactively coupled to said tank circuit to reflect a desired reactance across the tank circuit, and connection means for impressing voltage developed across a selected one of said pair of reactances upon the control tube input circuit, and said means including a device for preventing development of oscillator output voltage across the second of said pair of reactances.

4. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances in the output circuit of the oscillator tube, a control tube provided with an input circuit and having an output circuit reactively coupled to said tank circuit to reflect a desired reactance across the tank circuit, a connection means for impressing voltage developed across either of said pair of reactances upon the control tube input circuit, means for selecting the reactance of said pair of reactances across which voltage is developed by the oscillator output current, and said pair of reactances being of opposite sign.

5. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances in the output circuit of the oscillator tube, a control tube provided with an input circuit and having an output

circuit reactively coupled to said tank circuit to reflect a desired reactance across the tank circuit, and connection means for selectively impressing voltage developed across either of said pair of reactances upon the control tube input circuit, one of said pair of reactances being a condenser, and the other being an inductor.

6. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances in the output circuit of the oscillator tube, a control tube provided with an input circuit and having an output circuit reactively coupled to said tank circuit to reflect a desired reactance across the tank circuit, and connection means for impressing voltage developed across either of said pair of reactances upon the control tube input circuit, a signal receiving circuit, means for combining the signals with oscillations from the oscillator tube, and means responsive to a frequency change in the beat energy for selecting a predetermined one of said pair of reactances across which voltage is to be developed.

7. In a superheterodyne receiver of the type comprising a first detector circuit, a local oscillator tube provided with a tank circuit and an output circuit, an intermediate frequency output circuit for said first detector, means, responsive to a frequency shift in the intermediate frequency energy output of the detector, for producing a direct current voltage dependent in polarity on the sense of said shift, a control tube provided with an input circuit and having an output circuit connected with the oscillator tank circuit to produce a reactive effect thereacross thereby to adjust the tank circuit frequency, at least two reactances of opposite sign in the oscillator output circuit, connections from the control tube input circuit to said two reactances, and means, responsive to said direct current voltage polarity, selectively preventing a predetermined one of the two reactances from affecting the control tube input circuit through said connections.

8. In a superheterodyne receiver of the type comprising a first detector circuit, a local oscillator tube provided with a tank circuit and an output circuit, an intermediate frequency output circuit for said first detector, means, responsive to a frequency shift in the intermediate frequency energy output of the detector, for producing a direct current voltage dependent in polarity on the sense of said shift, a control tube provided with an input circuit and having an output circuit operatively associated with the oscillator tank circuit to produce a reactive effect thereacross thereby to adjust the tank circuit frequency, at least two reactances of opposite sign in the oscillator output circuit, connections from the control tube input circuit to said two reactances, and means, responsive to said direct current voltage polarity, selectively preventing a predetermined one of the two reactances from affecting the control tube input circuit, said last means comprising a pair of diodes, each diode being in shunt with a predetermined one of the two reactances, and a connection for impressing the direct current voltage upon said diodes, in dependence on the polarity of the voltage, thereby to selectively short-circuit said two reactances.

9. In combination with an oscillator tube provided with an output circuit and having a tuned tank circuit, a pair of reactances of opposite sign in the oscillator output circuit, a frequency control tube provided with an input circuit and having an output circuit electrically connected to said tank circuit to produce a desired reactive effect across said tank circuit, a connection between said control tube input circuit and said reactances for impressing voltage developed across either of said reactances upon said control tube input circuit, an electronic device operatively associated with each of said reactances for selectively rendering them ineffective to develop said voltage, and means for controlling the operation of said electronic devices.

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