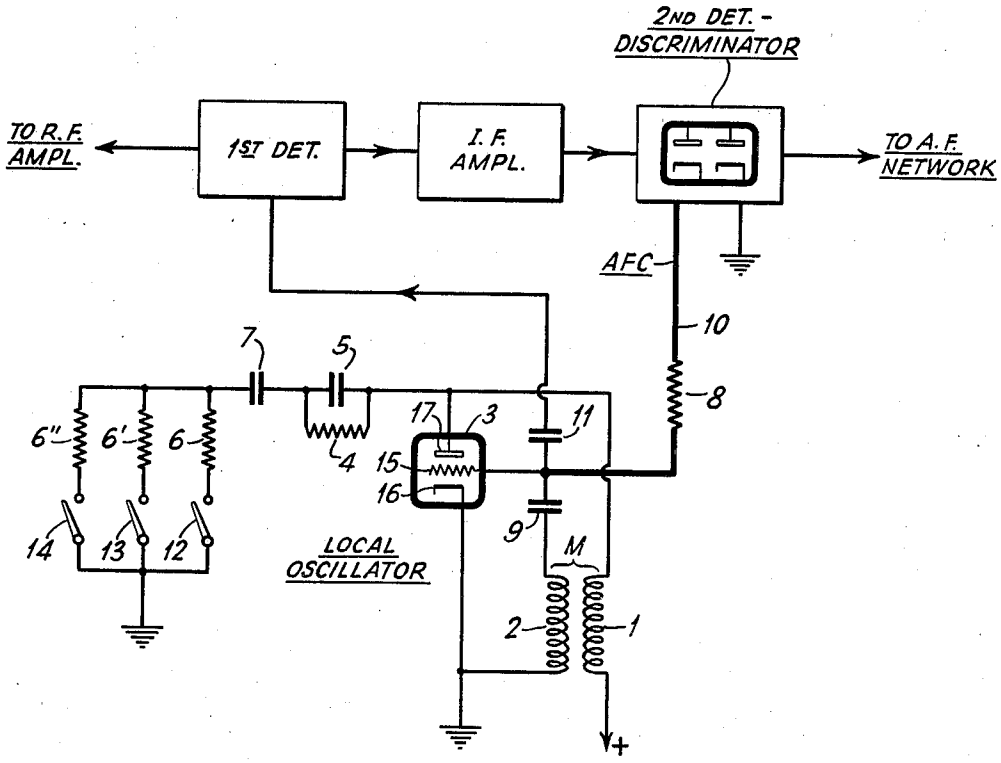
March 4, 1941. D. E. FOSTER 2,233,777

AUTOMATIC FREQUENCY CONTROL CIRCUIT

Filed July 7, 1938




INVENTOR.
DUDLEY E. FOSTER

BY H. S. Grover

ATTORNEY.

Patented Mar. 4, 1941 2,233,777

# UNITED STATES PATENT OFFICE

2,233,777

## AUTOMATIC FREQUENCY CONTROL CIRCUIT

Dudley E. Foster, South Orange, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application July 7, 1938, Serial No. 217,844

1 Claim. (Cl. 250—20)

My present invention relates to automatic frequency control circuits, and more particularly to a novel method of, and means for, supplementally adjusting the frequency of an oscillator employing non-reactive tuning elements.

One of the main objects of my present invention is to provide a method of adjusting the frequency of an oscillation circuit of the type employing resistance tuning; the frequency adjustment being auxiliary to the resistance tuning, and being accomplished by varying the magnitude of negative resistance in circuit with the resistor used for main tuning control.

Another important object of the invention may be stated to reside in the provision of an oscillator of the type using an electron discharge device having circuit elements associated therewith which comprise negative and positive resistance elements in a balanced state, the positive resistance element being adjustable in value to effect substantial frequency changes of the oscillator, and the negative resistance element being variable at selected values of the positive resistance element to produce small changes in frequency.

Another object of my invention is to provide a superheterodyne receiver which has a local oscillator of the type employing resistance of adjustable value for tuning over a wide range of frequencies; frequency shifts in intermediate frequency (I. F.) energy from an assigned frequency value being employed to produce a variable direct current voltage which is applied to the oscillator thereby to vary the oscillator frequency at selected values of the said resistance.

Still another object of my invention is to provide a superheterodyne receiver of the push button type; the local oscillator using a plurality of stable adjustable resistors in circuit with a regeneratively coupled tube, and each resistor representing a desired oscillation frequency; a frequency discriminator network, responsive to I. F. energy shifts from an assigned frequency value, producing direct current voltage, and the latter voltage being applied to the oscillator grid to vary the value of negative resistance in circuit with a selected one of said resistors thereby to maintain the assigned frequency value.

Still other objects of the invention are to improve generally the simplicity and efficiency of automatic frequency control circuits for radio receivers, and more especially to provide such control circuits in an economical manner.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claim: 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 now to the accompanying drawing, there is shown a superheterodyne receiver system of a generally conventional type, except for the construction of the local oscillator network. The receiver comprises the usual signal collector, adapted to collect signals in the broadcast band of 550 to 1500 k. c., feeding collected signal energy to the tunable radio frequency amplifiers (not shown). The radio frequency amplifier may comprise one or more stages of amplification, each stage including a tube provided with a tunable input circuit. The usual first detector network is supplied with amplified signal voltage by the tunable radio frequency amplifier, and the intermediate frequency (I. F.) output of the first detector is amplified by the conventional I. F. amplifier. The amplified I. F. energy may then be impressed upon a combined second detector-frequency discriminator network of the type disclosed by S. W. Seeley in application Serial No. 45,413, filed Oct. 17, 1935 granted June 21, 1938 as U. S. P. 2,121,103. In general, the present receiving circuit may be of the same type shown in the said Seeley patent, particularly Fig. 4 thereof; the construction of the local oscillator network and the frequency control mechanism being different in the present case.

Briefly, it may be stated that the function of the second detector-discriminator network, as is well known to those skilled in the art, is to derive audio energy and a frequency-dependent direct current voltage from the I. F. energy. The discriminator network can be entirely independent of the second detector circuit. As explained in said Seeley patent, the direct current voltage output of the discriminator varies in polarity and magnitude with the sense and amount respectively of frequency departure of the I. F. energy from the assigned I. F. value. The variable direct current voltage, or AFC bias, is transmitted over lead 10 to the local oscillator tube 3.

The local oscillator comprises the tube 3 which includes at least the cathode 16, the control grid 15 and plate 17. The plate is regeneratively coupled to the grid 15 by means of the inductive coupling M between the plate coil 1 and the grid coil 2. Direct current voltage of the proper

positive value is applied to plate 17 through coil 1, whereas coil 2 is connected between the grounded cathode 16 and the direct current blocking condenser 9. The plate 17 is further connected to ground through a path which includes a frequency-dependent impedance network 4—5, a condenser 7, and any one of a plurality of resistors 6—6'—6''. The impedance 4—5 comprises the condenser 5 and shunt resistor 4, and the function of this network will be explained at a later point. The resistors 6—6'—6'' function as the main tuning means for the local oscillator network. Each of these resistors has a magnitude such that when in circuit with the network 4—5, the local oscillator is tuned to a desired local oscillation frequency. In order to select the proper tuning resistor each of the shunt resistors is connected to ground through a push-button switch; hence, resistors 6—6'—6'' have associated with them switches 12, 13 and 14 respectively.

It will be understood that closing any of these push-button switches results in adjustment of the local oscillator to a desired oscillation frequency. The local oscillation energy is impressed on the first detector network in any desired manner, one well known arrangement being shown in the drawing by illustrating the grid 15 as being connected through condenser 11 to the first detector network. Of course, the frequency of the local oscillations will differ from the signal frequency impressed on the first detector by the frequency value of the I. F. energy. It should be understood that the tunable circuits of the radio frequency amplifier and first detector may also include push-button switches to select appropriate tuning condensers so as simultaneously to vary the signal circuits to differ carrier frequencies of the broadcast band. In such case the switches 12, 13 and 14 of the local oscillator network will be mechanically operated with the signal circuit selector switches so that at different adjustments of the oscillator and signal circuits the I. F. energy will have substantially the assigned I. F. value. The function of the AFC circuit is to correct for any deviation from the assigned I. F. value, should the oscillator or signal circuits shift in frequency. In place of the plurality of resistors 6—6'—6'' there may be employed a single adjustable resistor.

The AFC bias is applied to grid 15 by lead 19 through the grid leak resistor 8. The variation in bias of grid 15 is converted into a change in gain of tube 3; the change in gain, in turn, is translated into a frequency shift of the oscillator network. The polarity of the AFC bias determines the direction in which the oscillator frequency is varied to compensate for the I. F. energy frequency departure. As explained in the aforesaid Seeley patent, the direct current voltage output of the discriminator rectifiers arranged in opposition will be positive or negative with respect to ground depending upon whether the I. F. energy has shifted to one side or the other of the assigned I. F. carrier frequency value.

The local oscillator network functioning will now be described. The network is of a type described in "Wireless Engineer" for Sept. 1937 on page 469; essentially the network employs negative and positive resistance to produce oscillations of a desired frequency. The regeneratively coupled tube 3 provides the negative resistance; resistor 6 provides positive resistance whose magnitude is adjusted to vary the oscillation frequency. By varying the gain of tube 3 the value of negative resistance can be adjusted. Hence at selected values of positive resistance 6, the AFC bias can be used to secure small frequency adjustments in order accurately to tune the oscillator to that frequency which will cause the proper I. F. value to be produced. The grid 15 has a normal negative bias value by virtue of grid current flow due to tube 3 being in an oscillator circuit. It is desirable to maintain grid 15 at such a bias value as to cause the frequency shift to be substantially symmetrical with variations in applied discriminator potential about a mean value.

The following detailed considerations of the functioning of the oscillator network will make the operation clearer. In a circuit consisting of a pure negative resistance, which is a function of frequency, and a positive resistance in series therewith, oscillation will occur when the net resistance around the circuit is zero. The frequency of oscillation is that frequency which will make the negative resistance component equal to the positive resistance component. Therefore, changing the positive resistance component will change the oscillation frequency. Now the required negative resistance which is a function of frequency can be secured by connecting across a negative resistance which is independent of frequency a reactance, and in series with that combination a reactance of opposite signs hunted by a resistance of approximately the same magnitude as the negative resistance. Therefore, small changes of the magnitude of the negative resistance will likewise affect the oscillation frequency.

In the circuit shown inductance 1 is coupled to coil 2 and through blocking condenser 9 to the grid of tube 3. The output of tube 3 is connected to coil 1 so an oscillation circuit is formed. The plate-cathode impedance of tube 3 forms negative resistance in shunt with coil 1. In series with this combination is condenser 5, and positive resistance 4 in shunt therewith, approximately equal to negative tube resistance. This combination 1—3—4—5 forms a negative resistance which is a function of frequency, as resistance 4 and the negative resistance of 3 are approximately equal and each is approximately equal to

$$\sqrt{L/C}$$

where L is the inductance of coil 1 and C is the capacity of condenser 5.

Now if resistance 6 is zero, the frequency is

$$\frac{1}{2\pi}\sqrt{LC}$$

or the normal frequency of an oscillation circuit composed of inductance L of coil 1 and capacity C of condenser 5. If resistance 6 equals resistance 4, the oscillation frequency is theoretically infinite, but is actually limited to some finite value by the distributed capacity of coils. Decreasing negative resistance a small amount so that the relationship that negative resistance is equal to resistance 4 and to

$$\sqrt{L/C}$$

still holds approximately, will likewise cause frequency increase. If the AFC bias is applied to the grid of tube 3, through a d. c. amplifier if necessary to obtain a low impedance source since tube 3 being an oscillator will draw some grid current, it will change the operating transconductance of tube 3, and hence the magnitude of negative resistance between plate and cathode. If the grid of 3 is made more negative the transconductance of tube 3 will decrease, and the negative

resistance will increase thereby resulting in a decrease of oscillation frequency, and vice versa.

From the foregoing considerations and relationships it is believed that those skilled in the art will be able to construct an AFC circuit for a superheterodyne receiver wherein frequency shifts of the I. F. energy from an assigned I. F. value are compensated for. It will be observed that in this oscillator network automatic frequency shift correction is secured without using an auxiliary frequency control tube; the existing oscillator network is provided with means for providing the correction tuning adjustments. Hence, the present arrangement simplifies the frequency control circuit in that the oscillator tube acts both as a primary tuning means by variation of the positive resistance 6, and as an AFC device by virtue of the variable bias applied to the oscillator grid.

It is also pointed out that in receivers employing push-button tuning the present invention has great advantage. In such push-button sets it is difficult to secure a stable adjustable capacity, and it is costly to secure a stable oscillator circuit by a multiplicity of adjustable inductances where the station selection is by selection of pre-set tuned circuits. Stable adjustable resistances are procurable. Since in resistance tuning a tube is used for attaining proper phase relationships, the advantages of employing adjustable stable resistance for resistance tuning of the oscillator, with AFC secured by varying the gain of the oscillator tube, may readily be secured.

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 claim.

What I claim is:

In a superheterodyne receiver of the type including an intermediate frequency transmission network and a discriminator circuit adapted to derive a direct current voltage from the intermediate frequency energy whose polarity and value is a function of the sense and magnitude of frequency departure of the intermediate energy from an assigned intermediate frequency value, a local oscillator of the type whose frequency is a function of positive and negative resistance and which comprises a tube having at least a cathode, control grid and anode, means for regeneratively coupling the anode and grid to provide said negative resistance, variable resistive means adjustable to different values in circuit with the tube to provide said positive resistance, means for varying said resistive means to tune the oscillator to a desired frequency, and means for applying said direct current voltage to the oscillator tube grid thereby to vary the magnitude of said negative resistance sufficiently to adjust the oscillator frequency for correction of oscillator frequency inaccuracy at a selected positive resistance value.

DUDLEY E. FOSTER.