Nov. 8, 1938. G. MOUNTJOY 2,135,946

AUTOMATIC FREQUENCY CONTROL CIRCUIT

Filed April 21, 1937

Fig. 1

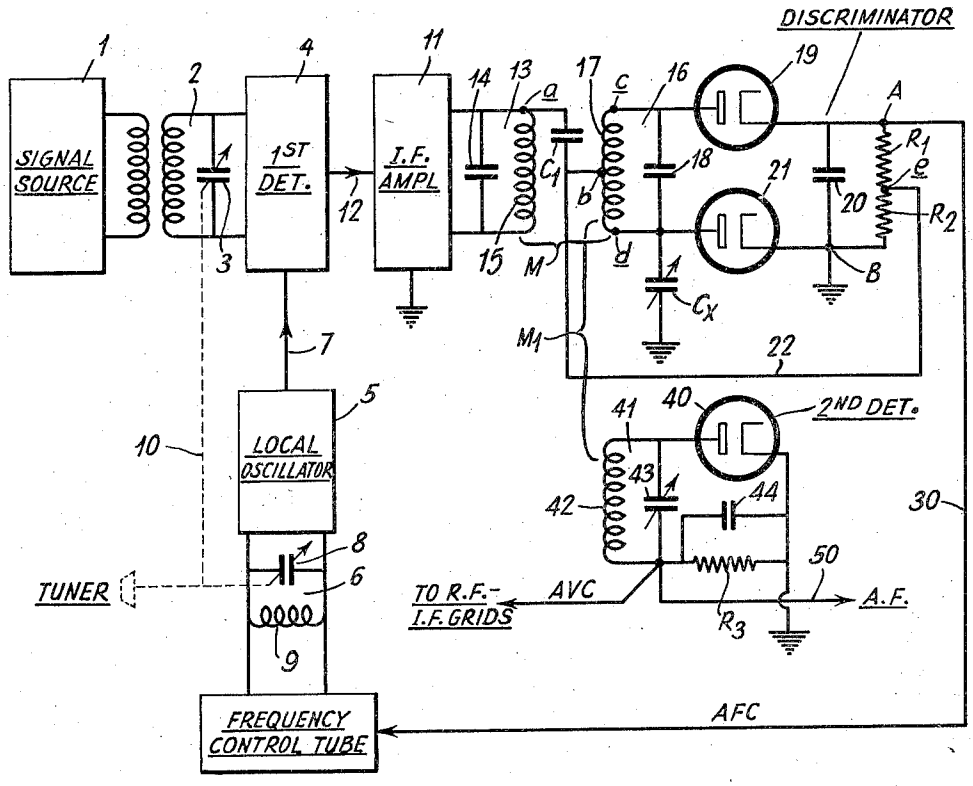
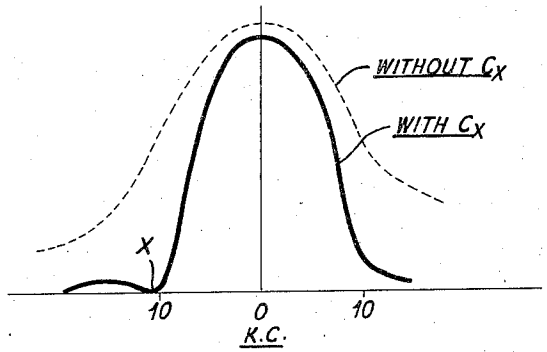


Fig. 2



INVENTOR
GARRARD MOUNTJOY
BY H. S. Grover
ATTORNEY

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AUTOMATIC FREQUENCY CONTROL CIRCUIT

Garrard Mountjoy, Bayside, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

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5 Claims. (Cl. 250—20)

My present invention relates to frequency control circuits for radio receivers, and more particularly to improved and highly selective demodulation networks for superheterodyne receivers employing automatic frequency control.

There has been disclosed by D. E. Foster in application Serial No. 72,495, filed April 3, 1936, an automatic frequency control arrangement AFC for a superheterodyne receiver; the AFC comprising a discriminator developing the AFC bias from I. F. energy. The discriminator includes a pair of diodes having a common I. F.-tuned input circuit magnetically coupled to the I. F. amplifier output circuit. Furthermore, the audio voltage is developed by a demodulator having its I. F.-tuned input circuit magnetically coupled in cascade with said discriminator input circuit. While such cascading of the I. F. amplifier tuned output circuit, discriminator tuned input circuit and demodulator tuned input circuit provide satisfactory selectivity to the demodulator, yet the selectivity of such an arrangement may be insufficient completely to prevent response to strong adjacent channel signals. Particularly in the case of an AFC receiver is it necessary to prevent response to strong adjacent channels signals. Insufficient selectivity to prevent such response creates the impression, to the user of the AFC receiver, that the AFC mechanism is not operating efficiently and that the receiver is not accurately tuned.

Accordingly, it may be stated that it is one of the main objects of my present invention to provide in an automatic frequency control arrangement for a superheterodyne receiver, a discriminator-audio demodulator network whose reactive constants are so chosen that the overall response characteristic of the network has a substantially complete cut-off at the limits of the upper and lower side bands of the I. F. carrier.

Another important object of the invention is to provide in an automatic frequency control circuit for a superheterodyne receiver, a discriminator unit and an audio demodulator unit whose resonant input circuits are arranged in cascade with the resonant output circuit of the I. F. amplifier, and reactances of opposite sign being employed to couple the I. F. amplifier output circuit to the discriminator input circuit in such a manner that the overall response curve of the three cascaded resonant circuits has substantially complete cut-off at the upper and lower limits of the cascaded I. F. band whereby adjacent channel signal interference is effectively prevented.

Still other objects of the invention are to improve generally the selectivity and efficiency of the discriminator and audio demodulator in the case of an AFC superheterodyne receiver, and more especially to provide such networks of improved selectivity in a manner which permits the networks to be readily and economically assembled in superheterodyne 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.

In the drawing:

Fig. 1 schematically shows a superheterodyne receiver of the AFC type which embodies my present invention,

Fig. 2 is a graphic comparison of the overall response curves of the discriminator-audio demodulator network of Fig. 1.

Referring now to the circuit arrangement shown in Fig. 1 of the drawing it will be seen that there is shown a superheterodyne receiver of the general type disclosed in the aforesaid Foster application. In general, the numeral 1 denotes the signal source which may comprise the usual signal collector followed by one or more stages of tunable radio frequency amplification. It will be understood, of course, that the signal collector can be of the grounded antenna type; a loop antenna; a radio frequency distribution line; or even an antenna used on a mobile vehicle. The signal collector will feed one or more amplifiers which may be provided with tunable input circuits, and the usual variable tuning condensers will be employed in such input circuits. The amplifier radio frequency signals are impressed upon the tunable input circuit 2 of the first detector, or mixer, 4. The numeral 3 denotes the variable tuning condenser of the first detector input circuit, and it will be understood that the rotors of the variable condensers in the radio frequency amplifier input circuits will be mechanically uni-controlled with the rotor of the variable condenser 3.

The local oscillator 5 is provided with a tunable tank circuit 6. Locally produced oscillations from the oscillator 5 are impressed on the first detector through a path 7. The variable condenser 8 functions to tune the oscillator tank coil

9 through a range of frequencies differing at all times from the signal circuit frequencies by the operating I. F. It will be observed that the dotted lines 10 represents the mechanical "tuner" which simultaneously adjusts rotors of the different variable condensers of the receiver.

Assuming that the receiver is of the broadcast type, then the signal circuits will be simultaneously tuned through a frequency range of approximately 500 to 1500 k. c. The tank circuit 6 will simultaneously be tuned through a frequency range ordinarily above the signal frequency range, and constantly differing from the latter by the operating I. F. For example, the operating I. F. may be chosen from a range of approximately 75 to 480 k. c. Those skilled in the art are fully aware of the fact that padder condensers may be used in the tank circuit 6 to maintain such constant frequency difference between the signal and oscillator tank circuits. Furthermore, those skilled in the art are also fully aware of the fact that the first detector 4 and oscillator 5 may utilize separate tubes, or they may be embodied within a pentagrid converter network employing a 2A7 type tube.

The I. F. energy is amplified in an I. F. amplifier 11, and the latter may comprise one or more stages of amplification. The numeral 12 denotes the path through which the I. F. energy is transmitted from the mixer 4 to the amplifier 11. The resonant circuits of the I. F. amplifier will, of course, be tuned to the operating I. F. The numeral 13 designates the resonant output circuit of the I. F. amplifier, and it is fixedly tuned by means of condenser 14 and coil 15 to the operating I. F. The resonant circuit 13 is magnetically coupled to the discriminator input circuit 16, and the reference letter M designates such magnetic coupling.

The discriminator unit produces the AFC bias from the I. F. energy when the latter shifts in frequency from the assigned I. F. value. This production of AFC bias is accomplished by connecting the high alternating potential point *a* of coil 15 to the mid-point *b* of coil 17 of circuit 16 through a condenser C_1. The condenser 18 connected across coil 17 fixedly tunes the latter to the operating I. F. The diode rectifier 19 has its plate, or anode, connected to the high alternating potential side of coil 17, while its cathode is connected to ground through a path which includes resistors R_1 and R_2. The anode of diode 21 is connected to the low alternating potential side of coil 17, while its cathode is connected to the grounded side of resistor R_2.

The point *b* of coil 17 is connected by lead 22 to the junction *e* of resistors R_1 and R_2. The low alternating potential side of coil 17 of input circuit 16 is connected to ground through a condenser C_x and the function of the latter will be described at a later point. The discriminator unit, therefore, employs an input circuit 16, tuned to the operating I. F., which is relatively loosely coupled, as at M, to the coil 15 of I. F. amplifier output circuit 13. The direct current voltage at the point A of resistor R_1 will be either positive or negative with respect to the point B, depending on which way the I. F. energy shifts in frequency value from the assigned I. F. This is readily seen when the following is considered. The condenser C_1 between point *a* and point *b* is assumed to be so large the voltage drop in it is negligible; the points *a* and *b* are at the same alternating current potential.

Now, the phase of *a* with respect to ground potential is zero when the I. F. energy is of the correct frequency value, for at resonance there is no phase shift in the circuit 13. Hence, point *b* is at zero phase. Furthermore, the alternating current in circuit 13 induces an alternating voltage in circuit 16, and this is distributed equally about the midpoint *b*. At a given instant the point *c* of coil 17 is as much positive as the point *d* is negative. The alternating voltages impressed on the two diodes 19 and 21 are therefore equal, although opposite in phase. The rectified direct current outputs depend only on the magnitudes of the voltages impressed on the rectifiers, and hence the direct current voltage drops across resistors R_1 and R_2 will be equal. Since the rectifiers 19 and 21 are connected in series opposition, the potential difference at resonance between points A and B will be zero. This balance occurs only when the frequency of the carrier energy is equal to the resonant frequency of the loosely coupled circuits 13 and 16.

If, now, the I. F. energy differs considerably from the assigned I. F. value, there will be a phase shift of nearly 90 degrees in the circuit. The voltages induced in the two halves of the secondary coil 17 are still equal in magnitude, but opposite in phase with respect to the point *b*. The voltage drop across circuit 13 is now added vectorially to the voltages induced in circuit 16. This potential at one side of the secondary, say point *c*, will be the sum of the voltage induced in portion *b*—*c* and the voltage drop across circuit 13, while the potential of the other point *d* will be the difference between the drop in circuit 13 and the voltage induced in coil portion *b*—*d*. The potential is measured with respect to ground for the primary circuit 13 is grounded to alternating current on one side. The cathodes of the two rectifiers are also grounded with respect to the alternating current. It follows that the input voltage of one rectifier, the upper in the assumed case, is much greater than that in the diode 21. Further, the voltage drop across resistor R_1 will be greater than that across resistor R_2, and point A will be positive with respect to point B.

When the I. F. energy shifts in frequency in the opposite direction, the above explanation leads to the conclusion that point A becomes negative with respect to point B. Further, dependent on the sense of I. F. energy shift, the point A can assume either a positive or a negative potential with respect to point B. The magnitude of this potential depends upon the amount of frequency departure of the I. F. energy. The potential developed at point A is applied through the AFC bias path 30 to the frequency control tube. Of course, the path 30 will include the proper filter network to suppress pulsating voltage components in the AFC bias. The frequency control tube may be of any desired construction, and its associated circuits will be such that there will be produced, or simulated, across the tank circuit 6 a reactive effect which will vary in intensity dependent on the magnitude of the AFC bias.

As an example of such a frequency control tube the aforesaid Foster application is referred to, and in that application it is disclosed that the frequency control tube simulates across the coil 9 of the tank circuit an inductive reactance. By varying the gain of the frequency control tube 9 with AFC bias it is possible to vary the magnitude of the simulated inductance across coil 9, and hence the effective frequency of the

tank circuit 6 may readily be controlled. Since the frequency control tube and its associated connections to the tank circuit 6 is not an essential part of the present invention, it is schematically represented in Fig. 1. It is merely emphasized that the AFC bias is utilized to vary the frequency of the oscillator tank circuit in that direction which will produce oscillations of a frequency differing from the signal frequency by the assigned I. F. This AFC arrangement will compensate for tuning errors regardless of how they arise.

The audio demodulator, or second detector, employs a diode rectifier 40 whose anode is connected to the high alternating potential side of the tuned input circuit 41. The circuit 41 comprises a coil 42 which is magnetically coupled to coil 17 as at M_1, and the condenser 43 connected across coil 42 fixedly tunes the coil to the operating I. F. The grounded cathode of diode 40 is connected to the low alternating potential side of input circuit 41 through a load resistor R_3, the latter being shunted by an I. F. bypass condenser 44. The direct current voltage component developed across resistor R_3 may be used as AVC bias to control the gain of each of the radio frequency and I. F. amplifiers. Such AVC arrangement is well known to those skilled in the art, and it is merely pointed out that the AVC bias would be used to vary the gain of the controlled amplifiers in a sense to maintain the I. F. energy level at the input circuit 16 substantially uniform over wide signal variations at the signal collector. The audio voltage component of the demodulated I. F. energy is impressed upon one or more audio amplifiers through the path 50.

The overall response curve of circuits 13, 16 and 41 in cascade is graphically represented by the dotted line curve in Fig. 2. For usual reception, and particularly in those cases when adjacent channel signal interference is not appreciable, a response curve of this type is satisfactory. However, when adjacent channel signal interference is marked, then it is highly desirable to increase the selectivity of the discriminator-audio demodulator network. The function of the condenser C_x is to cooperate with the reactance M to provide a response curve of the type designated by the full line curve in Fig. 2. In the latter it will be observed that the full line curve has a band width of substantially 20 k. c. and that there is complete rejection of the adjacent channel signal at the lower limit of the mid-band frequency. The upper limit is close to cut-off, and a marked selectivity improvement occurs. Comparison with the dotted line curve, which is secured without C_x, shows marked improvement in selectivity of the discriminator-audio demodulator network.

An arrow is shown passing through the condenser C_x in Fig. 1, and it will be understood that this arrow denotes factory adjustment of the condenser. The condenser C_x couples circuits 13 and 16 in subtractive relation to the magnetic coupling M. The magnitude of the condenser C_x is chosen so as to secure a substantially complete rejection of signal energy at a predetermined frequency distance from the carrier frequency; it may have a value, for example, of the order of 3 mmf. In other words, the magnitude and phase of condenser C_x may be chosen to secure the "nil" point x of the full line curve in Fig. 2, 10 k. c. or even 20 k. c. from the mid-band frequency. The phase and magnitude selection of the capacitative reactance C_x will depend upon the particular conditions encountered in the entire receiver. Attention is directed to my co-pending application Serial No. 77,655, filed May 4, 1936 wherein there is disclosed and claimed coupling networks utilizing inductive and capacitative reactance in opposed phase, with phase and magnitude adjustment of the coupling capacity to secure substantially complete cut-off at the extremities of the accepted band.

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 is claimed is:

1. In a superheterodyne receiver of the type including an intermediate frequency amplifier having a resonant output circuit, a discriminator unit including a pair of opposed rectifiers having a common input circuit, and a demodulator having a resonant input circuit, means for reactively coupling said resonant output circuit and said common input circuit, means for reactively coupling said demodulator input circuit and said common input circuit, each of said resonant circuits being tuned to the same carrier frequency, and an additional reactive coupling between said resonant output circuit and said common input circuit, said additional reactive coupling being of a sign opposite to that of the reactive coupling between the output circuit and said common input circuit, and the phase relation between said latter two reactive couplings being so chosen that the overall response curve of the three coupled resonant circuits is provided with substantially complete cut-off at a predetermined frequency distance from the mid-band frequency.

2. In combination with a source of modulated carrier frequency energy, a detector for said energy, at least three resonant circuits reactively coupled in cascade between said source and detector, an additional reactive coupling between at least two successive circuits of said three coupled circuits, said additional reactive coupling being opposite in sign and phase with respect to the first named reactive coupling between said two coupled circuits whereby the overall response curve of the network between said source and detector has substantially complete cut-off at one limit of the accepted transmission band and a rectifier network coupled to the second of the cascaded circuits.

3. In a superheterodyne receiver of the type including an intermediate frequency amplifier having a resonant output circuit, a rectifier network having a resonant input circuit coupled magnetically to said output circuit, means for deriving a direct current voltage from said rectifier network, a detector network having a resonant input circuit magnetically coupled to said first resonant input circuit, means for deriving an audio voltage from said detector circuit, and a capacitative coupling between said amplifier output circuit and said first resonant input circuit, said capacitative coupling being subtractively related to the magnetic coupling between these two circuits, and the magnitude of said capacitative coupling being so chosen that the overall response curve between said amplifier and said

detector is provided with substantially complete cut-off at the upper and lower limits thereof.

4. In a superheterodyne receiver of the type including an intermediate frequency amplifier having a resonant output circuit, a rectifier network having a resonant input circuit coupled magnetically to said output circuit, means for deriving a direct current voltage from said rectifier network, a detector network having a resonant input circuit magnetically coupled to said first resonant input circuit, means for deriving an audio voltage from said detector circuit, a capacitative coupling between said amplifier output circuit and said first resonant input circuit, said capacitative coupling being subtractively related to the magnetic coupling between these two circuits, and the magnitude of said capacitative coupling being so chosen that the overall response curve between said amplifier and said detector is provided with substantially complete cut-off at the upper and lower limits thereof, a first detector network feeding intermediate frequency energy to said amplifier, a local oscillator circuit, and means for utilizing the direct current voltage output of said rectifier network for automatically controlling the frequency of said local oscillator.

5. In a superheterodyne receiver of the type including a first detector network, an intermediate frequency amplifier fed with signals from said first detector, and an audio detector, a local oscillator circuit connected to impress locally produced oscillations on said first detector, said local oscillator being provided with a tunable tank circuit, an automatic frequency control circuit which comprises a pair of rectifiers whose direct current outputs are in opposed relation, a common resonant input circuit for said rectifiers, a circuit responsive to the direct current voltage output of said rectifiers for controlling the frequency of said tank circuit, means magnetically coupling said amplifier output circuit to the common input circuit of said rectifiers, said audio detector having a resonant input circuit magnetically coupled to the common input circuit of said rectifiers, each of said resonant input circuits being tuned to the intermediate frequency, and a capacity coupling between the amplifier output circuit and the common input circuit of the rectifiers, said capacity coupling being in phase opposition to the magnetic coupling thereby to provide the overall response curve of the network between the audio detector and the intermediate frequency amplifier with substantially complete cut-off at the upper and lower limits of the intermediate frequency band.

GARRARD MOUNTJOY.