Jan. 17, 1939. C. TRAVIS 2,144,235

AUTOMATIC FREQUENCY CONTROL SYSTEM

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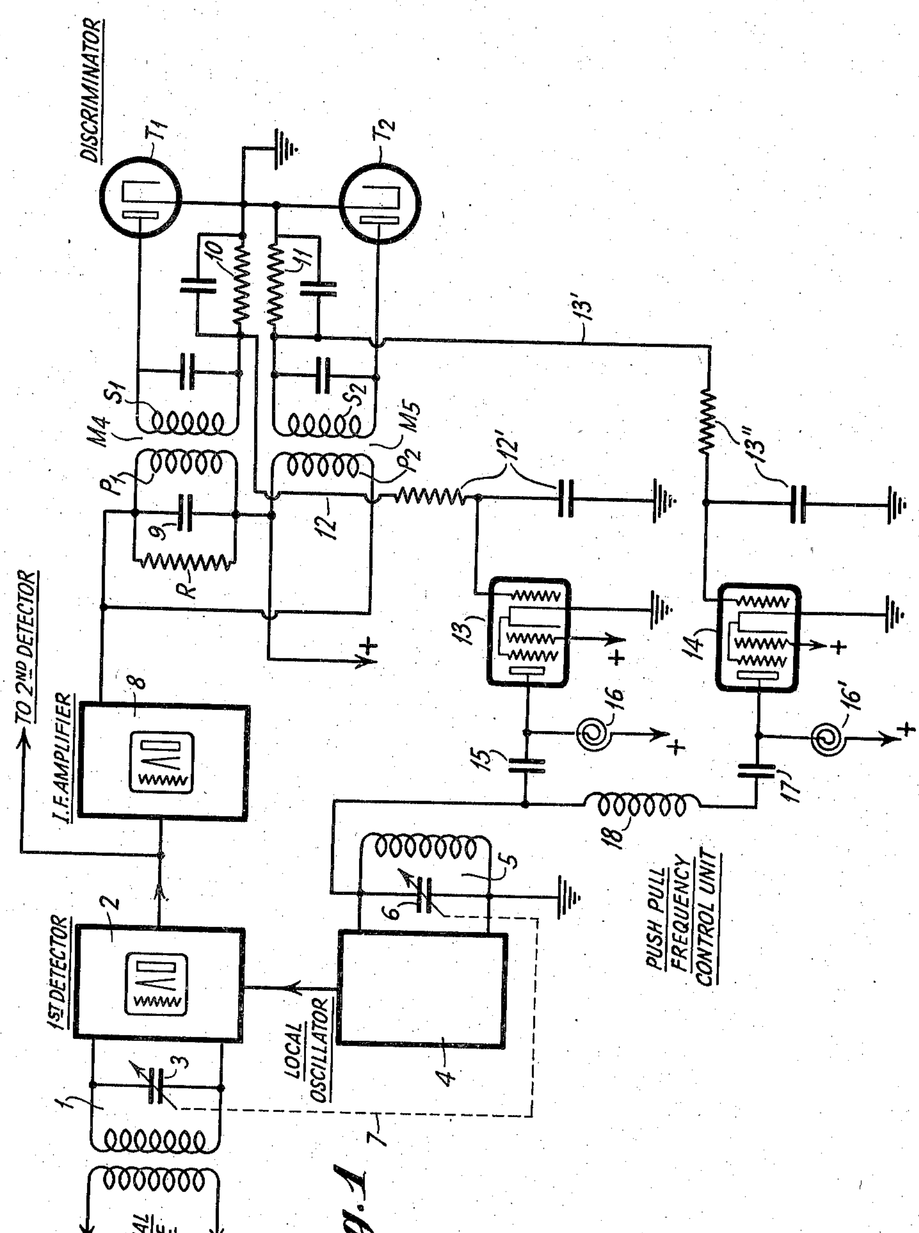

TO SIGNAL SOURCE

Fig. 1

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Fig. 2

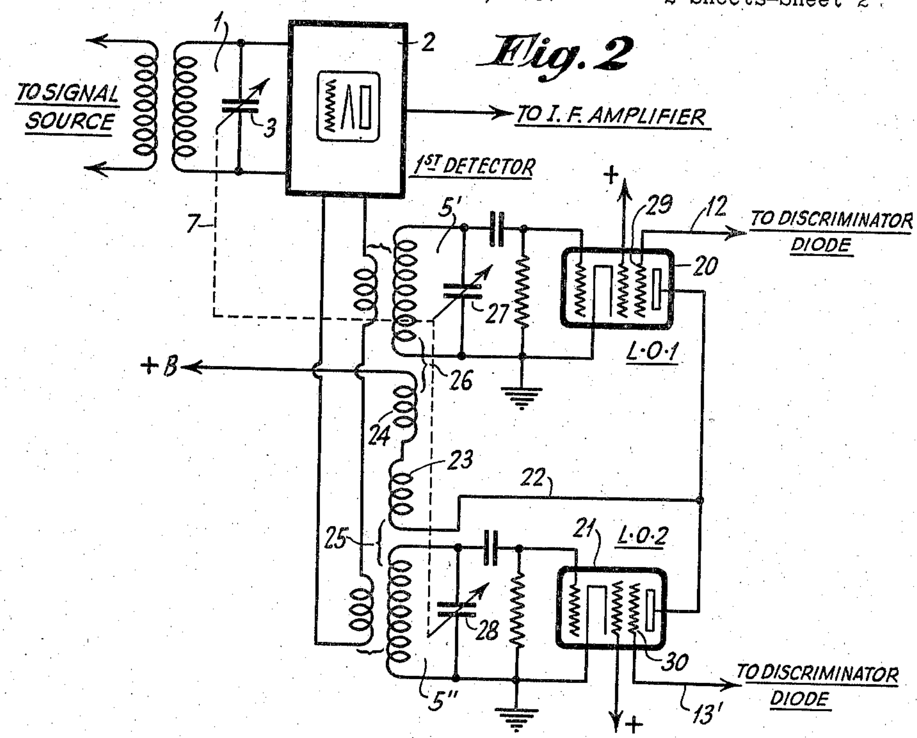
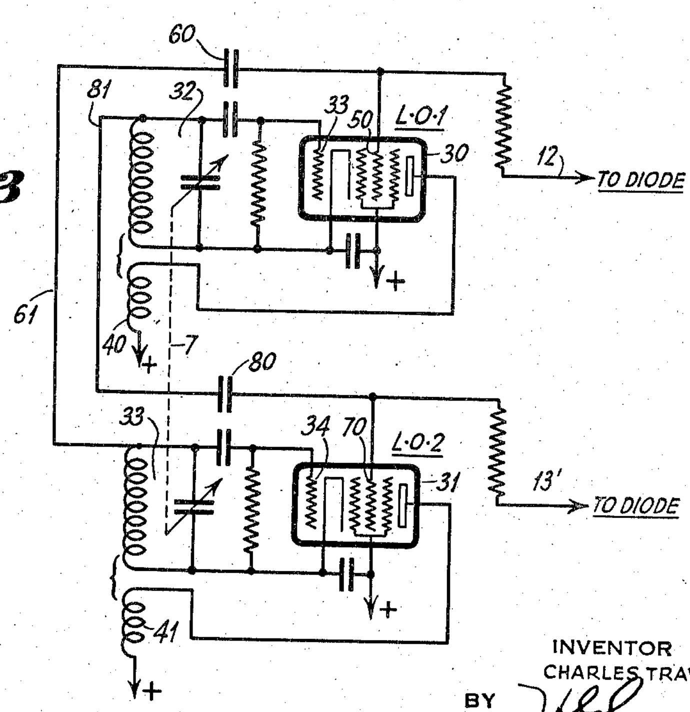


Fig. 3



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AUTOMATIC FREQUENCY CONTROL SYSTEM

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4 Claims. (Cl. 250—20)

My present invention relates to automatic frequency control systems for regulating the local oscillator tuning of a superheterodyne receiver, and more particularly to push-pull frequency control networks for use in such systems.

In my co-pending application Serial No. 4,793, filed February 4, 1935, I have disclosed various arrangements for automatically adjusting the frequency of the tunable local oscillator of a superheterodyne receiver in response to a predetermined shift in frequency of the I. F. energy from the assigned value thereof. In such systems the I. F. energy was impressed on a pair of rectifiers mistuned from the assigned I. F. by equal frequency amounts; and the direct current voltages produced by rectification were differentially combined, and employed to vary the gain of an electron discharge tube connected across the oscillator tank circuit to function as a reactance.

For various reasons it may be desirable to employ a push-pull control circuit in the frequency control network. For example, such a circuit would be employed to avoid practical difficulties that arise in ganging the oscillator circuit and the control circuit when the oscillator and control circuit are tunable over a band, such ganging being shown in Fig. 11 of my aforesaid application. In general, push-pull frequency control devices will require two separate bias channels such that a change of frequency, or phase, at the discriminator produces approximately equal but opposite changes in the two biases. Each discriminator diode would, in other words, feed a separate bias line. The control circuit itself would comprise independent tubes arranged to produce positive or negative reactance effects across the oscillator tank circuit depending on the action of the bias connections to the control tubes.

In other forms of the invention the local oscillator network may be constructed to utilize the push-pull control biases. In such cases the oscillator generally includes a pair of oscillator tube circuits tuned to slightly different frequencies, both combining to generate oscillations at a common mid-frequency; and the relative gains of the two oscillator circuit tubes would then be varied by the push-pull control bias.

Hence, it may be stated that the utilization of the afore-described push-pull frequency control circuits in superheterodyne receivers, is a main object of this application.

Another important object is to improve the action and efficiency of automatic frequency control (AFC) arrangements for superheterodyne receivers; the essential distinction over my aforesaid pending application residing in the use of separate bias connections from the discriminator rectifiers for controlling the gain of each of a pair of tubes constructed and arranged to vary the oscillator network frequency by a corrective frequency value when the I. F. energy shifts in frequency from its assigned magnitude.

Still other objects of the invention are generally to improve the operation and reliability of automatic frequency control systems, and more especially to provide a push-pull frequency control network which is not only efficient and reliable, but is economically, and readily, manufactured and 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 drawings in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawings:

Fig. 1 shows a frequency control circuit embodying one form of the invention,

Fig. 2 illustrates a modification applied to the oscillator,

Fig. 3 shows a modified form of the invention illustrated in Fig. 2.

Referring now to the accompanying drawings, wherein like reference characters in the different figures denote similar circuit elements, there is shown in Fig. 1 that portion of a superheterodyne receiver located between the signal source and the second detector. Those skilled in the art fully understand the manner of constructing the networks conventionally represented in Fig. 1. The signal source may be a grounded antenna circuit, a radio frequency distribution line, or an automobile radio antenna. The tunable input circuit 1 of the first detector 2 is coupled through one, or more, tunable radio frequency amplifiers to the source of signals. The variable condenser 3 may be adjusted to tune the circuit 1 over a wide signal frequency range; such as 400 to 1600 k. c.; or through the short wave ranges. The local oscillator 4 is provided with a tunable tank circuit 5; the variable condenser 6 thereof being adjustable through a range of frequencies differing at all times from the signal range by the operating I. F. The dotted line 7 denotes the usual tuning mechanism, which terminates in a manually adjustable device on the receiver operating panel, mechanically coupling the rotors of the various variable condensers.

The I. F. energy produced by the first detector 2 is impressed upon one, or more, stages of I. F. amplification; the amplified energy is detected in the usual second detector circuit. The audio voltage component of detected I. F. energy is amplified in one, or more, amplifiers, and finally reproduced by any desired type of loudspeaker device. The I. F. may be chosen from a range of 75 to 450 k. c., and all resonant circuits between the first detector and second detector will be tuned to the selected I. F. value. Of course, any desired type of automatic volume control circuit may be utilized; such volume control circuit may be employed as shown in Fig. 1 of my aforesaid pending application.

A portion of the I. F. energy, for example at the input to the second detector, is impressed upon the I. F amplifier 8. In the plate circuit of amplifier 8 the primaries P_1 and P_2 of two similar transformers M_4 and M_5 are connected in parallel and tuned to the exact center of the I. F. band by the condenser 9. The resonance curve of this composite primary is broadened by the resistor R, shunted across primary P_1; the resistor may have a magnitude of 25,000 to 50,000 ohms. The secondaries S_1 and S_2 are respectively tuned equal increments above and below the I. F mid-band frequency.

Owing to the presence of resistor R across the common primary, the latter is essentially a constant voltage source, and, as there is no direct coupling between the two secondaries, the total effective coupling between the latter is negligible. The secondaries each operate into one of the anodes of the diodes T_1 and T_2. The cathodes of the diodes are connected in common to ground for direct current. The load resistance 10, shunted by an I. F. by-pass condenser, is connected between the low potential side of the input coil S_1 and the grounded cathode of diode T_1. The load resistor 11, shunted by an I. F. by-pass condenser, is connected between the grounded cathode of diode T_2 and one side of the secondary S_2. Of course the separate diodes may be replaced by a double diode rectifier having a common cathode, such as a tube of the 6H6 type.

It is necessary to separate the resonant points of the two secondaries S_1 and S_2 by a minimum amount approximately equal to the I. F. mid-band frequency divided by the

$$Q\left(\text{or, } \frac{\omega L}{r} \text{ ratio}\right)$$

of the circuits. For example, at an I. F. of 450 k. c. without considering losses introduced by the primary and by the diode load, a value to Q of 200 is about the highest that can be obtained in the usual size of commercial I. F. coils. This corresponds to a minimum separation of 2.25 k. c. between the two secondary resonant points. After losses are accounted for, a separation of 4 or 5 k. c. would probably be excellent at this frequency.

There is connected to the anode side of resistor 10 the connection 12; and this latter connection is made to the input grid of tube 13, functioning as one of the frequency control tubes. The connection 13′ is made from the input grid of control tube 14 to the anode side of load resistor 11. Both connections 12 and 13′ include low pass filters which serve to suppress the alternating current voltage components in the rectified I. F. energy. The numerals 12′ and 13″ denote the low pass filters inserted respectively in connections 12 and 13′. The tubes 13 and 14 may be of the well-known pentode type.

The presence of a signal in the discriminator network, having a frequency in the I. F. range, will always produce negative biases on both tubes 13 and 14. As the I. F. value changes one bias will become negative, and the other bias will become less negative. That is, approximately equal, but opposite, changes in AFC biases are produced as the I. F. energy departs from its assigned frequency.

The tunable tank circuit 5 has its high alternating potential side connected to the plate of tube 13 through a condenser 15. The cathode lead of tube 13 is grounded, and the positive potential for the plate of tube 13 is supplied through a choke coil 16. The plate of tube 14 is connected to the high alternating potential side of tank circuit 5, through a series path which includes condenser 17 and coil 18; the positive potential for the plate of tube 14 being applied through choke 16′. It will be noted that the low alternating potential side of the tank circuit 5 is grounded, and the cathodes of tubes 13 and 14 are also grounded. It is to be understood that a common source of direct current potential may be employed for energizing the various electrodes of tubes 13 and 14, and this may well be the common direct current voltage supply for the rest of the receiver circuits.

It will now be seen that the oscillator tank circuit 5 is shunted by two arms, one of them comprising the condenser 15 which is in series with the variable tube resistance of tube 13; and the other arm comprising the inductance 18 in series with the variable tube resistance of tube 14. The condenser 17 functions as a low impedance blocking condenser in order to separate the direct current potentials. The magnitude of condenser 15 and that of inductance 18 are so proportioned that the square root of the inductance of coil 18 divided by the capacitance of condenser 15 is equal to the mean value of the internal resistances of tubes 13 and 14, and this mean value may be expressed by the symbol R_p. Furthermore, condenser 15 and coil 18 should be chosen to resonate in the middle of the band of frequency coverage. In other words, condenser 15 and coil 18 are designed to resonate in the middle of the frequency range of the tunable local oscillator tank circuit 5. In place of the self-inductance coil 18, the leakage inductance of a coil loosely coupled to the tank circuit coil may be used.

Under these conditions the variation in the internal resistances of tubes 13 and 14, which variation is caused by the direct current control biases derived from resistors 10 and 11, will be approximately equal but opposite. The resistive part of the admittance thrown across the tank circuit 5 will be constant with frequency and with variation in the two biases (equal to R_p, the mean value), but the reactive component will vary as the internal resistance of tube 13 increases, while the internal resistance of tube 14 decreases, or vice versa. This method of push-pull frequency control gives a close approximation to uniform oscillator action and uniform (percentage) control action over the tuning band.

Considering the operation of the arrangement shown in Fig. 1 more specifically, it will be seen that if the received I. F. energy varies in frequency from the assigned mid-band frequency, then there will be developed an increasing direct current voltage across the diode load resistor disposed in series with the discriminator diode input circuit which is tuned to the side of the frequency shift. For example, assuming that the assigned I. F. value is 450 k. c., then a shift in I. F. energy to 445 k. c. will cause direct current voltage to be developed across resistor 10; assuming that the secondary S_1 is tuned to 445 k. c. When such mistuning occurs, the increased voltage developed across resistor 10 is applied to the input grid of tube 13, and the internal resistance of the tube is increased; this decreasing the effect of the capacitative arm across tank circuit 5. This, in turn, reduces the effective capacity in the tank circuit 5, and increasees the frequency of the tank circuit. As a result, the frequency of the local oscillations impressed on the first detector increases, and the frequency value of the I. F. energy increases. Of course, the constants of the circuit are so chosen that the effect of the capacity path across the tank circuit 5 is reduced to an extent sufficient to have the I. F. energy output of first detector 2 rise in frequency value to approximately 450 k. c. In this way it is possible to compensate for a shift in frequency of the I. F. energy to a value below the assigned value of 450 k. c.

Under the assumed conditions, the secondary S_2 would be tuned to 455 k. c.; assuming now that the I. F. energy shifts in frequency to a value of 455 k. c., direct current voltage will be produced across resistor 11, and the internal resistance of tube 14 will be increased. This will reduce the shunt inductive effect of coil 18 across tank circuit 5, and cause the local oscillator tank circuit frequency to decrease. The decrease in oscillator frequency is sufficiently great to bring the output energy of first detector 2 back to approximately 450 k. c. It will, therefore, be appreciated that by means of the separate control bias lines 12 and 13', and the capacity and inductance arms across tank circuit 5, it is possible automatically to adjust the oscillator tank circuit frequency to compensate for frequency shift of the I. F. energy away from the assigned mid-band frequency. It will be realized that such a frequency shift is not only due to thermal effects, as when the superheterodyne receiver is operating for a long period of time, but may, also, be cause during the process of adjusting the tuning of the receiver. With the control circuit disclosed it is possible to secure accurate tuning, since the function of the discriminator and frequency control unit is to "pull" the local oscillator into accurate tuning relation with the incoming signal. Theoretically considered, there is provided in Fig. 1 a frequency control unit which comprises an oscillator tank circuit having parallel capacity and inductive arms shunted across the tank circuit, discriminator means being provided selectively to regulate the effect of the arms depending upon the direction of frequency shift of the I. F. energy impressed on the discriminator. A variation of the push-pull frequency control unit shown in Fig. 1 would be to use a tuned-grid, tuned-plate oscillator with an inductive control on one tuned circuit and a capacitive control on the other.

If two oscillator tube circuits are tuned to slightly different frequencies, and are loosely coupled, both will combine to generate oscillations at some common mid-frequency period. Varying the relative gains of the two oscillator circuit tubes, which may be done by the use of the push-pull control bias arrangement described, will shift the generated frequency towards the natural frequency of the circuit of the tube having the larger gain. Now if the reactive coupling is weak, only a small frequency range is possible, and if this coupling is increased difficulties will be encountered because of the fact that the common tank circuit has two degrees of freedom of oscillation. In such case, there would be two possible operating frequencies and "drag loop" effects with sudden jumps from one frequency to the other will occur. To avoid this last effect, it is proposed to keep the physical reactive coupling between the two tank circuits as small as need be, no coupling being desirable, and to make the operating frequency dependent upon electronic coupling. Thus, in Fig. 2 there is shown an arrangement which is desirable in operation, and embodies the action described.

In Fig. 2 there is shown an arrangement embodying this form of frequency control network. The local oscillator network comprises a pair of tubes, of the pentode type, having independent tunable circuits 5' and 5''. The tank circuits 5' and 5'' are tuned to slightly different frequencies, but each cooperates with the other to generate a common mid-frequency oscillation which is used to heterodyne with the received signal frequency to produce the operating I. F. The plates of tubes 20 and 21 are connected to a source of proper positive potential through a common path 22 including tickler coils 23 and 24 in series. The coil 23 is magnetically coupled, as at 25, to the tank circuit 5''; the coil 24 is magnetically coupled, as at 26, to the tank circuit 5'. Both tank circuits are coupled to the first detector network to feed local oscillations thereto.

The uni-control adjusting means 7 actuates the tuning condenser 3 and variable condensers 27 and 28. The AFC bias from the discriminator diodes may be applied to the suppressor grids 29 and 30; leads 12 and 13', for example of Fig. 1, may be connected to the grids 29 and 30. The control biases may, also, be inserted at the screens, but this is not as desirable since the screens draw current. If the plate impedances of the tubes 20 and 21 are high, there will be little physical coupling between the two tank circuit coils due to the fact that the tickler coils 23, 24 are in series with a high impedance.

In Fig. 3 there is shown an alternative of the arrangement illustrated in Fig. 2. The tubes 30 and 31 are tubes of the pentode type. The tunable tank circuit 32 is connected between the grid 33 and cathode of tube 30, while the tank circuit 33 is connected between the grid 34 and cathode of tube 31. The plate of tube 30 is magnetically coupled to the tank circuit 32 by the tickler coil 40, and the tickler coil 41 magnetically couples the plate of tube 31 to the tank circuit 33. The suppressor grid 50 of tube 30 is connected through the AFC connection 12 to one of the discriminator diodes, and the grid 50 is furthermore connected through condenser 60 and lead 61 to the high alternating potential side of tank circuit 33. The grid 70 of tube 31 is connected through the AFC connection 13' to the second discriminator diode, and condenser 80 and lead 81 connect the grid 70 to the high alternating potential side of tank circuit 32.

There is thus provided in Fig. 3 an oscillator network which comprises two oscillator tubes, each using one grid and the plate as the oscillator elements, and the other grid as a means for injecting the voltage from the opposite oscillator tube; both grids being shielded by a positive screen. In the circuit of Fig. 3 the plate and the grid **33** of tube **30** are the oscillator elements; the grid **34** and the plate of tube **31** are the oscillator elements of the latter tube. "Locking in" takes place by electronic cross-coupling on the outer grids **50** and **70**. When the AFC bias applied through lead **12** becomes more negative, and the bias applied through lead **13'** becomes less negative, the common mid-frequency is brought nearer to the natural frequency of oscillator tank circuit **33**. Conversely, when the bias applied to grid **50** becomes less negative, and the bias applied to grid **70** becomes more negative, then the common mid-frequency of the network is brought nearer to the natural frequency of tank circuit **32**. As in the case of Fig. 2, the tank circuits **32** and **33** are tuned to slightly different frequencies on either side of the predetermined mid-frequency.

Instead of using pentode tubes, it is possible to use tubes of the 6A7 type, and in such case the grid to which the AFC bias is applied would be the outer, or fourth, grid. Furthermore, the functions of the grids in each tube can be interchanged; the outer or fourth grid may function as the oscillator element, and the "locking-in" action can be secured by means of the first, or inner, grid. In either of the circuits of Figs. 2 or 3 it is possible so to gang the tank circuits that constant frequency control sensitivity is produced over a tuning band, or possibly so that any desirable variation of this sensitivity with mean frequency is to be had.

While I have indicated and described several systems 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 organizations 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 a superheterodyne receiving system, a local oscillator network including a tunable tank circuit, at least two reactive circuits of opposite sign shunted across the tank circuit, and means, responsive to a shift in the frequency of the intermediate energy from a predetermined assigned value, for automatically regulating the effects of said shunt circuits on the tank circuit.

2. In combination with the local oscillator and first detector of a superheterodyne receiver, a pair of diode rectifiers connected to the first detector output circuit to rectify the intermediate energy output of the detector, said oscillator including a tuned tank circuit, a pair of reactive arms of opposite sign in shunt with the oscillator tank circuit, and separate bias connections from the diodes to said arms to regulate the effectiveness of the arms in accordance with the relative magnitudes of the outputs of said rectifiers.

3. In a superheterodyne receiver of the type including a converter network having an intermediate frequency output circuit and a local oscillator network provided with a tuned tank circuit, an automatic frequency control arrangement including a discriminator network having an input circuit coupled to said output circuit, said discriminator having a direct current voltage output circuit producing two voltages in polarity opposition, a pair of independent reactive circuits in shunt across said tank circuit, said shunt circuits each including reactances of opposite sign, a tube in each shunt circuit having its internal impedance in series with the reactance thereof, and means impressing each of said two voltages upon a predetermined tube in each shunt circuit for controlling the effect of the reactances.

4. In combination with the local oscillator network of a superheterodyne receiver, said network including a resonant tank circuit provided with a tuning means, an automatic frequency control arrangement including at least two reactive arms shunted across the tank circuit, said arms including reactances of opposite sign and which are resonant to a frequency at the middle of tank circuit tuning range, and means for varying the effects of said shunt arms on the tank circuit.

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