March 26, 1940. O. E. KEALL 2,194,557

AUTOMATIC FREQUENCY CONTROL CIRCUITS

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Fig. 1

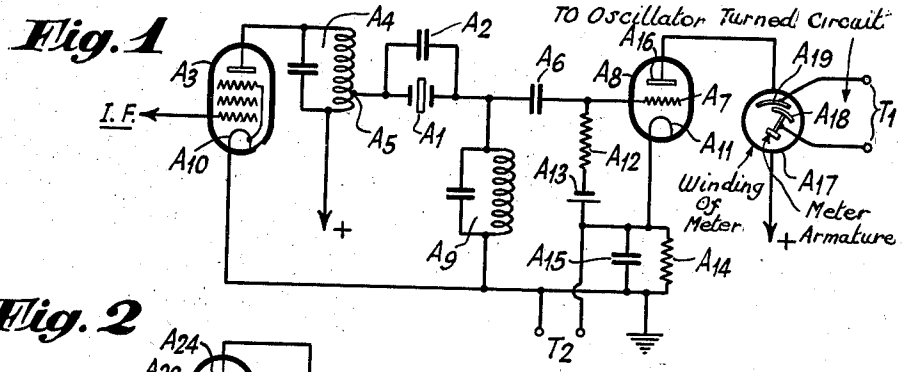


Fig. 2

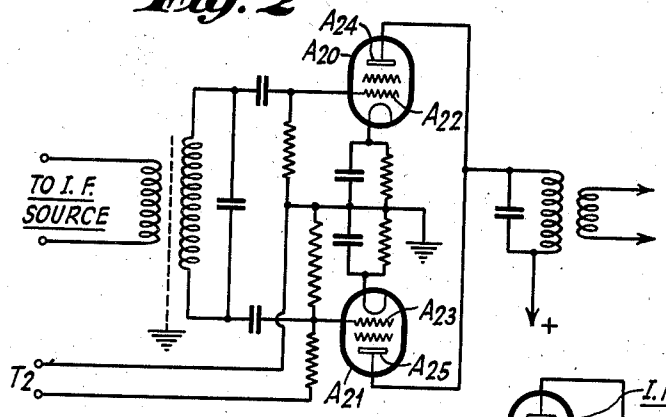
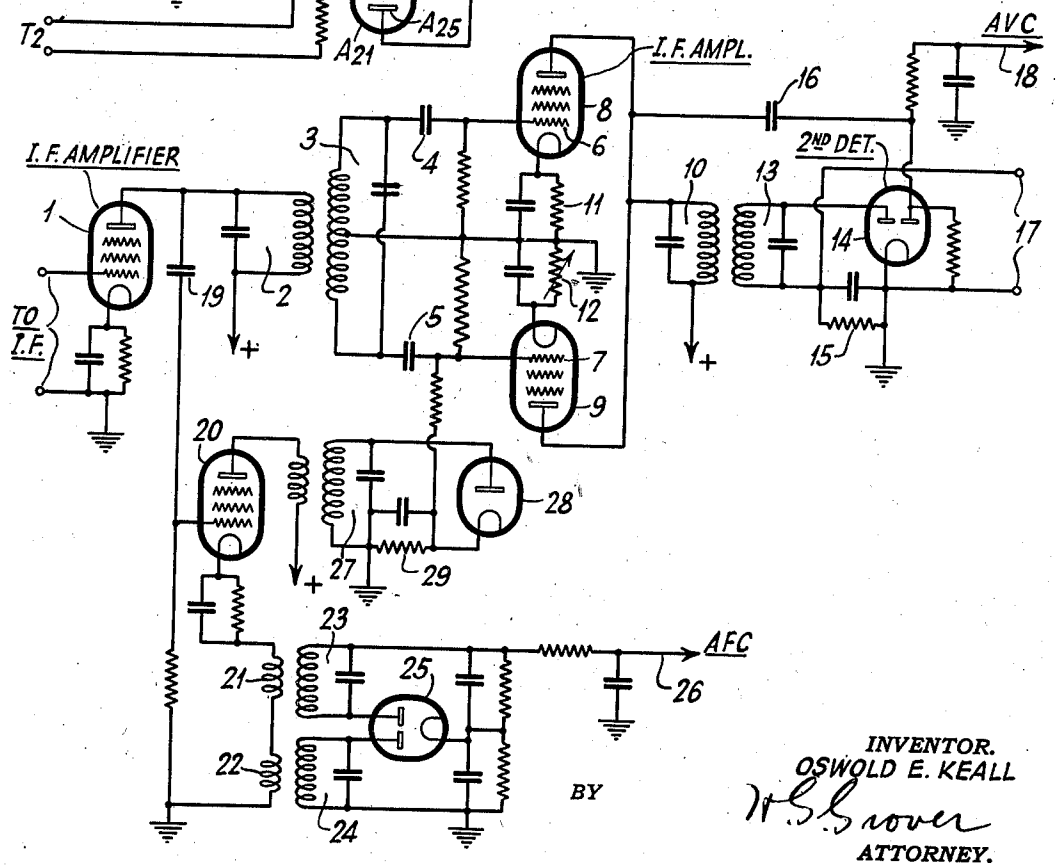


Fig. 3



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Fig. 4

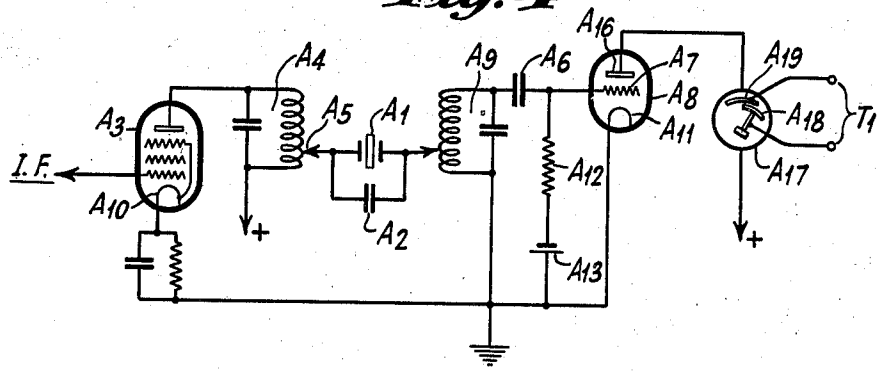


Fig. 5

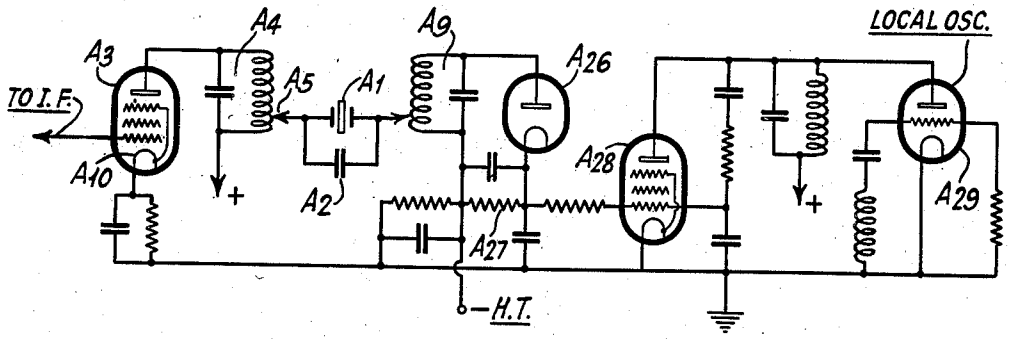
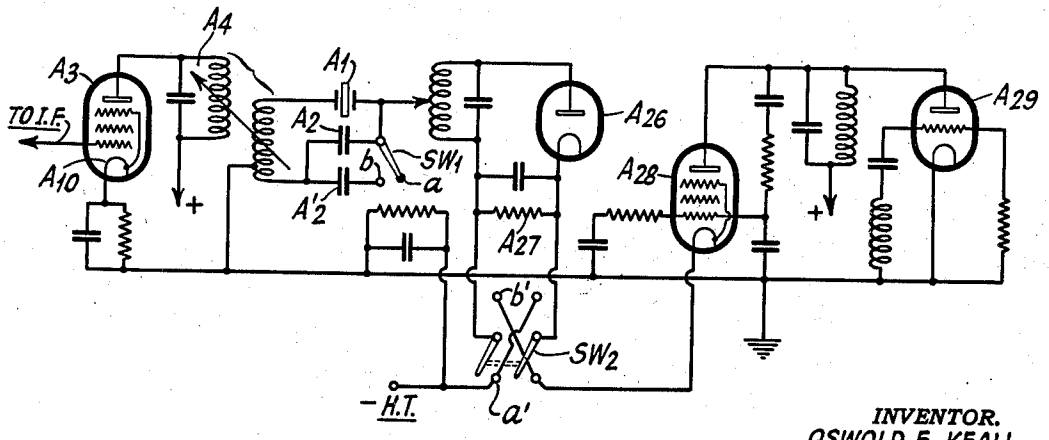


Fig. 6



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UNITED STATES PATENT OFFICE

2,194,557

AUTOMATIC FREQUENCY CONTROL CIRCUITS

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Application December 3, 1937, Serial No. 177,903
In Great Britain December 31, 1936

5 Claims. (Cl. 250—20)

This invention relates to radio and like receivers, and more particularly to automatic frequency control systems for use therein.

By the expression "automatic frequency control system" (AFC system) as herein employed is meant a system whereby the tuning of a receiver as a whole is automatically maintained correct for a station to be received when once the said tuning has been set—usually manually—within a predetermined range on either side of the correct tuning position for that station. AFC systems are sometimes (rather loosely) termed automatic tuning systems since a measure of automatic tuning is obtained thereby, although, in fact, the AFC system provides merely accuracy of tuning, selection as between stations being effected by other means, usually an ordinary manually controlled tuning knob.

The range over which an AFC system can operate to secure accuracy of tuning is, of course, limited; that is to say, unless the manual tuning control handle is moved to a position which is not more than a predetermined distance (which will depend upon the design of the AFC system) from that for correct tuning, the AFC system is unable to operate to secure accuracy of tuning. In any AFC system there will be a limited width of frequency band within which the frequency of a station desired to be received must fall and which defines the range of operation of the AFC systems; that is to say, if it be desired to receive a particular station, the manual tuning control must be so operated as to bring said station within the right band of the said width before the AFC system can operate to secure accuracy of tuning. In some systems the band is symmetrical about the frequency of the desired station (when accurate tuning has been obtained); in others it is asymmetrical about said frequency (again, when accurate tuning has been obtained). By a symmetrical action AFC system is meant a system such that a departure from accurate tuning of a certain amount on one side of the correct tuning position will produce a tuning correction which is equal and opposite to that produced as the result of a departure from accurate tuning of the same amount on the other side of the correct tuning position. The fact that an AFC system has a limited range of operation leads to the defect that it is quite easy, especially (though not exclusively) in the case of a receiver with an asymmetrical action AFC system, as distinct from a symmetrical action system for an unskilled operator to pass right through a desired station or find it difficult to tune in, for, in the ordinary way, there is nothing to indicate to the operator whether the AFC system is in operation or not; that is to say, there is nothing to inform the operator when he has tuned in a station sufficiently accurately for the AFC system to take charge.

The principal object of the first feature of the present invention is to avoid the above defect and this object is achieved, according to the said first feature, by providing the receiver with a so-called "automatic silencing system" so arranged that the set is silent, i. e., ineffective to reproduce, except when tuned within a predetermined range including a correct tuning position, said range being either coextensive with or (preferably) inside the range of operation of the AFC system. Automatic silencing systems are, of course, well known, per se, and have been widely used to secure so-called "silent tuning" being usually so arranged that the set is unable to reproduce signals below a predetermined strength. The first feature of the present invention, however, resides in the stated co-relation of the "silencing" range with the AFC operating range. Preferably the control voltage developed for AFC action is also employed for the automatic silencing control.

A second feature of this invention is concerned with superheterodyne receivers having AFC systems of the asymmetrically acting type, i. e. the type wherein a departure from accurate tuning of a certain amount on one side of the correct tuning position will produce a tuning correction which is not equal and opposite to that produced as the result of a departure from accurate tuning of the same amount on the other side of the correct tuning position. The object of the second feature of this invention is to produce an asymmetrically acting AFC system having a good shape of operating characteristic.

According to the second feature of this invention asymmetrically acting AFC voltage is obtained by means including a piezo-electric crystal, or equivalent very sharply resonant circuit or device, in effective series with a parallel tuned circuit which is resonant at the intermediate frequency of the receiver, said crystal being series resonant at or very near to the said intermediate frequency, the control voltage for AFC action being derived from the network including said crystal and tuned circuit, and said network being energized from a suitable intermediate frequency point of the receiver. With this arrangement, at the series resonant frequency of the crystal, maximum energy is transferred to the parallel

tuned circuit but at a frequency above this and corresponding to the parallel resonant frequency of the crystal, the energy in the parallel tuned circuit is very greatly attenuated. The energy in the parallel tuned circuit is passed to a rectifier and the relationship between the rectifier output and the applied frequency to the network is such as to constitute a highly satisfactory characteristic for AFC purposes.

Preferably the crystal is shunted by a small condenser so as to control the parallel resonant frequency of the crystal, and/or the rectifier is biased beyond cut-off, and/or the crystal is tapped on to the tuned circuit in series therewith. All these expedients improve the shape of the AFC characteristic.

In the drawings:

Fig. 1 shows one embodiment of the invention,

Fig. 2 illustrates an arrangement for securing silencing,

Fig. 3 shows a modification of the invention,

Fig. 4 shows a modification of the arrangement in Fig. 1,

Fig. 5 illustrates a further modification of the invention,

Fig. 6 shows a modification of the circuit in Fig. 5.

The accompanying Fig. 1 shows one embodiment of the invention as applied to a superheterodyne receiver having an asymmetrical action AFC system. The receiver, which is shown in part in the accompanying Fig. 1, is in accordance with both features of this invention. Referring to the accompanying Fig. 1, AFC action is obtained by means including a crystal A1 shunted by a capacity A2 and connected in a suitable part of the intermediate frequency portion of the receiver. As shown, there is included in the anode circuit of a valve A3 a parallel tuned circuit A4 resonant to the predetermined intermediate frequency, and a point A5 on the inductance of this tuned circuit, preferably near the low alternating potential end thereof, is connected to one electrode of the quartz or similar piezo-electric crystal A1 which is resonant at or very near to the intermediate frequency. The valve A3 may be the frequency changer valve of the receiver but it is preferably a valve whose grid is fed from a suitable intermediate frequency point in the receiver so that it acts as a "buffer" or isolating stage between the intermediate frequency amplifier proper of the receiver and the discriminator circuits, and thus prevents energy being fed back from the latter to the former. The other electrode of the crystal A1 which is shunted by the condenser A2 (which is of small size) is connected through a coupling condenser A6 to a suitable rectifier, for example, to control grid A7 of a triode A8 operated as an anode bend rectifier, and is also connected through a further intermediate frequency parallel tuned circuit A9 to earth and to the cathode A10 of the valve A3.

Between control grid A7 and cathode A11 of the anode bend rectifier A8 is connected a resistance A12 in series with a bias potential source A13 and the said cathode A11 of the rectifier A8 is connected to earth through a resistance A14, hereinafter termed the "silent control" resistance and which is shunted by a capacity A15. The rectified output from the rectifier A8 is utilized to effect AFC control in any convenient way; for example, as shown, the circuit to the rectifier anode A16 may include the operating winding of a suitable meter type instrument A17 whose armature carries a plate A18 in electrostatic association with a fixed plate (or plates) A19 so that the instrument constitutes a variable condenser whose value depends upon the current through the winding. This condenser is included in the frequency determining circuit (not shown) of the local oscillator not shown); e. g. the terminals T_1 may be connected across the normally provided tuning condenser (not shown) in said frequency determining circuit. The voltage set up across the silent control resistance A14 which voltage will obviously depend upon the anode current through the rectifier A8 is taken from terminals T_2 and utilized in any manner, known per se, to control the reproduction of the receiver as a whole so that the said receiver is unable to reproduce, or reproduce at any material strength, except when said voltage exceeds a predetermined minimum. By suitable design of the AFC circuits it can be arranged that the current through the rectifier A8 will not rise to a sufficient value to produce this predetermined minimum voltage until the automatic controlling device has taken charge of the tuning.

With this arrangement the action of the system will be somewhat as follows: As the tuning of the receiver approaches the correct position for a station to be received, the tuning being varied in the direction of increasing frequency, the rectifier output current, which is normally zero, will, when the tuning position reaches a predetermined distance from the correct position, commence to rise. The meter-condenser instrument A17 is, of course, so arranged that, as soon as it receives current from the rectifier, it varies the local oscillator tuning towards the correct position. At some point on the tuning scale the AFC system will take charge, and the frequency will jump towards, and close to, the correct tuning position. It is at the rectifier current corresponding to the point where the AFC system commences to take charge that the predetermined minimum voltage should be generated for cutting out the automatic silencing system so that, until the AFC system has acted, the receiver is silent. The actual silencing control may be achieved in any convenient way; e. g. by utilizing the voltage across the silent control resistance to "release" a normally "backed-off" amplifier, or detector, valve in the receiver.

One convenient way of achieving silencing control is shown in Fig. 2. This figure shows one intermediate frequency stage of the receiver, said stage comprising a pair of amplifier valves A20, A21, having their control grids A22, A23 connected in push-pull and fed with intermediate frequency energy, and their anodes A24, A25 in parallel. In the grid circuit of one only of these valves (the valve A21) is applied voltage from the silent control resistance, the sense of application being such as to reduce the gain of said one valve. The terminals T_2 of Figs. 1 and 2 are the same terminals electircally. The arrangement is such that in the absence of voltage from the silent control resistance A14 the valves A20, A21 are both in the high gain condition and the stage is substantially balanced, giving substantially no output. When, however, the AFC system operates, the gain of the valve A21 is reduced, the balance is upset, and the receiver is no longer silent. Obviously, in place of using, in the normally balanced stage, valves with their grids in push-pull and their anodes in parallel,

the grids may be in parallel and the anodes in push-pull.

The specific embodiment of Fig. 1 is, as stated, an embodiment for application to a superheterodyne receiver having an asymmetrically acting AFC system, and, as will have been appreciated, depends for its operation upon the fact that the voltage from the frequency discriminating network (the crystal and rectifier network) by means of which the AFC action is obtained is always in the same direction and of varying magnitude. The first feature of this invention can, however, be applied to a receiver employing a symmetrical action AFC system wherein the voltage obtained from the frequency discriminating network for AFC action is not always in the same direction, but changes direction in dependence upon the direction of "mistuning" the said voltage becoming zero in the position of accurate, exact tuning.

In one way of applying the first feature of this invention to a superheterodyne receiver having a symmetrically acting AFC system the receiver is arranged to be automatically silenced, except when tuned within a predetermined range over which the AFC system is in charge, by means including a band pass filter of narrow, predetermined pass range which is energized from a convenient intermediate frequency circuit of the receiver, and which is utilized to provide an output voltage which is employed in any convenient manner, known per se, to render the receiver operative to reproduce signals. For example, this voltage may be rectified and employed to overcome a cut-off bias voltage applied to some convenient valve in the receiver, or the said voltage may be rectified and employed in manner similar to that already described with reference to Fig. 2, to upset the balance of a normally balanced stage in the receiver. The band pass filter is arranged to pass a band whose mid-frequency coincides with the predetermined intermediate frequency of the receiver, and the width of this band is coextensive with, or less than, the width of the band of frequencies over which the AFC system can take charge. In place of using an ordinary band pass filter, a quartz crystal filter, including a quartz crystal resonating at the predetermined intermediate frequency and connected in series with a parallel tuned circuit also resonant at that frequency, may be employed.

An embodiment as generally described in the immediately preceding paragraph has the defect that it involves a somewhat serious increase in the cost of a receiver, and moreover, although the automatic apparatus for removing the normal "silenced" condition of the receiver is co-related with the AFC system the association between the AFC and "silencing" systems is, from the circuit point of view, not very close. For these reasons an embodiment as described in the said preceding paragraph, though quite suitable for a receiver for commercial reception, is not regarded as preferable for application to a broadcast radio receiver where cheapness and simplicity are important desiderata. In the case of application to a broadcast radio receiver, or in other cases where cheapness is an important matter, and the receiver has an AFC system with a frequency discriminating network whose output voltage is not always in the same direction, it is preferred to employ an embodiment as illustrated diagrammatically in Fig. 3.

Referring to Fig. 3, 1 represents a normally provided intermediate frequency amplifier valve in the receiver, said valve having a tuned output circuit 2 coupled to a tuned circuit 3 the ends of which are coupled through condensers 4, 5, to the input grids 6, 7, of two valves 8, 9, which have a divided input circuit (3) connected in push-pull, and feed in parallel into a common output circuit including the tuned circuit 10. Normally, that is to say in the absence of signal input to the valve 1, the valves 8 and 9 are in balanced condition so that there is no output from circuit 10. In order to facilitate the obtaining of this normally balanced condition, one or both of the capacity shunted resistance 11, 12, in the cathode legs of the valves 8, 9, and serving as the usual self-bias resistances, may be made variable. As shown the resistance 12 is variable. Obviously other means may be provided for facilitating the obtaining of balance; for example, means may be provided for adjusting screen grid voltage, or suppressor grid voltage in one or both valves. The circuit 10 is coupled to a circuit 13 which feeds into one half of a double diode 14 with which half is associated a capacity shunted load resistance 15. The anode of valve 8 is coupled through a condenser 16 to the other half of the double diode 14. The first mentioned half of the double diode 14 acts as the normal demodulating detector of the receiver, providing audio frequency potentials at the leads 17 for utilization in the ordinary well known way. The other half of the double diode provides over a lead 18 an anti-fading automatic volume control potential which again is utilized in any well known way.

The anode of the valve 1 is coupled through a condenser 19 to the control grid of a valve 20 whose cathode leg includes two coupling coils 21, 22, in series. One of these coupling coils is coupled to one, and the other to the other, of two tuned circuits 23, 24; one tuned slightly above, and the other an equal amount below, the predetermined intermediate frequency of the receiver. These tuned circuits feed, as shown, into a differentially arranged double diode circuit including a double diode tube 25 so that the voltage provided over lead 26 will be a differential voltage depending upon the voltage introduced into the circuits 23, 24, this differential voltage being zero when the voltages introduced into the circuits 23, 24, are equal, i. e. when the receiver is accurately in tune. The network including the circuits 23, 24, is the symmetrically acting frequency discriminating AFC network, and the voltage provided over lead 26 is utilized in any manner known per se automatically to control the tuning of the receiver in a direction to correct for any error in tuning.

The output of the valve 20 is coupled to a circuit 27 which is tuned to the predetermined intermediate frequency of the receiver, and which feeds into a diode tube 28 having a capacity shunted load resistance 29. The voltage across the load resistance 29 is fed as bias to the grid of one of the valves 8, 9, (as shown to the grid of the valve 9) this voltage serving to upset the normal balance condition for the valves 8, 9, and thus render the receiver able to reproduce signals. In this way elimination of background noise and silent tuning between stations is achieved, and, once the receiver has been tuned sufficiently close to the correct position to enable the AFC system to take charge, the voltage set up across the resistance 29 removes the "silencing".

It will be noted that the coils 21, 22, with which the discriminator circuits 23, 24, are coupled are included in both the grid and the anode circuits

of the valve 20 and accordingly these discriminator circuits produce negative feedback at and close to their own resonant frequencies, and, therefore, at these frequencies there will be a reduction in the voltage fed to the circuit 27 as compared to the voltage which this circuit receives at frequencies between the resonant frequencies of the circuits 23, 24. Thus one of the results of the connection of circuits 23, 24, in the manner described, is, in effect, to reduce the "skirts" of the resonance curve of the tuned circuit 27, and this is of great assistance in ensuring that the AFC system will take charge before "silencing" is removed from the stage including the valves 8, 9. Where, as in the illustrated arrangement, voltage for automatic volume control is taken from the signal diode side (half of the double diode tube 14) of the balanced circuit, it is preferred to arrange the balanced valves to be in the balanced condition when in a relatively low gain condition, increasing the gain of one valve to destroy balance when the "silencing" is to be removed. The full signal strength developed is thus available for operation of the AFC system, automatic volume control being applied immediately the station is automatically tuned in. This may result in the occasional "skipping" of a weak station, but all stations of strength sufficient to give good "program results" will be received. In receivers in which expense is a secondary consideration, however, a separate automatic volume control system could be provided and operated from the grid of one of the balanced valves or from some prior point in the circuit, in which case substantially constant input strength to the AFC and automatic silencing systems would be obtained and the liability of "skipping" weak stations considerably reduced. It would then be possible to operate the balanced valves so as to be balanced when in a high gain condition, and to destroy the balance to remove "silencing" by decreasing the gain of one of them.

The voltage for automatic "silencing" (or to be more exact, for the removal of the "silenced" condition) may operate in other ways to remove a normal cut-off bias on an intermediate frequency stage, or a detector stage, or an audio frequency stage, or it may operate (as described in Fig. 3) to upset the balance of a normally balanced stage, which again may be an intermediate frequency stage or a detector stage, or an audio frequency stage. Further, the automatic volume control circuit may be associated either with an intermediate frequency stage of the receiver, or with the demodulating detector stage, or with the AFC circuits. For example, the valve 20 of Fig. 3 might be replaced by a diode pentode, and the voltage for automatic volume control obtained from the diode portion of this diode-pentode. Further, if a suitable meter or other indicating device be included in series with the load resistance 29 of diode 28, visual indication of the correctness of tune will be given thereby. Alternatively voltage developed across the load resistance 29 could be employed to operate a suitable visual indicator.

The first feature of the present invention is not primarily concerned with the design of the AFC system employed nor with that of the silencing system employed, but with the co-relation of these two systems so as to obtain silence except when the AFC system is in action. Any suitable AFC system may be used in carrying out the said first feature and similarly any silencing system may be used.

Fig. 4 shows a circuit embodying the second feature of this invention only. The circuit of this figure is very similar to that of Fig. 1, and corresponding references are used for corresponding parts. The main differences are (1) the omission of the elements A14, A15 and the associated terminals T_2 (since the first feature of invention is not embodied), and (2) the crystal A1 is variably tapped upon the two tuned circuits one on each side thereof. Of course, if the first feature of the invention were also to be embodied, the elements A14, A15 and terminals T_2 would be provided as in Fig. 1.

Fig. 5 shows a further embodiment of the second feature of this invention. The circuit to the left of the tuned circuit A9 is like that of Fig. 4, but a diode rectifier A26 replaces the anode bend rectifier A8 of Fig. 4. A capacity shunted load resistance A27 is in series with the diode A26 and tuned circuit A9 and the rectified output from A26 is fed to the control grid of a control valve A28 associated for frequency control purposes in manner known per se with a back coupled oscillator A29 which constitutes the local oscillator of the receiver.

In order that the AFC action of an asymmetrically acting AFC system shall be equally effective irrespective of the direction of movement of the manual tuning control handle of the receiver, i. e. irrespective of whether the tuning is being varied (manually) from a higher frequency to a lower or vice versa—it is, of course, necessary to provide switching or equivalent means for changing the AFC circuit connections when the direction of manual tuning variation is reversed. Such means, which are preferably automatically actuated from the manual tuning control handle itself, are known per se. In order to achieve satisfactory two-way tuning with an asymmetrically acting AFC discriminator network the general requirement is that the characteristic shall be inverted with respect to both frequency and sign of output when the direction of variation of tuning is changed. The inversion with respect to frequency may be performed by the use of the crystal bridge by means of which the parallel resonant frequency of the crystal may be changed from just above to just below the series resonant frequency (or vice versa) by changing the value of the balancing capacity.

Inversion with respect to sign of output may be performed by means of a double pole switch in the "rectified" output circuit and actuated automatically (as is variation of the balancing capacity) upon change of direction of tuning variation. Fig. 6 shows the circuit of Fig. 5 modified to be adapted for two-way tuning. Here there are two condensers A2, A'2 associated with the crystal A1; A'2 being added in parallel with A2 when a switch arm SW_1 is moved into position *b*. The rectifier circuit includes a double pole-double throw switch arm SW_2 having two positions *a'* and *b'*. Both switches are gang-controlled to be either in positions *a* or positions *b*; any convenient means (not shown) being provided for operating these switches together when the direction of manual tuning variation is changed. In other respects Figs. 5 and 6 are very similar. In Fig. 6 it will be noted that the crystal circuit is mutually coupled to circuit A4 instead of being tapped thereon.

Although Figs. 4, 5, 6 have been shown as embodying the second feature only of this invention, obviously any of them could be modified to em-

body both features of the invention by adding means, such as those of Figs. 1 and 2 for securing silencing action except when within the range of operation of the AFC system.

Having now particularly described and ascertained the nature of my invention, and in what manner the same is to be performed I declare that what I claim is:

1. In a superheterodyne receiver of the type provided with an intermediate frequency amplifier network comprising a pair of amplifier tubes having a common tuned input circuit and a common output circuit, said tubes being normally balanced to prevent transmission of signal energy therethrough, means, responsive to frequency shifts in the intermediate signal energy from an assigned frequency value, for developing control voltage adapted to be used to compensate for said shifts, a network coupling said common input circuit to said control voltage means to transmit said signal energy to the latter, and means responsive to intermediate signal energy of said assigned frequency value for controlling the gain of at least one of the amplifier tubes in a sense to permit said signal energy transmission.

2. In a superheterodyne receiver of the type provided with an intermediate frequency amplifier network comprising a pair of amplifier tubes having a common tuned input circuit and a common output circuit, said tubes being normally balanced to prevent transmission of signal energy therethrough, means, responsive to frequency shifts in the intermediate signal energy from an assigned frequency value, for developing control voltage adapted to be used to compensate for said shifts, a network coupling said common input circuit to said control voltage means to transmit said signal energy to the latter, and means responsive to intermediate signal energy of said assigned frequency value for controlling the gain of at least one of the amplifier tubes in a sense to permit said signal energy transmission, said last means being coupled to said coupling network, and the latter being constructed to prevent efficient transfer of signal energy to the said last means at frequencies off said assigned frequency value.

3. In a superheterodyne receiver of the type provided with an intermediate frequency amplifier network comprising a pair of amplifier tubes having a common tuned input circuit and a common output circuit, said tubes being normally balanced to prevent transmission of signal energy therethrough, means, responsive to frequency shifts in the intermediate signal energy from an assigned frequency value, for developing control voltage adapted to be used to compensate for said shifts, a network coupling said common input circuit to said control voltage means to transmit said signal energy to the latter, means responsive to intermediate signal energy of said assigned frequency value for controlling the gain of at least one of the amplifier tubes in a sense to permit said signal energy transmission, said coupling network comprising an amplifier tube having a signal energy connection to said common input circuit, said last means being coupled to the output circuit of the last-named tube, and means for degenerating the latter for frequencies off said assigned frequency value.

4. In a superheterodyne receiver of the type provided with an intermediate frequency amplifier network comprising a pair of amplifier tubes having a common tuned input circuit and a common output circuit, said tubes being normally balanced to prevent transmission of signal energy therethrough, means, responsive to frequency shifts in the intermediate signal energy from an assigned frequency value, for developing control voltage adapted to be used to compensate for said shifts, a network coupling said common input circuit to said control voltage means to transmit said signal energy to the latter, and means responsive to intermediate signal energy of said assigned frequency value for controlling the gain of at least one of the amplifier tubes in a sense to permit said signal energy transmission, said last means comprising a rectifier having an input circuit, tuned to said assigned frequency, coupled to said coupling network, and the rectifier having a gain control connection to said one amplifier tube.

5. In a superheterodyne receiver of the type including an intermediate frequency amplifier and a demodulator, a frequency discriminator network having an intermediate frequency energy input circuit, said discriminator having an output circuit adapted to compensate for frequency shift of the intermediate energy from an assigned frequency value an amplifier coupling said intermediate amplifier to said input circuit, means for controlling the signal transmission between said intermediate amplifier and demodulator in a sense to provide normal transmission of intermediate energy after compensation by said discriminator, said means comprising a rectifier coupled to said coupling amplifier and deriving intermediate frequency energy therefrom, said coupling amplifier being constructed to provide negative feedback between its output and input circuits at frequencies off said assigned frequency.

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