Sept. 16, 1941. J. D. BRAILSFORD 2,255,746

AUTOMATIC FREQUENCY CONTROL

Filed Sept. 2, 1938 2 Sheets-Sheet 1

Fig. 1

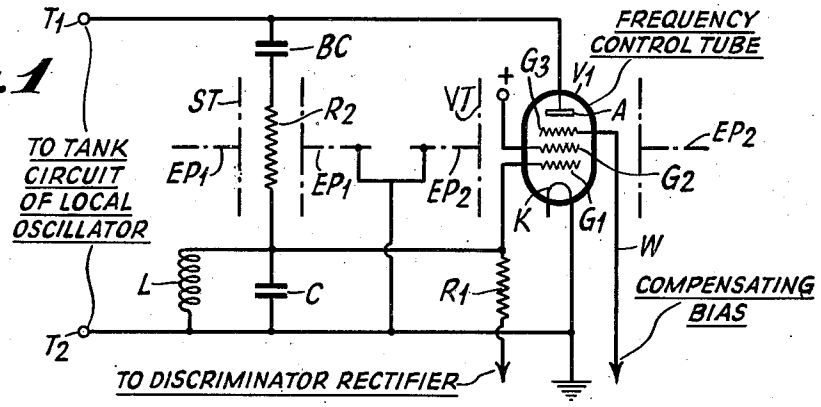


Fig. 2

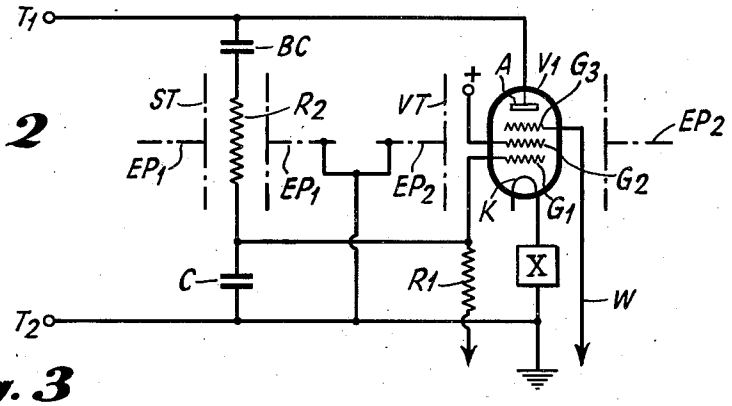


Fig. 3

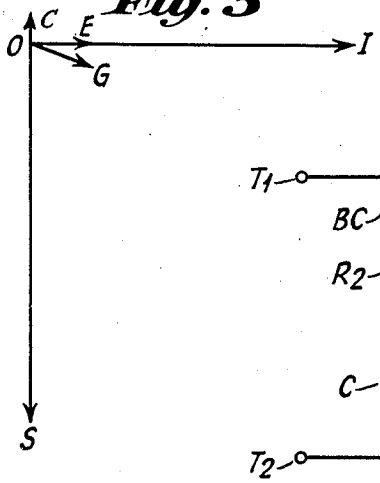
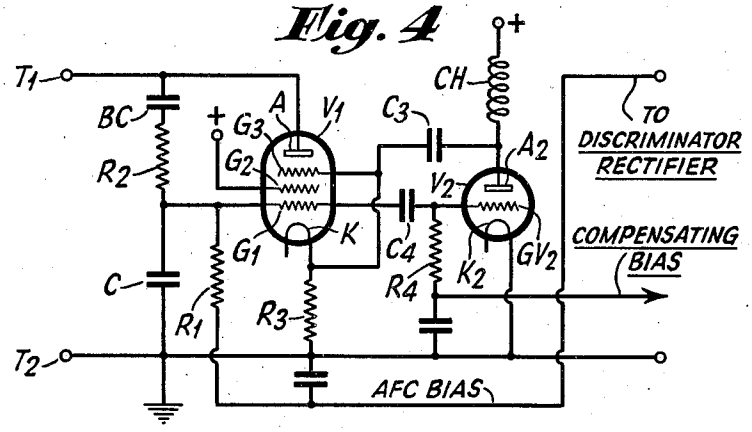


Fig. 4



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Filed Sept. 2, 1938 2 Sheets-Sheet 2

Fig. 5

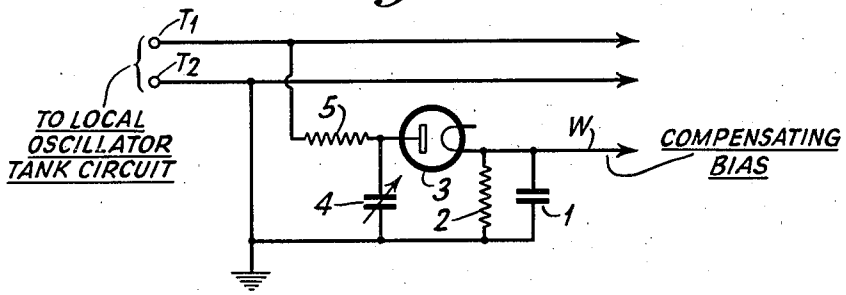


Fig. 6

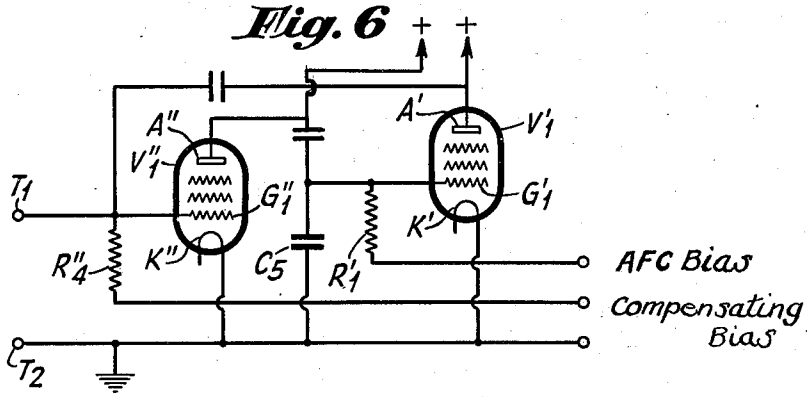
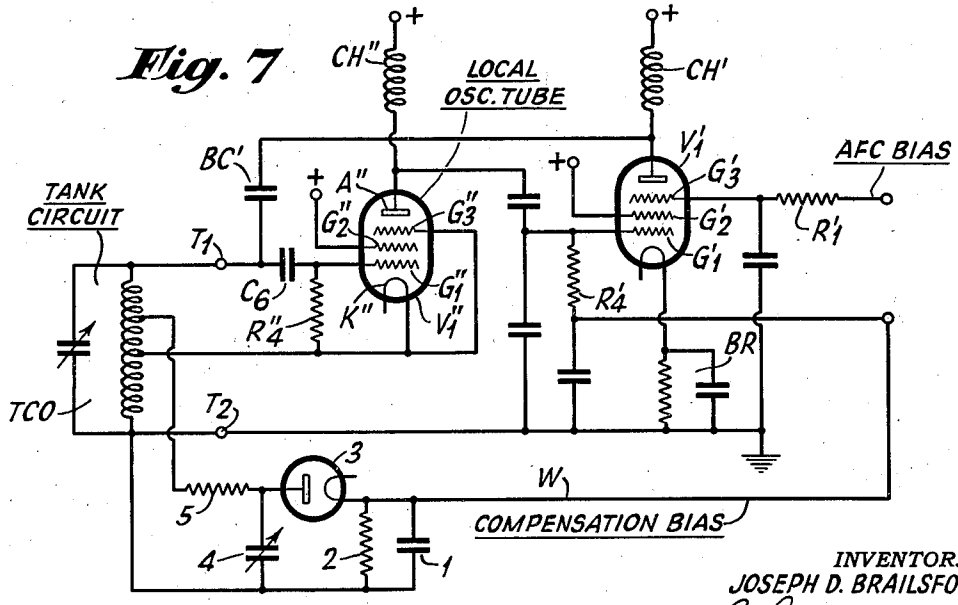


Fig. 7



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AUTOMATIC FREQUENCY CONTROL

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Application September 2, 1938, Serial No. 228,137
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8 Claims. (Cl. 250—40)

This invention relates to radio receivers, and more particularly to automatic frequency control systems (A. F. C.) for use in superheterodyne receivers.

By the expression A. F. C. 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 manually within a predetermined short distance of the correct tuning position for that station. A. F. C. systems are sometimes rather loosely termed "automatic tuning systems" since a measure of automatic tuning is obtained thereby, although in fact an A. F. C. system provides merely accuracy of tuning, selection between stations being effected by the usual manually variable tuning control means.

Superheterodyne receivers with A. F. C. system are now well known and in common use. In general, such systems operate by taking energy from some convenient intermediate frequency point of the receiver, passing it through a discriminator network which is frequency selective, and utilizing the discriminator network output to actuate an auxiliary control device which exercises a measure of control upon the local oscillator frequency, the arrangement being such that so long as the intermediate frequency energy actually fed to the discriminator network is the predetermined intermediate frequency of the receiver no control is exercised, but (assuming the receiver is first manually tuned within a predetermined small distance of the correct tuning position for the station to be received) if the intermediate frequency energy fed to the discriminator network departs from the predetermined intermediate frequency the output from the said network actuates the auxiliary control device to vary the local oscillator frequency to such an extent, and in such a sense, as to bring the intermediate frequency actually produced into substantial coincidence with the predetermined value. In the usual type of arrangement the output from the discriminator network is rectified to produce a control bias which is applied to the control grid of a control valve whose anode-cathode space is included in a circuit which is connected across, and forms part of, the frequency determining circuit of the local oscillator so that the control valve acts as a variable reactance dependent in value upon the bias applied thereto, and, therefore, in turn dependent upon the discriminator network output.

Now, it is very desirable that the range and law of control of an A. F. C. system in a superheterodyne receiver shall be substantially constant throughout the tuning range of the receiver, and a defect of known A. F. C. systems is that this desirable result is not achieved, the range and law of control varying throughout the tuning range of the receiver in dependence upon the setting of the manual tuning control. It has been sought to reduce this defect by providing an inductance across the grid-cathode circuit of the control valve. This inductance is, therefore, in parallel with the effective condenser which is responsive for the phase changing action and has the effect of providing a circuit which, while acting as a capacity over the range of frequencies concerned, has an impedance-frequency law such that a correcting action takes place. Although this provision does undoubtedly reduce the variation of range and law of control, it still leaves an undesirably large amount of variation over the tuning range.

The principal object of the present invention is to reduce or avoid this defect.

The deviation of known A. F. C. systems from the ideal constant control is most marked on the higher frequency tuning bands, and it is, therefore, on these bands that the invention can be applied with most advantage. The said invention is, however, of general application, and is not limited to its use on any particular wave band.

According to this invention a superheterodyne radio receiver is characterized in that control for A. F. C. action is exercised not only in dependence upon departures from correct tuning, but also in dependence upon the setting of the manual tuning control means for the receiver as a whole, the second mentioned control being a supplementary, or compensating, control operating to insure that the range and degree of A. F. C. action shall be substantially the same throughout the tuning range of the receiver. It will thus be seen that the characteristic feature of the present invention resides in the use in combination of (1) the hitherto usual type of control in dependence upon departures from a correct tuning position, and (2) the supplementary control for compensating purposes, this control operating automatically in dependence upon the setting of the manual tuning control means of the receiver.

The present invention may be employed alone, or in conjunction with the known expedient

above referred to of providing an inductance across the grid circuit of the control valve.

In the drawings:

Fig. 1 shows one form of the invention,

Fig. 2 illustrates an alternative wherein the frequency control tube of Fig. 1 includes a phase shift correction reactive impedance,

Fig. 3 graphically shows the effect of the phase shift correction impedance of Fig. 2,

Fig. 4 shows another embodiment,

Fig. 5 shows a manner of securing compensating bias,

Fig. 6 illustrates still another modification,

Fig. 7 shows an alternative embodiment using the arrangements of Figs. 5 and 6.

Referring to Fig. 1, which shows diagrammatically one way of carrying out the invention, use is made as the control valve or "variable reactance valve" of a valve V1—as shown, a pentode—having at least two grids one of which G1 receives through resistance R1 main control bias obtained from a rectifier (not shown) fed from a suitable discriminator network (not shown) as in the usual way, and another of which G3 receives over lead W compensating bias applied in accordance with this invention and depending upon the setting of the manually variable control means of the receiver. G2 is a screen grid. The anode-cathode space of the valve V1 is connected at T1, T2, across the frequency determining circuit (not shown) of the local oscillator (not shown) of a superheterodyne receiver. The anode A is connected to the cathode K, which is earthed, through a blocking condenser BC, a resistance R2, and a second condenser C all in series in the order stated; the junction point of the condenser C with the resistance R2 being connected to the first control grid G1. If desired an inductance L may be connected as known per se across the condenser C.

With this arrangement, by suitably dimensioning the elements R_2—C the valve circuit may be caused to act like a reactance across the terminals T_1—T_2, the value of the reactance varying with the mutual conductance of the valve.

In the description of Fig. 1 so far given it has been assumed that R_2 is a pure ohmic resistance and C a pure reactance. In practice, of course, this assumption is inaccurate and there will be a stray capacity in shunt with R_2 while, of course, the condenser C is shunted by the grid impedance of the valve V1 and various auxiliary components. These departures from the theoretical ideal constitute causes of troubles which may, especially at higher frequencies and where a big range of control is desired, become serious. Such difficulties may, however, be largely avoided where necessary, by screening the valve V1 and the resistance R_2 by earthed screens. Such screening is represented in chain lines in Fig. 1 where it is shown as constituted by a metallic screening tube ST through which the resistance R_2, passes, and which itself passes through, and is connected to, an earthed metal plate EP_1 and a metallic screening tube VT for the valve V_1, the tube VT similarly passing through, and being connected to, an earthed metal plate EP_2. An effect of the screening is to increase the effective capacity at C and also the stray capacity between T_1 and T_2 but this is of negligible consequence. The important and desired effect of the screening is to reduce the capacity across R_2.

Fig. 2 shows a further modification which differs from Fig. 1 mainly in that a reactive impedance X, provided for the purpose of correcting for undesired phase shift, is inserted in the cathode leg of the valve V_1. The impedance X may be an inductance, or a capacity (with a choke across it to pass the D. C.) or a combination of either with resistance. The effect of the impedance X is illustrated vectorially in Fig. 3. Assume that after the phase correction has been made by means of the cathode impedance X the anode current OI (the vector of reference in Fig. 3) is in quadrature with the voltage across the input terminals T_1T_2. Then OE represents the voltage between G1 and K. The supply voltage OS must, by assumption, be in quadrature. The voltage between G1 and earth will lead OS by nearly 90° and be smaller. OG represents this voltage. OE is the resultant of OG and the cathode voltage reversed in sign (minus the cathode voltage). If X is a pure inductance the voltage across it will lead the current OI by 90° and therefore minus the cathode voltage—this is represented by the vector OC—will lead OI by 90°. OC must be so dimensioned that OE is the resultant of OG and OC for the original assumption—namely that OI and OS are in quadrature—to hold good. This requirement may clearly be satisfied by suitably selecting the dimensions of X.

In a modification (not illustrated) the compensating bias is applied to the first control grid G1 and the main control bias to the third grid G3.

In the embodiment illustrated in Fig. 4 the required compensating action is obtained by utilizing an auxiliary valve V2 automatically to vary feedback for a control valve V_1 which, as before, constitutes a variable reactance in the local oscillator frequency determining circuit. Here, as before, a pentode V_1 is used as the control valve and the anode-cathode space A—K of this pentode in series with a resistance R_3 in its cathode leg is connected at T_1—T_2 across the frequency determining circuit (not shown) of the local oscillator (not shown). Also connected across the series circuit V_1—R_3 is a series circuit consisting of a blocking condenser BC, a resistance R_2, and a second condenser C; the junction point of the elements R_2 and C being connected to the grid G_1 as before. The main control bias obtained from the discriminator network and associated rectifier (not shown) is applied through a resistance R_1 to the grid G_1; the second grid G_2 acts as a screen grid; and the third grid G_3 is connected to the cathode K to act as a suppressor. The cathode K is capacity coupled by a condenser C_3 to the anode A_2 of the auxiliary valve V_2, and the grid G_1 is capacity coupled by a condenser C_4 to the control grid GV_2 of the said valve. The auxiliary valve V_2 may be as shown a triode. This auxiliary valve receives anode potential through a suitable choke CH and compensating bias varying in dependence upon the setting of the manual tuning means of the receiver is applied through a suitable resistance R_4 to the control grid GV_2 thereof. The cathode K_2 of the auxiliary valve V_2 is connected to earth. With this arrangement the cathode leg resistance R_3 produces negative feedback due to the control valve anode current and positive feedback due to the auxiliary valve. Thus since the compensating bias controls the mutual conductance of the auxiliary valve V_2 the total feedback produced will depend upon the compensating bias.

In the foregoing description the method of obtaining the compensating bias has not been set forth, but obviously there are various different

circuits which can be used for this purpose. For example the compensating bias could be derived from a graded potentiometer gang-controlled with the manual tuning condenser. The tuning condenser law of most modern receivers is such that an ordinary logarithmically graded potentiometer would suffice for this purpose. Again a rectifier fed through a suitable frequency dependent or shaping network from across the frequency determining circuit of the local oscillator could be utilized to provide the compensating bias. For the case where the voltage across the frequency determining circuit of the local oscillator is constant or sufficiently nearly constant, excellent results may be obtained, as shown in Fig. 5, by deriving the compensating bias from across a capacity shunted resistance combination **1**, **2**, in the cathode leg of a diode **3** which is in series in a loop circuit with said resistance **2** and with a (preferably adjustable) condenser **4**, the said condenser being connected at the terminal remote from the diode anode to the "earthy" side T_2 of the frequency determining circuit (not shown) of the local oscillator and being connected at its other terminal through a resistance **5** to the other side T_1 of the said frequency determining circuit.

The invention is not limited to the use of a single valve control circuit for other arrangements are possible. For example, as shown in Fig. 6, the main control bias may be applied through a suitable resistance R'_1 to the control grid G'_1 of one control valve V'_1 said control grid being connected through a condenser C_5 to earth and to the anode A'' of a second control valve V''_1 to whose control grid G''_1 the compensating bias is applied through a suitable resistance R''_4. The cathodes K'—K'' of the two control valves are connected together and to the "earthy" side of the frequency determining circuit (not shown) of the local oscillator, the control grid G''_1 of the second valve V''_1 being connected both to the other side of said predetermined frequency circuit and also to the anode A' of the first control valve V'_1. Any known convenient means are provided for applying static bias potentials to the various valve electrodes but it is not thought necessary to describe such means herein.

In Fig. 6 the anode and grid static biasing arrangements have been omitted for the sake of clarity. It is, therefore, a diagrammatic representation of a two-valve circuit for producing a reactance by electronic means. The physical reactance C_5 causes the voltage fed to the grid G'_1 to be in quadrature with the anode current of the valve V''_1. Thus, the anode current of V'_1 is in quadrature with the anode current of V''_1 and, therefore, with the grid voltage of V''_1. It will be seen, therefore, that the application of an alternating voltage to the terminals T_1—T_2 results in a current between these terminals which is in quadrature with the applied voltage. Fig. 6 is equivalent, therefore, to a reactance connected between the terminals T_1—T_2. The value of this reactance can be shown by analysis to be dependent upon the product

$$\frac{C_5}{g''_1 g'_1}$$

g''_1 and g'_1 being the respective mutual conductances of valves V''_1 and V'_1. The fact that the compensating bias is applied to the valve V''_1 is simply to illustrate this possibility, as it will be seen from the aforesaid expression that variation of any of the factors C_5, g''_1 or g'_1 will vary the apparent reactance between the terminals T_1—T_2 and, therefore, affect the control. The terminals T_1—T_2 are, of course, connected to the oscillator circuit as in the case of the previous figures.

In a modification shown in Fig. 7 of the last described arrangement the second control valve V''_1 is also employed as the local oscillator of the receiver. In this modified arrangement the main control bias is applied through a suitable resistance R'_1 to the third grid G'_3 of a pentode V'_1 which constitutes the first control valve, and the compensating bias is applied through a suitable resistance R'_4 to the first control grid G'_1 of this valve, the second grid G'_2 acting as a screen grid. The valve receives automatic bias by means of the usual capacity shunted resistance combination BR in its cathode leg, and its anode-cathode circuit includes in addition to this self-bias resistance a blocking condenser BC' and the manually variable frequency determining circuit TCO of the local oscillator. The control grid G'_1 of this first control valve is connected through a condenser to earth and is capacity coupled to the anode A'' of a second control valve V''_1 (also a pentode) whose first control grid G''_1 is connected to its cathode K'' through a resistance R''_4. This resistance is shunted by a condenser C6 in series with a portion of the inductance of the frequency determining circuit TCO. The second grid G''_2 of the second control valve acts as a screen grid, and the third grid G''_3 thereof is connected to the cathode K'' to act as a suppressor grid. Both valves receive anode potentials through suitable chokes CH' CH''. Voltage is taken from the frequency determining circuit TCO from across a portion of the inductance thereof to a diode network which supplies the compensating bias. This network is as shown in Fig. 5. This arrangement is particularly suitable for use on short waves.

Fig. 7 is complicated by the fact that the valve V''_1 acts in the dual role of oscillator and the first valve of the arrangement of Fig. 6. The position of the terminals T_1—T_2 will make this clear. Because of the resistance-capacity combination **5**—**4**, the voltage across the condenser **4** will fall as the frequency rises. Now it can be shown that the control effect is proportional to the product of frequency times effective mutual conductance of the compensating valve (or in the case of Fig. 6 compensating valves). In order that the control effect should be constant the effective mutual conductance must be inversely proportional to frequency; that is, as the frequency rises the effective mutual conductance must fall. It will be evident, therefore, that since the voltage across the condenser **4** falls as frequency rises, the positive compensating bias applied to G'_1 decreases and the mutual conductance falls, thus fulfilling the required condition. Variation of the tuning of T. C. O. will, of course, change the frequency. Now, the bias over W is derived from rectification of the high frequency voltage across the condenser. This condenser is in turn fed through the resistance **5**. The impedance of **4** varies with frequency, and, therefore, by potentiometer action the voltage across **4** varies with frequency. Correct dimensioning of **4** and **5** results in a variation in the bias W which is a very close approximation to that required for complete compensation of the control.

The invention is not limited to the particular

circuits above described and various modifications may be made. In particular the network by means of which the compensating bias is obtained need not be as above specifically described but may take any of a variety of filter or frequency dependent forms known per se in dependence upon the requirements in any particular case as to the law of compensation.

What is claimed is:

1. In combination with a tunable oscillator circuit, means for tuning the circuit over a range of frequencies, an electron discharge tube having its plate to cathode impedance connected across the oscillator circuit to provide a supplemental tuning element, means for varying the gain of the tube to vary the magnitude of the said impedance, and auxiliary means, responsive to adjustment of said tuning means over said range, for varying the gain of said tube supplementally of the first means with voltage derived from said oscillator circuit, said tube including at least two control grids between its plate and cathode, said first means varying the voltage of one grid, and said auxiliary means varying the voltage of the second grid.

2. In combination with a tank circuit of an oscillator adapted to be tuned over a wide range of frequencies, a tube having at least a cathode, anode and two control grids, means connecting the anode to cathode path of the tube across the tank circuit thereby to provide a reactive effect across the latter, means for varying the voltage of one grid to adjust the magnitude of said effect, and means for supplementally varying the voltage of the second grid with voltage derived from the tank circuit to maintain said magnitude adjustment according to a predetermined law of variation.

3. In combination with the tank circuit of an oscillator adapted to be tuned over a wide range of frequencies, a tube having at least a cathode, anode and two control grids, means connecting the anode to cathode path of the tube across the tank circuit thereby to provide a reactive effect across the latter, means for varying the voltage of one grid to adjust the magnitude of said effect, and means for supplementally varying the voltage of the second grid with voltage derived from the tank circuit to maintain said magnitude adjustment according to a predetermined law of variation, and both said varying means consisting of sources of direct current voltage of variable magnitude.

4. In combination with the tank circuit of an oscillator adapted to be tuned over a wide range of frequencies, a tube having at least a cathode, anode and two control grids, means connecting the anode to cathode path of the tube across the tank circuit thereby to provide a reactive effect across the latter, means for varying the voltage of one grid to adjust the magnitude of said effect, and means for supplementally varying the voltage of the second grid to maintain said magnitude adjustment according to a predetermined law of variation, said supplemental varying means comprising a rectifier coupled to said tank circuit to derive direct current voltage from oscillations, and means for applying the derived voltage to the second grid.

5. A radio receiver having manually controlled tuning means for selecting any one of a number of different carriers within a range of frequencies, electronic means actuated by any inaccuracy in the operation of said tuning means which substantially compensates therefor, and a source of voltage derived from high frequency energy, whose magnitude is dependent on the tuning means adjustment, for controlling said electronic means to maintain the ratio of said compensation to said inaccuracy uniform over said range.

6. In combination with a tunable oscillator circuit, means for tuning the circuit over a range of frequencies, an electron discharge tube having its plate to cathode impedance connected across the oscillator circuit to provide a supplemental tuning element, means for varying the gain of the tube to vary the magnitude of the said impedance, and auxiliary means, responsive to adjustment of said tuning means over said range, for varying the gain of said tube supplementally of the first means with voltage derived from said oscillator circuit.

7. In combination with a tunable oscillator circuit, means for tuning the circuit over a range of frequencies, an electron discharge tube having its plate to cathode impedance connected across the oscillator circuit to provide a supplemental tuning element, means for varying the gain of the tube to vary the magnitude of the said impedance, and auxiliary means, responsive to adjustment of said tuning means over said range, for varying the gain of said tube supplementally of the first means, said auxiliary means comprising a rectifier coupled to said oscillator circuit to derive a direct current voltage from oscillations produced in the oscillator circuit, and means for applying the derived voltage to said tube.

8. In combination with a tunable oscillator circuit, means for tuning the circuit over a range of frequencies, an electron discharge tube having its plate to cathode impedance connected across the oscillator circuit to provide a supplemental tuning element, means for varying the gain of the tube to vary the magnitude of the said impedance, and auxiliary means, responsive to adjustment of said tuning means over said range, for varying the gain of said tube supplementally of the first means with voltage derived from said oscillator circuit, said oscillator circuit including a tube, means coupling the plate circuit of the oscillation tube and an input electrode of said first tube, and said auxiliary means being connected to said input electrode to vary the voltage thereof.

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