

Aug. 22, 1939.

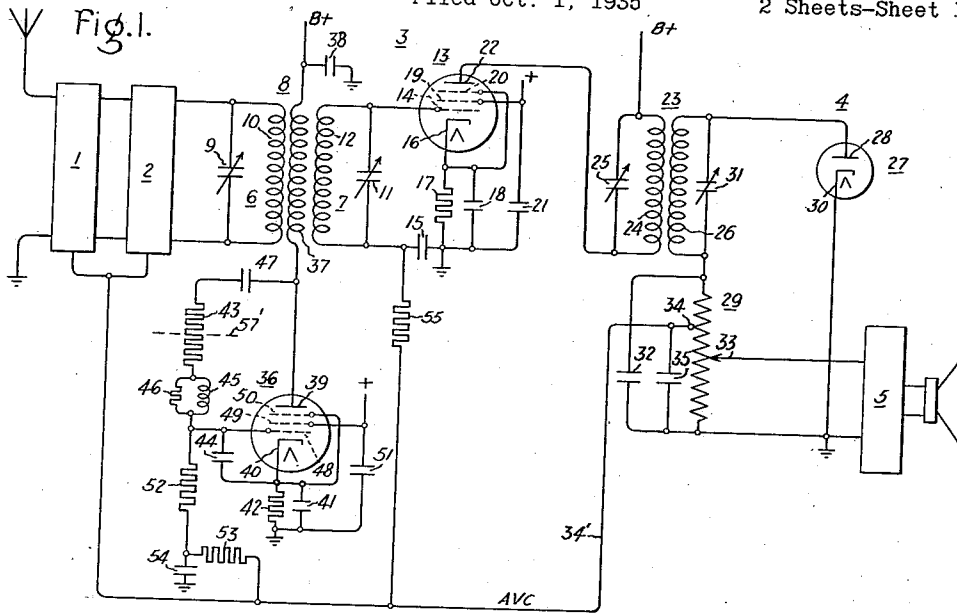
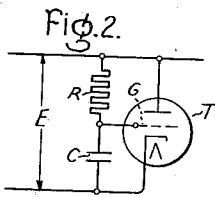
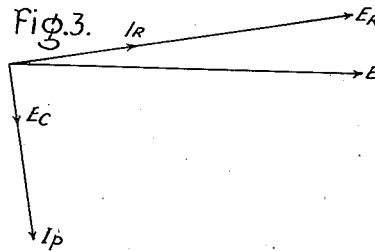
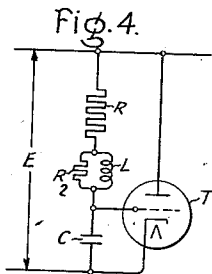
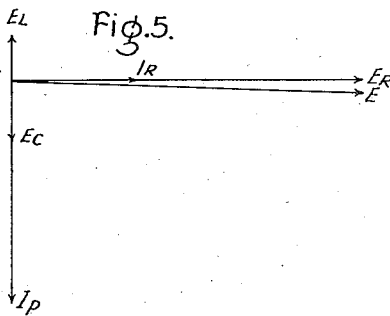
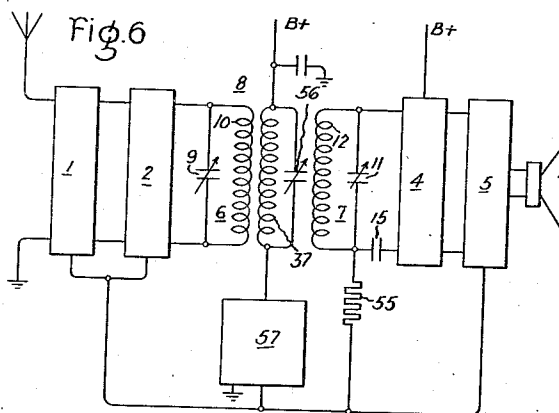
W. C. HAHN

2,170,475

AUTOMATIC FIDELITY CONTROL

Filed Oct. 1, 1935

2 Sheets-Sheet 1



Inventor:  
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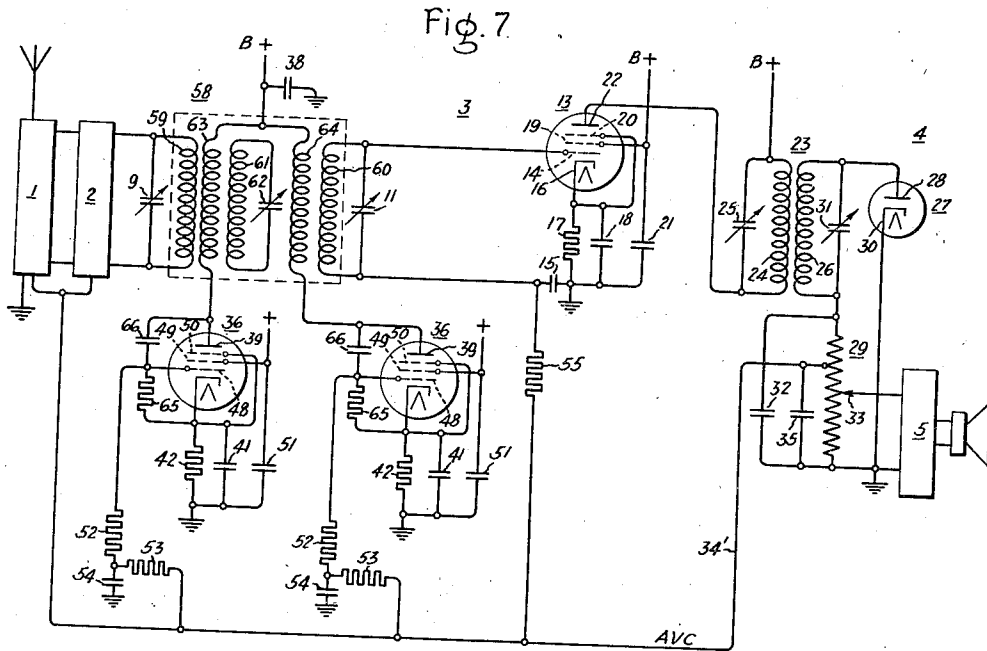
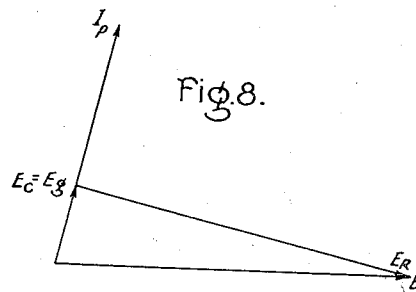
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2,170,475

AUTOMATIC FIDELITY CONTROL

Filed Oct. 1, 1935

2 Sheets-Sheet 2



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## UNITED STATES PATENT OFFICE

2,170,475

## AUTOMATIC FIDELITY CONTROL

William C. Hahn, Scotia, N. Y., assignor to General Electric Company, a corporation of New York

Application October 1, 1935, Serial No. 43,004

16 Claims. (Cl. 250—20)

My invention relates to electric circuits and more particularly to the control of coupling in electric networks.

The characteristic shape of the transmission curve of a resonant network which includes a plurality of coupled circuits depends, among other things, upon the nature and the degree of coupling. When two circuits, tuned to the same frequency, are critically coupled they form an extremely narrow band pass filter. If this filter network be part of the intermediate frequency, or radio frequency channel of a radio receiving system, the system is in its most selective condition. There are, however, certain disadvantages to a radio receiving system which has a narrow pass band characteristic, namely, the high notes of the audible range are sharply discriminated against due to the fact that side band frequency cut-off occurs at approximately 4 to 5 kilocycles from the carrier frequency.

If the pass band of the resonant network be widened as by varying the coupling so that side band cut-off occurs at approximately 8 kilocycles or more from the carrier frequency, the fidelity of the receiver (that is the degree of faithfulness of reproduction of all notes in the audible range) is greatly improved but the selectivity is reduced and the gain may be decreased. Hence, it is apparent that improvement in reception would result if the pass band of the resonant network be widened when strong signals are received and contracted when weak signals are received. One of the objects of my invention is to provide improved means for automatically effecting such widening and contraction of the pass band of the receiver.

A further object of my invention is to provide an improved means for varying the coupling of two oscillatory circuits of a resonant network.

It is a further object of my invention to provide an automatic means for varying the coupling of two oscillatory circuits in a radio receiving system in response to variations in the magnitude of the received carrier wave.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 is a diagrammatic view of an embodiment of my invention in a radio receiving system. Fig. 2 is a simple diagram illustrating the use of an electron discharge de-

vice circuit which is equivalent to a variable inductance. Fig. 3 is a vector diagram illustrating the operating characteristics of the circuit of Fig. 2. Fig. 4 is a simple diagram of an improved circuit for obtaining an equivalent value of inductance. Fig. 5 is a vector diagram illustrating the operating characteristics of the circuit shown in Fig. 4. Fig. 6 is a modification of Fig. 1 wherein a triple peak transmission curve characteristic is obtained rather than the double peak characteristic of Fig. 1. Fig. 7 is a different modification wherein an equivalent capacity network is used in the place of an equivalent inductance network and wherein a five-coil coupling transformer is used in the place of a three-coil transformer. Fig. 8 is a vector diagram illustrating the operating characteristics of the phase shifting network used in the modification shown in Fig. 7 for obtaining an equivalent value of capacity.

Referring to Fig. 1 of the drawings, I have illustrated therein a radio receiver constructed in accordance with my invention, and which includes a stage of radio frequency amplification 1, a first detector and oscillator stage 2, an intermediate frequency amplifier stage 3, a second detector stage 4, and an audio frequency amplifier stage 5.

In the modification illustrated in Fig. 1, a method for adjusting the coupling of two oscillatory circuits 6 and 7 which are tuned to the intermediate frequency and which are coupled by a three-coil intermediate frequency transformer 8 are shown. Circuit 6 includes a condenser 9 and the primary winding 10 of the transformer 8, and is directly connected to the first detector and oscillator stage. Circuit 7 includes a condenser 11 and the secondary winding 12 of the transformer 8. The high voltage side of the circuit 7 is connected to the control grid 14 of the intermediate frequency amplifier 13. The low voltage side of circuit 7 is connected through a by-pass condenser 15 to ground. The cathode 16 of the electron discharge device 13 is provided with a self-biasing resistor 17 and a by-pass condenser 18 to maintain the cathode at the desired potential. The screen grid 19 and the suppressor grid 20 are connected to the circuit in the conventional manner, the screen grid 19 being given a suitable positive bias and connected to ground 50 through a by-pass condenser 21, while the suppressor grid 20 is directly connected to the cathode 16. The anode 22 of electron discharge device 13 is connected to one side of the primary winding 24 of the coupling transformer 23. A

condenser 25 is connected across the primary winding 24 in the conventional manner. The opposite side of the primary winding is connected to the high voltage source (indicated as B+).

The high voltage side of the secondary winding 26 is connected to the anode 28 of the diode 27 while the low voltage side of secondary winding 26 is connected through a potentiometer 29 to the cathode 30 of diode 27. A condenser 31 is connected across the secondary winding 26 in the conventional manner. A by-pass condenser 32 is connected across potentiometer 29. One side of the audio frequency amplifier stage 5 is connected to the cathode 30 of diode 27 while the other side of audio frequency stage 5 is connected through a movable contact 33 to the potentiometer 29, the output volume of the receiving system being determined by the position of contact 33.

Automatic volume control is provided by tapping the potentiometer 29 at a point 34 and connecting this point to the electron discharge devices in the radio and intermediate frequency amplifier and first detector stages in the conventional manner. A by-pass condenser 35 is connected between point 34 on potentiometer 29 and the cathode of tube 27.

In order to vary the effective coupling of circuits 6 and 7, advantage is taken of the fact that if a third coil be introduced between the primary and secondary of an over-coupled coupling transformer and impedance be shunted across the third coil, the third coil will act as a magnetic shield, between the other two coils and the effective coupling of the primary and secondary will be decreased. That is to say, when inductance, capacitance or resistance is placed across the third coil, current will be induced therein and a magnetic field will be set up which opposes the flux due to the primary. Because of these opposing fluxes, there will be fewer magnetic interlinkages between the primary and the secondary and hence the effective coupling is decreased. The maximum shielding effect occurs when there is a direct short circuit placed across the third coil for then the flux induced in the third coil is equal and opposite to that set up by the primary. At some intermediate point of shielding, a condition of critical coupling will exist between the primary and secondary. It will thus be seen that as the current induced in the third coil is decreased by increasing the shunt impedance, the shielding effect becomes less and less, and a condition of overcoupling follows due to the mechanical spacing of the primary and secondary. I have found through experience that the use of inductance or capacitance is preferable, since the use of resistance introduces substantial losses.

To eliminate the necessity of using moving parts to cause a change in the effective coupling of circuits 6 and 7, the cathode anode circuit of an electron discharge device is connected across the tertiary coil of the coupling transformer and the current flowing through the electron discharge device is caused to lag or lead the applied voltage by substantially 90° depending upon whether an equivalent inductance or capacitance is required. By varying the negative bias on the control grid, the mutual conductance of the electron discharge device will be varied and correspondingly the amount of lagging or leading current passing through the device will be varied. Since the equivalent value of inductance or capacitance which is placed across the tertiary coil

of the coupling transformer is a function of the lagging or leading current which flows through the electron discharge device, it is obvious that the degree of coupling of circuits 6 and 7 may be controlled by varying the negative bias on the control grid of the electron discharge device. If the control grid be connected to the automatic volume control circuit, the value of negative grid bias will be proportional to the magnitude of the mean signal carrier amplitude.

In accordance with the foregoing principles I connect the electron discharge device 36 across the tertiary coil 37 of the coupling transformer 8. This is done by connecting the side of coil 37 which is connected to the high voltage source (indicated as B+) through a by-pass condenser 38 to ground, and by connecting the other side of coil 37 to the anode 39 of electron discharge device 36. The circuit is completed through the cathode 40 of electron discharge device 36 and a by-pass condenser 41 to ground. Cathode 40 is also provided with a self-biasing resistor 42 which is connected in parallel with condenser 41 in the conventional manner.

The plate current of electron discharge device 36 may be caused to lag approximately 90° with respect to the applied voltage by connecting the resistor 43 and a series condenser 44 between the anode 39 and the cathode 40 and by connecting the control grid between resistor 43 and the condenser 44.

This circuit in its simplest form is shown in Fig. 2 and a vector diagram illustrating the underlying principles of the circuit is shown in Fig. 3. The applied voltage across the tube T of Fig. 2 may be represented by a vector E of Fig. 3. The current flowing through resistor R of Fig. 2 slightly leads the applied voltage, as indicated by vector  $I_R$ , due to the influence of condenser C. The voltage across condenser C may be represented by a vector  $E_C$ . The voltage  $E_G$  is also the voltage on the grid G. Since the plate current flowing through the electron discharge device leading from the source of plate voltage towards the anode is always in phase with the grid voltage, the plate current  $I_P$  may be represented by a vector in phase with  $E_G$ . Since the current passing through the tube lags with respect to the applied voltage by approximately 90°, the circuit is equivalent to an inductance placed across the line. Variations in the negative bias on the control grid merely change the length of the current vector  $I_P$ . Hence as  $I_P$  becomes smaller the equivalent value of inductance increases.

The vector diagram of Fig. 3 indicates that losses are introduced due to the fact that the current vector  $I_P$  does not lag with respect to the applied voltage by exactly 90°. Since minimum losses occur when the load is all reactive and there is no in-phase current being drawn, it is desirable that the current through the electron discharge device be as close to 90° out of phase with the applied voltage as possible. The losses involved in the simple circuit shown in Fig. 2 may be reduced by employing the arrangement of Fig. 4 in which inductance L is added in series with resistor R to counterbalance the capacitive effect of condenser C. A further improvement is obtained by adding a resistor  $R_2$  in parallel with inductance L, the resistance of which is small with respect to the reactance of the inductance L. Without the addition of resistor  $R_2$  the reactance of inductance L will more than counterbalance the reactance of condenser

C at high frequencies since reactance of an inductance coil increases with increased frequency and the reactance of a condenser decreases with increased frequency.

The vector diagram of Fig. 5 illustrates the operating characteristics of the circuit shown in Fig. 4. It will be seen that due to the addition of inductive reactance that the current through the electron discharge device is now nearer 90° out of phase with the applied voltage than it was without the addition of the inductance L. It should be noted that the total impedance of the R—L—C path should be large with respect to the impedance of the path through the electron discharge device since the R—L—C path is merely the control circuit for the other.

Hence in the embodiment of my invention illustrated in Fig. 1, the parallel combination of inductance 45 and resistor 46 is added in series with resistor 43. A blocking condenser 47 between the anode 39 and resistor 43 is also employed to prevent the unidirectional voltage of the high voltage source from reaching the control grid 48 of the electron discharge device 36.

The screen grid 49 and the suppressor grid 50 are connected in the conventional manner, the screen grid being given a suitable positive bias and connected to ground through the by-pass condenser 51, and the suppressor grid being connected directly to cathode 40.

The control grid 48 is also connected through a grid leak 52 and a filter resistor 53 to the AVC circuit. The grid leak side of filter resistor 53 is grounded through a by-pass condenser 54. Resistor 53 and condenser 54 act as a filter to prevent feed back from the main circuit.

Secondary coil 12 of coupling transformer 8 is also connected to the AVC circuit through a filter resistor 55. Resistor 55 and condenser 15 act as a filter to prevent feed back from the main circuit.

The operation of the system is as follows: A high frequency signal is picked up and amplified in the radio frequency amplifier stage 1 and is then passed through the first detector stage 2 to the intermediate frequency coupling transformer 8. The signal as it is impressed on the primary coil 10 of the transformer 8 is at some intermediate frequency value such as 175 kc. The coupled oscillatory circuits 6 and 7 are adjusted to resonate at the intermediate frequency by condensers 9 and 11, respectively and, of course, pass currents of this frequency to amplifier 13. The signal is amplified in the intermediate frequency stage by the amplifier 13 and is then transmitted to the second detector 27 through the coupling transformer 23. Audio frequency is taken from the second detector stage, amplified in the audio stage 5 and is finally emitted as a sound wave from the loud-speaker. The desired audio volume may be obtained by adjusting the movable contact 33 on the potentiometer 29. The automatic volume control means operates in the customary manner.

Now upon receipt of a signal, as determined by the magnitude of the unidirectional voltage in the AVC circuit, electron discharge device 36 by reason of the increased negative voltage applied to its grid 48, in effect, adds inductance across the tertiary coil 37 of the coupling transformer 8. This causes an expansion in the width of the pass band of the resonant network and may also cause some decrease in the gain through the circuit. Since the width of the pass band is a function of the equivalent value of inductance

which is shunted across the tertiary coil of the coupling transformer, automatic fidelity control, as a function of the magnitude of the received carrier wave, is obtained.

The circuit of Fig. 1 may be improved by placing a variable condenser across the tertiary coil 37 of coupling transformer 8 as is illustrated at 56 in Fig. 6. The circuit comprising coil 37 and condenser 56 is tuned to the intermediate frequency. The effect of tuning the tertiary coil of the coupling transformer is to give a triple peak transmission resonant curve in its expanded condition rather than the characteristic double peak curve where the tertiary coil is not tuned. Because the triple peak gives a flatter top transmission resonant characteristic curve, this modification approaches nearer to the ideal rectangular form. The remaining portions of the circuit diagrammatically shown in Fig. 6 are similar to the portions of Fig. 1, the equivalent inductance circuit, however, being generally indicated as 57.

Some further improvement may be obtained by inserting resistor 43 through an opening in an electrostatic shield 57', such as a sheet of metal, so as substantially to prevent end to end capacity of resistor 43 from affecting its associated circuit.

In Fig. 7 I have illustrated a different modification of my invention wherein an electron discharge device is shunted across one coil of a multi-coil coupling transformer and wherein the current through the electron discharge device is caused to lead with respect to the applied voltage approximately 90°. Portions of the circuit which are similar to like portions in Fig. 1 have been given the same reference numerals and the functions of such portions will not be further discussed. In this modification a five-coil coupling transformer 58, three-coils of which are tuned and two coils of which are not tuned, is substituted in the place of the three-coil coupling transformer 8 of Fig. 1. The primary and secondary windings 59 and 60 are tuned to the intermediate frequency by condensers 9 and 11 and a third winding 61 of the transformer 58 is tuned to the intermediate frequency by condenser 62. Fourth and fifth windings 63 and 64 may or may not be tuned to the intermediate frequency depending upon whether a five hump or a three hump transmission resonant curve is desired. It will be understood that the number of humps which appear in the characteristic transmission resonant curve when windings 59 and 60 are in an overcoupled position depends upon the number of coils which are tuned to the intermediate frequency. As illustrated in Fig. 7 a three-hump characteristic curve will be obtained since three of the five coils of the coupling transformer 58 are tuned to the intermediate frequency.

Since coils 63 and 64 are not at the same potential, it is necessary to have two separate equivalent networks to cause the current flowing through each coil to lag or lead with respect to the applied voltage. Where it is desired to place an equivalent value of capacitance across the intermediate windings of the coupling transformer in order to bring about a change in the effective coupling, it is only necessary to reverse resistance 43 and condenser 44 of Fig. 1. Thus in Fig. 7 a resistor 65 has been substituted in the place of the condenser 44 of Fig. 1 in each phase shifting network and a condenser 66 has been substituted in each network in the place of resistor 43 of Fig. 1. Due to the position of condenser 66 in each circuit an additional blocking condenser is no longer necessary to prevent uni-

directional voltage from the high voltage source from affecting the control grids 48 of the electron discharge device 36. The remaining portion of each phase shifting network of Fig. 7 is equivalent to the corresponding portion of Fig. 1.

The nature of an equivalent capacitance network may be more readily understood by referring to the vector diagram in Fig. 8. Due to the position of condenser 66 with respect to the control grid 38, the control grid voltage will lead the applied voltage by approximately 90°. In the vector diagram the applied voltage is represented by the vector E and the voltage on the grid is indicated by the vector  $E_g$ . As previously pointed out the plate current of any electron discharge device is in phase with the voltage on the control grid and hence the current in this case will lead with respect to the applied voltage by approximately 90°. As is the case in the equivalent inductance network, the length of the current vector  $I_p$  depends upon the inductance of the electron discharge device and secondly the magnitude of the plate current is an inverse function of the unidirectional negative bias placed upon the control grid through the AVC circuit 34'.

The operation of the radio receiving system shown in Fig. 7 is similar to that of the system shown in Fig. 1 with the exception that capacitive reactance is shunted across two of the three intermediate coils of the coupling transformer 58 instead of inductive reactance being shunted across a single intermediate coil as shown in Fig. 1.

While in accordance with the principles of my invention the coupling of any pair of oscillatory circuits of the resonant network may be varied to effect an expansion of the pass band of the network, I prefer to vary the coupling of one or more of the intermediate frequency coupling transformers. Further it will be obvious that resistance may be shunted across the intermediate coil or coils of a coupling transformer to cause a change in the effective coupling by merely omitting condensers 66 and resistors 65. This will cause a current to flow through the intermediate coils which is in phase with the applied voltage.

While I have shown particular embodiments of my invention, it will of course be understood that I do not wish to be limited thereto since many modifications may be made both in the circuit arrangement and in the instrumentalities employed, and that I therefore contemplate by the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A radio receiving system having a resonant network, means comprising an air core transformer for providing said network with a multi-peak pass band characteristic, and means, all of whose component parts are stationary relative to each other, operative to modify the relative amounts of flux interlinking the windings of said transformer for expanding said pass band in response to variations in intensity of the received carrier wave.

2. A radio receiving system having a resonant network including at least one multi-coil coupling transformer, different portions of said network being coupled by two of said coils, means for adding inductance in parallel to a third coil of said transformer, and means responsive to variations in intensity of the received carrier wave for controlling the value of said inductance.

3. A radio receiving system having a resonant network including at least one air core coupling transformer, means for impressing a signal on said resonant network, means for deriving from said signal a direct current component proportional in magnitude to the amplitude of the received carrier wave, and means all of whose component parts are stationary relative to each other and including an electron discharge device operable in response to said direct current component for varying the coupling between the primary and secondary windings of said transformer.

4. A radio receiving system having a resonant network including at least one three-coil coupling transformer, means for tuning each coil to the desired frequency, an electron discharge device having an anode, cathode and a control grid connected across one of said coils, a series connected resistor and condenser connected between said anode and said cathode, means connecting said grid between said resistor and said condenser, and means for varying the bias on said grid.

5. In combination, a three-winding transformer, and means all of whose component parts are stationary with respect to each other for effectively varying the reactance across one winding of said transformer thereby to vary the coupling between the other two windings of said transformer.

6. A radio receiving system having a resonant network including a multi-coil coupling transformer, different portions of said network being coupled by two of said coils, means for adding reactance in parallel to a third coil of said transformer, and means responsive to variations in the magnitude of the mean signal carrier amplitude for controlling the value of said reactance.

7. A radio receiving system having a resonant network including a multi-coil coupling transformer, different portions of said network being coupled by two of said coils, means for tuning said two coils and a third coil of said transformer to the desired frequency, means for adding reactance in parallel to at least one additional coil of said transformer, and means responsive to variations in the magnitude of the mean signal carrier amplitude for controlling the value of said reactance.

8. A radio receiving system having a resonant network including a five-coil coupling transformer, different portions of said network being coupled by two of said coils, electron discharge devices connected in parallel to a third and fourth coil of said transformer, and means for shifting the phase of the plate current flowing through said electron discharge devices approximately 90° with respect to the applied voltage.

9. An equivalent inductance network comprising a thermionic tube having an anode, a cathode and a control grid, a resistor, an inductance and a capacitor connected in series between said anode and said cathode, a second resistor connected in parallel with said inductance, and means for connecting said grid between said inductance and said capacitor.

10. An equivalent inductance network comprising a thermionic tube having an anode, a cathode and a control grid, a resistor and a capacitor connected in series between said anode and said cathode, means connecting said grid between said resistor and said capacitor, and a shielding means secured about said resistor for

substantially preventing end to end capacity in said resistor from affecting said network.

11. A radio receiving system comprising a plurality of cascaded amplifiers and couplings between adjacent amplifiers, one of said couplings comprising a magnetic coupling device, having an air core, a rectifier, means for impressing signal frequency energy upon said rectifier, and means, all of whose component parts are stationary relative to each other, responsive to variations in potential of the rectified output of said rectifier for varying the mutual inductance of said device.

12. In a radio receiving system, a resonant network including an air core coupling transformer and apparatus responsive to an increase in the strength of the signal received by said system for increasing the fidelity of the system, said apparatus comprising means all of whose component parts are stationary relative to each other for causing an increase in the coupling between the primary and secondary windings of said transformer with an increase in the signal strength.

13. In a radio receiving system, a resonant network including an air core coupling transformer and apparatus responsive to a decrease in the strength of the signal received by the system for decreasing the width of the band of frequencies passed by the transformer, said apparatus comprising means all of whose com-

ponent parts are stationary relative to each other for causing a decrease in the coupling between the primary and secondary windings of said transformer with a decrease in signal strength.

14. An equivalent inductance network comprising a thermionic tube having an anode, a cathode and a control grid, a control circuit connected between said anode and cathode and including a resistor, an inductance and a condenser arranged in series, a second resistor arranged in shunt with said inductance and means connecting said grid with said circuit at a point thereof between the inductance and the condenser whereby the condenser is included in the grid-cathode circuit of the tube.

15. In combination, a plurality of coupled circuits having coupling windings provided with an air core, means for transmitting oscillations through said circuits and means, all of whose component parts are stationary relative to each other, responsive to the intensity of the oscillations for controlling the mutual inductance of said windings.

16. In combination, a plurality of tuned circuits, an air core coupling transformer between said circuits and means all of whose component parts are stationary relative to each other for varying the mutual inductance of said transformer.

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