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2,286,378

FREQUENCY MODULATED WAVE DETECTOR

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Fig. 1.

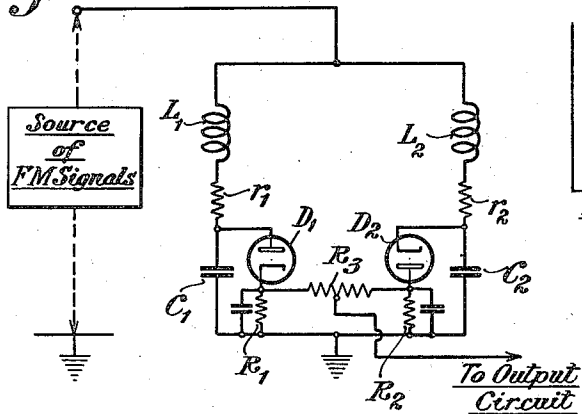


Fig. 2.

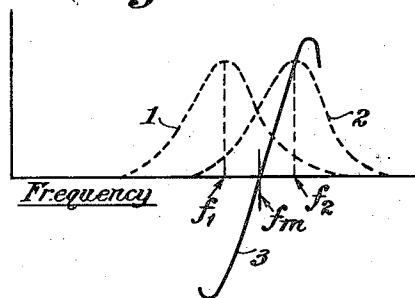


Fig. 3.

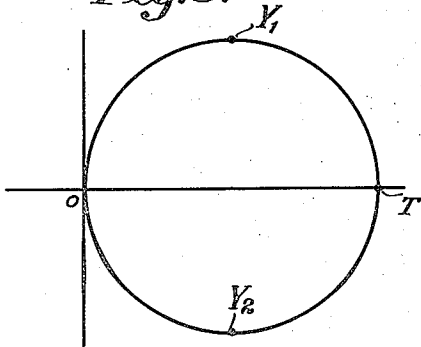


Fig. 4.

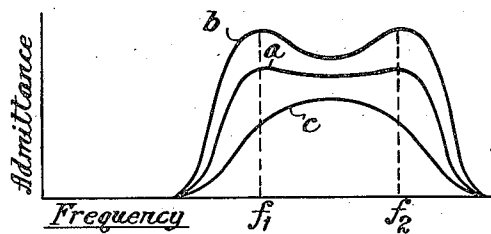
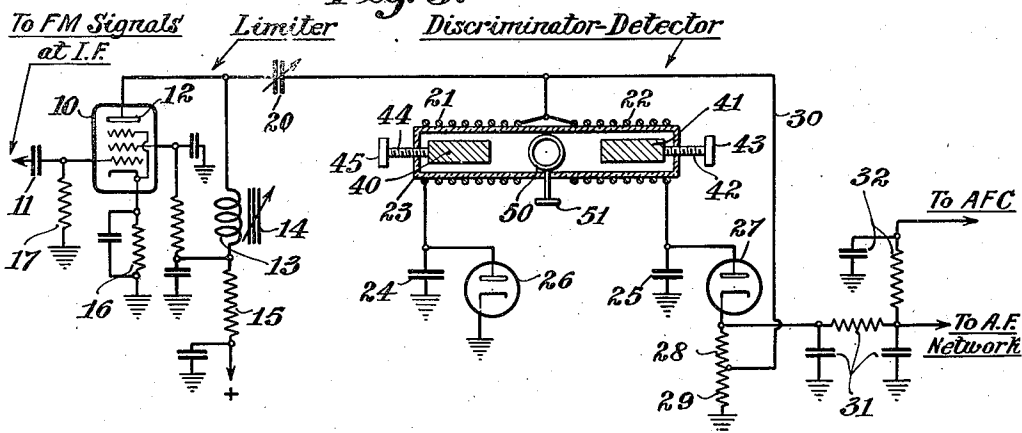


Fig. 5.



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FREQUENCY MODULATED WAVE
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11 Claims. (Cl. 250—27)

My present invention relates to frequency modulated wave (FM) detectors, and more particularly to novel and improved FM detectors of the balanced type.

The main object of the present invention is to provide an FM detector operating on the principle of balanced detectors each actuated solely by the voltage developed in one of a pair of circuits which are tuned respectively above and below the mean frequency of the applied FM signal, and, in particular, to provide a circuit of the above nature which is suitable for quantity manufacture and readily adjusted by a serviceman.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows a circuit diagram of an FM detector constructed in accordance with the invention.

Fig. 2 illustrates the detection characteristic of the FM detector of Fig. 1.

Fig. 3 is a graphic analysis of the detection circuit.

Fig. 4 shows various response characteristics of the detector circuit.

Fig. 5 is a circuit diagram of a preferred detector embodiment.

Referring now to the accompanying drawing, the invention will be explained in connection with the simplified circuit of Fig. 1. Here the detectors D_1 and D_2 , which may be diodes, are shunted in reversed relation across the condensers C_1 and C_2 respectively of the series tuned branches L_1-C_1 and L_2-C_2 . The FM signals, after conversion to a suitable intermediate frequency, are shown applied between the junction of L_1-L_2 and ground. The low potential terminals of C_1 and C_2 are at ground potential, while the properly by-passed resistors R_1 and R_2 are connected between the diodes D_1 and D_2 respectively and ground. Resistors R_1 and R_2 are the detector load resistors. The detected output voltage is tapped off from a resistor R_3 which connects the ungrounded ends of the resistors R_1 and R_2 . The symbols r_1 and r_2 represent the series resistances of the respective series resonant circuits.

The principle of operation may be explained in part by reference to Fig. 1 which shows the two series resonant circuits equally detuned one above and the other below the main frequency of the applied FM signal. A separate detector is energized by the voltage across the condenser in each circuit, although it is also possible to energize the detectors from the voltage developed across the inductive portion of each circuit. When a constant voltage of varying frequency is applied to the parallel combination of series tuned circuits of Fig. 1, the voltage across the detector in either circuit will vary with frequency, and will have a maximum value which is approximately Q times the applied voltage. The symbol Q is the ratio of coil reactance to coil resistance at the resonant frequency of the circuit.

Curve 1 of Fig. 2 shows how the voltage on detector D_1 varies with frequency, while curve 2 shows the corresponding variation of detector voltage in the case of detector D_2 . The symbol f_1 is the resonant frequency of the branch L_1-C_1 , while f_2 is the resonant frequency of the branch L_2-C_2 . The symbol f_m is the mean, or center, frequency of the applied FM signals. Curve 3 represents the difference between the magnitudes of the detector output voltages, or, in other words, the variation of direct current output from the detection system plotted against frequency. The foregoing analysis was based on the simplifying assumption of a source of constant voltage signals, whereas no practical vacuum tube acts as a constant voltage source. In accordance with my present invention, however, a vacuum tube amplifier adapted to supply more nearly constant current than constant voltage may be utilized, nevertheless, to maintain a substantially constant voltage across the network of Fig. 1. This will now be explained by reference to Fig. 3.

In Fig. 3 the circle represents the locus of the admittance of a series combination of inductance, resistance, and capacity plotted in the complex plane as frequency varies from the zero to infinity. As frequency increases, starting from zero, the point representing the admittance of the series circuit starts from the origin O , and travels clockwise around the circle. Point T represents its value at the resonant frequency, and is a pure conductance equal to the reciprocal of the series resistance of the circuit. As the frequency rises still further the point continues clockwise back to the origin. The point at the top of the circle is the admittance when the

frequency is just enough lower than the resonant frequency so that the circuit reactance is equal to its resistance. The point at the bottom of the circle is the admittance when the frequency is just enough higher than the resonant frequency so that the reactance is again equal to the resistance. If the resistances of the two circuits of Fig. 1 are equal the admittances of these circuits are both representable by the same circle, and the only difference is that due to one of the circuits being tuned above the mean frequency of the signal and the other one below the mean frequency. The two points representing respectively the admittances of the two circuits, will thus be, at any given frequency, at different positions on the circle.

To simplify the discussion let it be assumed that at the mean signal frequency the admittance of one circuit is represented by Y_1 , and that of the second circuit by Y_2 . The total admittance of the two circuits in parallel is, therefore, the vector sum of the admittances represented by points Y_1 and Y_2 . When these points are located as shown, their sum is obviously equal to the conductance represented by point T. If, now, the signal frequency increases until the first circuit is resonant, then point Y_1 moves clockwise on the circle to position T. Coincidentally, point Y_2 moves clockwise toward the origin, and comes to a position which represents a relatively small admittance which is, furthermore, preponderantly a susceptance. Hence, when this small admittance is added vectorially to the relatively large conductive admittance represented by point T, the resultant is very little greater in magnitude than the conductance of the first circuit alone. Similarly, if the frequency is lowered toward the resonant frequency of the second circuit, points Y_1 and Y_2 move counter-clockwise with similar results as far as the total admittance of the circuit is concerned.

Thus, the total admittance of the circuit varies with frequency approximately as shown in curve *a* of Fig. 4. This curve is substantially constant in value over the range of frequencies between the resonant frequencies of the two circuits. If, however, the Q of the circuits had been so related to the difference between their resonant frequencies that at the mid-frequency the points Y_1 and Y_2 had each fallen considerably nearer the origin, then the plot of admittance against frequency would have had a pronounced double hump as shown in curve *b* of Fig. 4. This represents the case where the Q of the circuit is chosen too large for the desired difference between the two resonant frequencies. On the other hand, if the Q is chosen so small that at the mid-frequency the points Y_1 and Y_2 each lie considerably closer to point T than shown in Fig. 3, then the admittance characteristic has no humps, but is as shown in curve *c* of Fig. 4. It is not desirable to use too high a Q value, because, as will be evident later, a fairly constant admittance over the operating range of frequencies is required. Nor yet too low a value should be used as the latter impairs the steepness and shape of the resultant curve 3 of Fig. 2. The optimum Q value of the circuits is, therefore, in the vicinity of that value which will make the resistance of the circuit equal to its reactance at the mean frequency.

This condition may be written: $r = 4\pi f_a L$, where f_a is the difference between the mean frequency and the resonant frequency of the circuit.

Hence, if we left f_m be the mean frequency, we have

$$Q = \frac{2\pi f_m L}{r} = \left(\frac{4\pi f_a L}{r} \right) \left(\frac{f_m}{2f_a} \right) = \frac{f_m}{2f_a}$$

approximately, since $4\pi f_a L$ has been assumed equal to r . Since $2f_a$ is approximately the maximum range of frequencies that can be accommodated by the useful part of curve 3 of Fig. 2, and since this range is about equal to the nominal width of the FM "channel," the optimum value of the Q of the coils of Fig. 1 is roughly equal to the ratio of mean frequency to channel width. Thus, in case frequency modulation employing a 200 kilocycle (kc.) channel is used, and assuming a mean frequency of 13 mc., for example, the Q value should, therefore, be of the order of 65. It has been shown that a suitable choice of the Q of the circuits of Fig. 1 will result in a substantially constant impedance for the parallel combination of these circuits. Thus, a constant current supplied to this combination will result in a substantially constant voltage so that the operation of the circuits will be as explained and illustrated by Fig. 2.

The amount of current available from an amplifier tube being relatively small, it is a further object of this invention to provide a current transforming network for greatly multiplying the current delivered by the amplifier tube. This is shown more specifically in Fig. 5, wherein the amplifier tube 10 may function also as a limiter. The tube 10 may have its input grid connected by a coupling condenser 11 to any desired source of FM signals. Specifically, and merely for the purpose of illustration, it is assumed that the signal source is the usual intermediate frequency (I. F.) amplifier network of a superheterodyne receiver. Those skilled in the art are sufficiently well acquainted with the construction of FM receivers of the superheterodyne type so as to make it unnecessary to describe in detail the networks which precede the limiter tube.

As is well known, the function of the limiter tube is to eliminate any amplitude variation in the FM carrier. Such amplitude variation, or more specifically amplitude modulation effects, arise by virtue of fading, noise and the like. The constants of the limiter tube are so chosen that there is delivered to the detector network a carrier wave at I. F. which is purely frequency modulated. The plate 12 of the limiter tube is connected to a source of positive potential through a coil 13 provided with an adjustable iron core 14. The resistor 15 is arranged in series with the coil 13. The cathode of the limiter tube is connected to ground through a properly by-passed self-biasing resistor 16, while the input grid of the tube is grounded through the grid leak 17. To secure limiting action the voltages applied to the plate and screen grid of tube 10, and the time constant of 11-17, are so chosen that the tube has a horizontal characteristic relating signal input and signal output voltages above a predetermined value of signal input voltage.

The plate end of coil 13 is connected by coupling condenser 20 to the junction of discriminator coils 21 and 22, each of the coils 21 and 22 being wound co-axially on an insulation form 23. Coil 21 is connected to ground through the series condenser 24, whereas coil 22 is connected to ground through the series condenser 25. The diode 26 is connected in shunt across condenser 24, whereas the diode 27 has its anode connected to the junction of coil 22 and condenser 25. The

cathode of diode 27 is connected to ground through the resistor sections 28 and 29. It is pointed out that resistor 29 functions as the load resistor of rectifier 26, whereas resistor 28 is the load resistor of rectifier 27. These load resistors are arranged in polarity opposition, and the junction of the two resistors is connected by lead 30 to the junction of coils 21 and 22.

Audio frequency voltage is taken off from the cathode end of resistor 28, and this voltage is passed through a filter network 31 prior to utilization in any desired type of audio frequency amplifier circuit. Of course, the audio frequency voltage corresponds to the frequency deviations imposed on the carrier at the transmitter, the amplitude of the audio frequency voltage corresponding to the frequency deviation of the carrier, whereas the frequency of the audio voltage corresponds to the rate of change of the frequency deviation. Automatic frequency control voltage (AFC) may be taken off from the output end of filter 31, a further filter 32 being employed to eliminate the audio pulsations in the voltage. As known to those skilled in the art the AFC voltage may be used to control a frequency control tube which is operatively associated with the local oscillator tank circuit in the manner of an electronic reactance. The AFC network functions to adjust the tank circuit frequency in a sense such that the predetermined I. F. value will be maintained.

To provide relatively simple servicing in a receiver embodying the system shown in Fig. 5, there are provided the pair of iron plugs 40 and 41 within the interior of the insulation form 23. These plugs are arranged in alignment, and are coaxial. Thus, plug 41 has a threaded adjusting stem 42 terminating in an external adjusting head 43. Similarly, the plug 40 may have a threaded stem 44 terminating in an adjusting head 45. Of course, appropriate walls are provided at the opposite ends of the form 23 so as to provide bearings for the threaded stems 42 and 44. Condensers 24 and 25 are chosen so as to tune the respective series resonant circuits correctly with the iron plugs at positions near the middle of their effective range of adjustment. That is, with the plug 40 adjusted to occupy a position about half way into coil 21, the series resonant circuit 21—24 is tuned to a frequency f_1 on one side of the mean frequency (f_m). On the other hand when the plug 41 is similarly adjusted, the series resonant circuit 22—25 is tuned to a frequency f_2 on the opposite side of the mean frequency. There is located a shorting ring, or vane, 50 within the form 23, and the ring is located midway between the ends of plugs 40 and 41. A manipulating knob 51 may be provided on the outside of the form 23 so as to adjust the position of ring 50. The ring 50 is set to about half its maximum effectiveness, when the plugs 40 and 41 are individually adjusted to tune the respective series resonant branches to their predetermined frequency as above described.

Thereafter, for alignment, only ring 50 need be adjusted as it adjusts both series resonant frequencies simultaneously while leaving the difference, or mean, frequency between them substantially unaltered. This is of considerable importance in the servicing of the discriminator network, since it saves a plurality of aligning adjustments. At the factory the plugs 40 and 41 and the initial position of ring 50 would be adjusted so as to produce the correct spaced fre-

quencies f_1 and f_2 . The mere fact that the serviceman need only manipulate knob 51 for future adjustments provides an important feature of this invention. In place of the ring 50 there may be used a thin powdered iron disk, as its effect would vary with angular setting. Also, if a slot be cut in the form between the coils an iron wedge could be inserted in such slot for the same purpose.

The impedance matching network between the limiter tube and the discriminator has the further advantage that the inductance element 13 acts as a direct current supply path for the plate circuit of the tube. The capacity element 20 acts as a direct current blocking condenser to keep the high voltage of the plate supply away from the detecting system. The values of inductance and capacity required for the network 13—20 depend upon the impedance of the tuned circuit network, and the latter in turn depends upon the series resistances of these circuits. The coil 13 and condenser 20 cooperate to provide a current step-up transformer. This transformer is also part of the impedance matching network between the tube 10 and the discriminator network.

For any particular constants chosen for the tuned circuits, and for any given tube, the required constants L and C for elements 13 and 20 of the network of Fig. 5 may be calculated from the following formulae:

$$L_{13} = \frac{1}{2\pi f_m} \left(\frac{\sqrt{R_1 R_2}}{\sqrt{1 - R_2/R_1}} \right) \quad (1)$$

$$C_{20} = \frac{1}{2\pi f_m} \frac{1}{\sqrt{R_1 R_2}} \frac{1}{\sqrt{1 - R_2/R_1}} \quad (2)$$

In the above formulae R_1 represents the plate resistance of the limiter tube; R_2 designates the mid-frequency resistance of the circuit of Fig. 1; while f_m is the mid-frequency. The core 14 is adjusted to satisfy the above equations. This is also true for condenser 20. The circuit 13—20 operates by resonance to match the high impedance tube 10 to the low resistance load of the detector circuit. Since the coils 21 and 22 in Fig. 5 are wound on the same form 23 there is mutual inductance between the coils. A more involved analysis indicates that the behavior of the system is generally the same as described, and that the value of the Q of the whole coil assembly should be in the vicinity of one to two times the ratio

$$\frac{IF}{\text{Channel width}}$$

The coil 13 and condenser 20 provide a current step-up transformer. By properly choosing the constants of 13—20 any given small load resistance can be transformed to a higher input resistance between input terminals. At the same time the load current is found to be greater than the input current. The greater the impedance change, the greater will be the current step-up. In Fig. 5 the input impedance is the high impedance of tube 10, while the output impedance is the low resistance of the discriminator-rectifier network. Hence, the current flow through the load of 13—20 is greater than the current flow through the high input impedance.

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. The generic term "angular velocity-modulated carrier wave" in the claims is to be understood as designating a frequency modulated, or phase modulated, carrier wave.

What I claim is:

1. In combination with a source of frequency modulated carrier waves, a transmission tube having its input electrodes coupled to said source, a detection network comprising a pair of series resonant circuits arranged in parallel, each of said resonant circuits being tuned to a frequency spaced from the center frequency of the carrier waves in opposite directions, and an impedance matching network coupling the output electrodes of said tube to the junction of said pair of resonant circuits and said matching network comprising an inductance in shunt across the said output electrodes and a condenser in series with said inductance.

2. In combination with a source of frequency modulated carrier waves, a transmission tube having its input electrodes coupled to said source, a detection network comprising a pair of series resonant circuits arranged in parallel, each of said resonant circuits being tuned to a frequency spaced from the center frequency of the carrier waves in opposite directions, and an impedance matching network coupling the output electrodes of said tube to the junction of said pair of resonant circuits, said matching network comprising a current step-up transformer.

3. In combination, a pair of series resonant circuits arranged in parallel across a source of angular velocity-modulated carrier waves, said resonant circuits being tuned to frequencies differing from a mid-frequency value by the same frequency amount and on opposite sides thereof, a rectifier operatively associated with each resonant circuit, means for combining the rectifier outputs in polarity opposition, said source of carrier waves consisting of an amplifier tube, and a current step-up transformer coupling said tube to the junction of said resonant circuits.

4. In combination, a pair of series resonant circuits, each resonant circuit consisting of a pair of reactances of opposite sign, a source of angular velocity-modulated carrier waves, said resonant circuits being oppositely mistuned to frequencies differing from a given frequency value by the same frequency amount, said circuits being connected to said source, a separate detector of the diode type connected across solely one reactance of each resonant circuit, said one reactance of each resonant circuit consisting of solely a condenser, and means for combining the detector outputs in polarity opposition.

5. In combination with a source of angular velocity-modulated carrier waves, a transmission tube having its input electrodes coupled to said source, a rectification network comprising a pair of series resonant circuits arranged in parallel, said resonant circuits being oppositely mistuned from the center frequency of the carrier waves by an equal amount, an impedance matching network coupling the output electrodes of said tube to the junction of said pair of resonant circuits, and said matching network comprising a current step-up transformer.

6. In a frequency responsive network adapted to respond linearly with respect to frequency departures from a fixed frequency over a range of frequencies, a pair of signal input terminals, a

first series tuned circuit resonant to a first frequency connected between said terminals, a second series tuned circuit resonant to a second frequency connected between said terminals, the ratio of inductive reactance to series resistance in each of said circuits being, at the mean of said frequencies, of the order of the ratio of said mean to the difference of said frequencies whereby the impedance between said terminals is substantially constant over the range between said frequencies, means for creating a substantially constant voltage across said terminals throughout said range, said last means comprising a device for supplying constant current to said terminals, a detector associated with each of said circuits and means for combining the output voltages of said detectors in opposition.

7. In a frequency responsive network adapted to respond linearly with respect to frequency departures from a fixed frequency over a range of frequencies, a pair of signal input terminals, a first series tuned circuit resonant to a first frequency connected between said terminals, a second series tuned circuit resonant to a second frequency connected between said terminals, each of said tuned circuits including a pair of reactances of opposite sign, the ratio of inductive reactance to series resistance in each of said circuits being, at the mean of said frequencies, of the order of the ratio of said mean to the difference of said frequencies whereby the impedance between said terminals is substantially constant over the range between said frequencies, means for creating a substantially constant voltage across said terminals throughout said range, said last means comprising a device for supplying constant current to said terminals, a separate detector connected across solely one reactance of each of said tuned circuits, and means for combining the output voltages of said detectors in opposition.

8. In a frequency responsive network adapted to respond linearly with respect to frequency departures from a fixed frequency over a range of frequencies, a pair of input terminals, a source of frequency modulated carrier energy connected to said terminals, a first series tuned circuit resonant to a first frequency connected between said terminals, a second series tuned circuit resonant to a second frequency connected between said terminals, each of said tuned circuits including a pair of reactances of opposite sign, said two frequencies being equally and oppositely located relative to the carrier frequency, a separate detector connected across solely one reactance of each of said circuits, means for combining the output voltages of said detectors in opposition, and a single means for adjusting the aforesaid two resonant frequencies simultaneously while maintaining said equal and opposite frequency relation therebetween.

9. In a frequency responsive network adapted to respond linearly with respect to frequency departures from a fixed frequency over a range of frequencies, a pair of input terminals, a source of frequency modulated carrier energy connected to said terminals, a first series tuned circuit resonant to a first frequency connected between said terminals, a second series tuned circuit resonant to a second frequency connected between said terminals, said two frequencies being equally and oppositely located relative to the carrier frequency, a detector connected with each of said circuits, means for combining the output voltages of said detectors in opposition, a single

means for adjusting the aforesaid two resonant frequencies in the same direction, said source including a network adapted to supply a substantially constant current of relatively small magnitude, and a current multiplying trans- 5 former connecting said network to said input terminals.

10. In combination, in an angular velocity-transmission system, a source of such waves, a wave transmission tube having input electrodes 10 upon which said waves are impressed, said tube being constructed to deliver a substantially constant current of relatively small magnitude, a rectification network comprising a pair of tuned circuits in parallel relation, each circuit com- 15 prising an inductance in series with a capacity, said tuned circuits being series resonant to frequencies on opposite sides of the mean frequency of said waves, a separate rectifier device connected across only the condenser of each tuned 20 circuit, an impedance matching network between the tube and said tuned circuits, said matching network comprising a coil in shunt across the tube output electrodes, and a condenser in series relation between the junction of the inductances 25 of said tuned circuits and said shunt coil.

11. In a frequency responsive network adapted to respond linearly with respect to frequency departures from a fixed frequency over a range of frequencies, a pair of signal input terminals, a first series tuned circuit comprising a coil and a condenser resonant to a first frequency connected between said terminals, a second series tuned circuit comprising a second coil and a second condenser resonant to a second frequency connected between said terminals, the ratio of inductive reactance in series resistance in each of said circuits being, at the mean of said frequencies, of the order of the ratio of said mean to the difference of said frequencies whereby the impedance between said terminals is substantially constant over the range between said frequencies, a separate detector associated with the condenser of each of said tuned circuits, means for combining the output voltages of said detectors in opposition, and a single means constructed and arranged to affect both said coils for adjusting the aforesaid two resonant frequencies concurrently while maintaining said mean frequency at its value.

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