

Oct. 20, 1942.

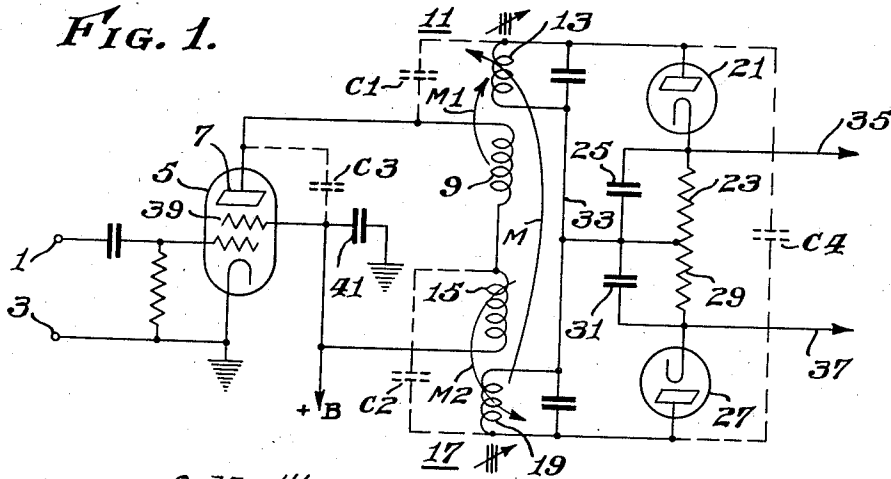
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2,299,581

FREQUENCY DISCRIMINATOR

Filed Jan. 25, 1941

FIG. 1.



$$Q = \sqrt{1.5} \frac{\omega_0}{W}$$

FIG. 2.

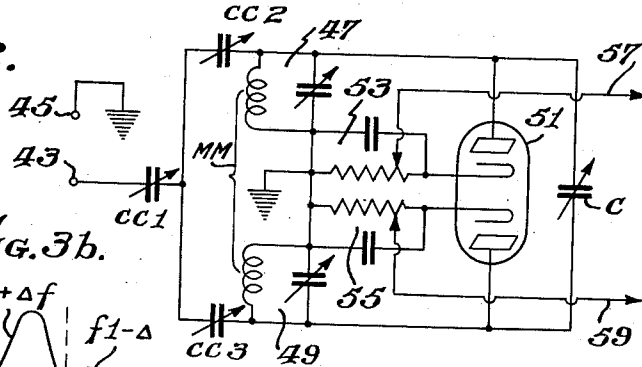


FIG. 3a.

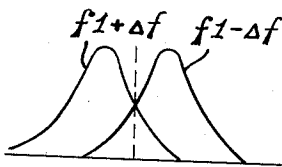


FIG. 3b.

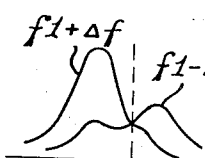


FIG. 4a.

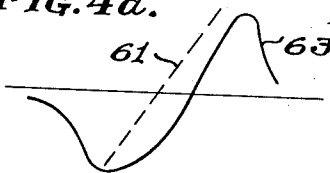


FIG. 4b.

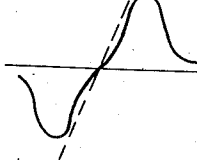


FIG. 4c.

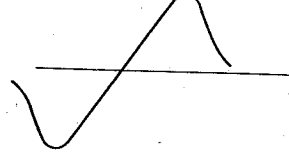
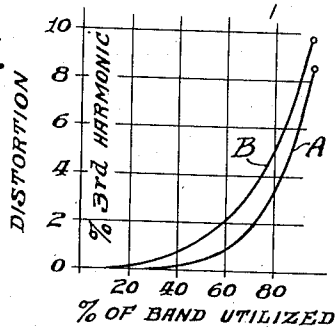


FIG. 5.



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FREQUENCY DISCRIMINATOR

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2 Claims. (Cl. 250-27)

This invention relates to frequency discriminators and more particularly to a frequency discriminator in which the deleterious effects of undesired coupling and improper relations of reactance to resistance are minimized.

Frequency modulated currents are not detected in the same manner as an amplitude modulated current. In general, it is necessary to convert the frequency modulated current into an amplitude modulated current for detection. Devices capable of such conversion have been called frequency discriminators. One type of frequency discriminator is disclosed in United States Patent 2,057,640 which issued on October 13, 1936, to Frank Conrad. The Conrad discriminator employs a pair of resonant circuits upon which the frequency modulated currents are impressed. One of the resonant circuits is made to have maximum response at a frequency above the mid-frequency of the applied currents, while the other resonant circuit is made to have maximum response to currents of a frequency below the mid-frequency. The currents applied to each of the resonant circuits are rectified and, after rectification, combined.

In practice it has been found that conventional discriminators of this general type may introduce distortion which was not present in the original currents. It is one of the principal objects of the present invention to provide means for eliminating such distortion. Another object is to provide frequency discrimination means in which distortion produced by undesirable coupling between resonant circuits is eliminated or minimized. Another object is to provide frequency discrimination means in which the distortion produced by an improper ratio of reactance to resistance is eliminated or minimized.

The invention will be described by referring to the accompanying drawing in which Figure 1 is a schematic diagram of one embodiment of the invention; Figure 2 is a schematic diagram of a modification of the invention; and Figures 3a, 3b, 4a, 4b, 4c and Figure 5 are graphs illustrating the mode of operation.

Referring to Fig. 1, the terminals 1, 3 represent the input circuit of a frequency discriminator in which the frequency modulated currents may be amplified, and limited if desired, by a thermionic tube 5. The thermionic tube includes an anode 7 which is connected through the primary 9 of a radio frequency transformer 11. The secondary of the transformer is a part of a circuit 13 resonant at frequency $f_1 + \Delta f$, where f_1 equals the mid-frequency and Δf is a frequency somewhat

larger than the frequency swing. The primary 9 may be connected in series or in shunt to the second primary 15 of a second radio frequency transformer 17. The second radio frequency transformer has a secondary which is a part of a circuit 19 resonant at frequency $f_1 - \Delta f$.

The resonant circuit of the first radio frequency transformer is connected to a rectifier such as the diode 21. The rectifier circuit includes a resistor 23 and a capacitor 25. The second resonant circuit 19 is connected to a second rectifier which may be a diode 27. The diode is connected through a resistor 29 and shunt capacitor 31 to the resistor and capacitor of the first diode and to a point intermediate the low potential ends of the resonant circuits which are connected together by a conductor 33. The output currents are applied to leads 35, 37 which are connected to include the resistors 23, 29.

The thermionic tube 5 includes a screen grid 39 which is connected to ground through a bypass capacitor 41 and to +B in the conventional manner. It should be understood that certain stray capacities unavoidably appear as, for example, C1 between the primary and secondary of the first radio frequency transformer 11, C2 between the windings of the second radio frequency transformer 17, C3 between the anode and screen grid of the tube 5, and C4 between the anodes of the rectifiers 21, 27. Furthermore, the transformers of necessity have mutual couplings M1 and M2 between their respective windings. In practice there is often mutual coupling M between the resonant circuits.

The circuit including capacity C3 and the primaries 9 and 15 forms a link circuit which couples the resonant circuits through the magnetic couplings M1 and M2 and to some extent through the capacity couplings C1, C2. Measurements have indicated that the frequency of the link circuit should be well removed from that of the two resonant circuits 13, 19; for example, two and one-half times the resonant frequency of either of the resonant circuits 13, 19 is a useful frequency for the link circuit resonance. Preferably, the link circuit should not respond to the fundamental or any of the harmonics of the signal. Furthermore, measurements have indicated that the sense of the magnetic couplings has an important bearing on distortion. It has been found that if the sum of the several mutual couplings between the resonant circuits is made equal to zero or nearly so, the distortion is minimized. That is,

$$\alpha M1 \pm \alpha 2 M2 M1 C3 - \alpha 3 C4 - \alpha 4 C1 - \alpha 5 C2 = 0$$

where $\alpha_1, \alpha_2, \alpha_3$, etc., are proportionality constants. In short, the several couplings are adjusted so that the resonant circuits 13, 19 are substantially without any mutual coupling.

In some practical arrangements, it is necessary to add elements in order that the undesired coupling may be minimized. In other arrangements, it is possible to utilize the couplings already provided in the circuits and arranging the amount and sense of such couplings so that the desired result may be obtained. The circuit of Fig. 1 is an example of the latter type of device. The circuit of Fig. 2 is an example of the former type of discriminator.

By way of example, in the circuit of Fig. 1 the constants for a five megacycle discriminator have been selected as follows: The transformers 11, 17 included primary and secondary windings on a core of a half inch diameter. The secondaries each included 22 turn of #30 enamelled copper wire spaced by the diameter of the wire. The primaries each included 28 turns #30 enamelled copper wire close wound. Each secondary was three-eighths of an inch long and spaced one and seven-thirty-seconds of an inch apart between the near edges. The primaries each occupied seven thirty-seconds of an inch in the space between the secondaries. The primaries were spaced one thirty-second of an inch from the secondaries. The effective secondary inductance of each secondary was about 10 microhenries; the mutual inductance of each primary to secondary was about 2.7 microhenries. The capacity across each secondary was approximately 100 micro-microfarads. The rectifiers were diodes of the type known as 6H6. The resistors 23 and 29 were each 120,000 ohms; the capacitors 21, 35 shunting the resistors were 33 micro-microfarads each. The primary circuit resonated at approximately 10.3 megacycles.

A method of adjusting the circuits is as follows: The primaries are connected so that the sense of the mutual coupling of the primaries as a link circuit is opposite to the direct mutual coupling between the secondaries. The second step includes short circuiting each of the secondaries in turn and tuning the other to resonate at the frequencies $f_1 \pm \Delta f$ respectively. The third step is to remove the short circuit. The fourth step is to plot the resonance curves as shown in Fig. 3a or 3b by any suitable means. If the curve corresponds to Fig. 3a, the mutual coupling is suitably neutralized; if the curve corresponds to Fig. 3b, the mutual coupling is not neutralized and must be readjusted by changing the spacing of the secondaries, the phasing of the primaries, or supplementing one of the existing couplings by an additional element.

In Fig. 2, the preceding thermionic tube has been omitted and the input terminals represented by the reference characters 43, 45. It will be seen that capacity couplings CC1, CC2 and CC3 are used to apply the frequency modulated currents to the resonant circuits 47, 49. The resonant circuits are connected to a pair of diode rectifiers which are within a single envelope 51. The rectifier circuits include resistor-capacity networks 53, 55. The output leads 57, 59 are connected to the cathodes of the rectifiers. The resonant circuits 47, 49 include magnetic coupling MM which is substantially neutralized by a capacitor C.

Fig. 3a is a graph showing the resonant response $f_1 + \Delta f$ and $f_1 - \Delta f$. These curves are symmetrical because it has been assumed that the

undesirable couplings have been eliminated. If the couplings had not been minimized, the curves might have been represented by the graph of Fig. 3b in which the distortion is indicated with respect to the curve $f_1 - \Delta f$. The effect of such distortion is to make the frequency discrimination characteristic asymmetrical, as in Fig. 4a.

It has also been found that the ratio Q of reactance to resistance in each of the tuned circuits has an important bearing upon the distortion. If the resonant circuits are adjusted so that

$$Q = \sqrt{1.5} \text{ times } \frac{\omega_0}{W}$$

the distortion will be minimized. In the above equation Q = the reactance to resistance, $\omega_0 = 2\pi$ times the mid-frequency and $W = 2\pi$ times the difference between the resonant frequencies of the two circuits, for example,

$$(f_1 + \Delta f) - (f_1 - \Delta f) \text{ or } 2\Delta f$$

It can be shown mathematically that the factor $\sqrt{1.5}$ is the optimum value for minimum distortion. Departures from the optimum value (curve A) produce distortion effects (curve B) which are shown in the graph Fig. 5.

Referring to the undesirable effects of mutual magnetic coupling, Fig. 4a shows the ideal characteristic of a frequency discriminator as a broken line 61. The solid curve 63 shows the departure which is caused by reversing the phase or sense of one of the magnetic couplings such as M1 of Fig. 1. Fig. 4b shows the distortion effects caused by an improper adjustment of the Q of the resonant circuits and Fig. 4c shows the characteristic of a properly adjusted discriminator.

Thus the invention has been described as a frequency discriminator employing a pair of resonant circuits tuned to frequency above and below the mid-frequency of the applied frequency modulated currents. The applied currents are rectified by a pair of rectifiers and the rectified currents are combined to produce amplitude modulated currents which may be detected in the conventional manner. In the practical arrangement of the device, undesirable mutual couplings are unavoidable. The effect of these couplings is minimized by adjusting the amount and sense so that the resultant coupling approaches zero. In some arrangements the inherent couplings are employed, and augmented or reversed as required. In other arrangements, additional coupling is added to neutralize the existing couplings. Furthermore, the Q of the resonant circuits is adjusted to minimize the distortion produced by an improper ratio of reactance to resistance. If the coupling has been minimized in accordance with the disclosure, the user will find that the circuits may be adjusted more readily than those of a conventional discriminator in which the circuits react upon each other.

I claim as my invention:

1. A frequency discriminator including a pair of resonant circuits respectively responsive to frequencies $f_1 + \Delta f$ and $f_1 - \Delta f$ respectively above and below a reference frequency f_1 , and further characterized by a ratio of reactance to resistance equal to

$$\sqrt{1.5} \frac{\omega_0}{W}$$

(where $\omega_0 = 2\pi f_1$ and $W = 2\pi(f_1 + \Delta f) - 2\pi(f_1 - \Delta f)$ and $2\pi\Delta f$ equals half the radian frequency varia-

tion of the applied currents) in each of said resonant circuits, an input circuit for applying frequency modulated currents to said resonant circuits and providing mutual coupling therebetween, and magnetic coupling means in said input circuit connected for minimizing the distortion effect of said couplings.

2. A frequency discriminator and detector including a pair of circuits resonant at frequencies substantially equally above and below a predetermined mid-frequency of an applied variable frequency signal, each of said circuits including the secondary winding of a coupling transformer, a primary winding coupled with each secondary winding, a signal input circuit connected with said primary windings and forming a link circuit

5 between the secondary windings which resonates at a frequency relatively widely different from the resonant frequencies of said secondary windings, said windings having the sense of the magnetic coupling adjusted for minimizing the effects of mutual and stray capacity coupling between said circuits, the sense of the mutual coupling of the primary windings as a link circuit being opposed to the direct mutual coupling between the secondary windings, means for rectifying the signal output from said secondary windings, and means for combining the rectified output from said last named means to provide the modulation component of the applied signal.

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