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FREQUENCY DISCRIMINATOR

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This invention relates to circuits which are responsive to frequency variation, and more particularly to a frequency discriminator adapted for use in the microwave range.

An object of the invention is to produce an output voltage which is proportional to, and the sign of which is determined by, the deviation of the input signal from a reference frequency.

A further object is to increase the sensitivity of a frequency discriminator.

Wave transmission systems often require a device which will develop across its output terminals a voltage the magnitude of which is substantially proportional to the deviation from the nominal or reference frequency of the input signal, and the sign of which depends upon whether the frequency is higher or lower than the reference. Such a device, called a frequency discriminator, finds application, for example, as a component in circuits for oscillator frequency stabilization or as a demodulator for frequency-modulated signals.

The frequency discriminator of the present invention makes use of hollow wave-guide structures and is particularly adapted for operation in the microwave frequency range. In the embodiments shown, by way of example only, the discriminator comprises a main wave guide, a cavity resonator coupled to one end thereof, two auxiliary wave guides directionally coupled to opposite sides of the main guide, and means at one end of each auxiliary guide for deriving a unidirectional potential proportional to the microwave energy therein. The auxiliary guides are short-circuited at their other ends at points so chosen that the difference between the length of the electrical path from the input end of the main guide to the shorted end of one of the auxiliary guides and the length of the path from the same point to the shorted end of the other auxiliary guide is approximately equal to an odd integral number of quarter wavelengths, and that each of these lengths differs from the length of the main guide by approximately an odd integral number of eighth wavelengths, at the resonant frequency of the resonator. These two potentials are combined in the series-opposing relationship to provide a voltage which is proportional to the deviation from the resonant frequency of the resonator, and the sign of which is positive for an increase in frequency and negative for a decrease. The resonator, which is resonant at the reference frequency, contributes materially to the sensitivity of the discriminator, since its reactance changes sign at its resonant

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frequency and has a steep slope on either side thereof. The microwave energy detectors may, for example, be crystals, thermistors, or thermionic diodes.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which

Fig. 1 is a longitudinal sectional view of a frequency discriminator in accordance with the invention;

Fig. 2 is an end view of the discriminator of Fig. 1 as seen from the right;

Fig. 3 shows the portion of Fig. 1 to the left of the line X—X and illustrates a modification in which the crystal detectors are replaced by thermistors;

Fig. 4 is similar to Fig. 3 and shows another modification in which the crystals are replaced by thermionic diodes; and

Fig. 5 is a typical discrimination characteristic of the discriminator showing the ratio of output to maximum voltage, plotted against the deviation of the input frequency from the reference frequency.

The frequency discriminator shown in Figs. 1 and 2 comprises a hollow main wave guide 10 of rectangular cross-section, a cavity resonator 11, two aperiodic rectangular auxiliary wave guides 12 and 13, and detecting means 14 and 15 for deriving unidirectional potentials proportional to the microwave energy within the auxiliary guides 12 and 13. Microwave energy of nominal or reference frequency f from some suitable source is fed into the left end of the main guide 10, as indicated by the arrow. The unidirectional output voltage appears at the terminals 16 and 17 and is measured by means of a direct-current voltmeter or other appropriate indicating device.

The cavity resonator 11 is electromagnetically coupled to the right-hand end of the main guide 10 by means of the orifice 18 and is adjusted to resonate at the frequency f by means of the slidable piston 19. For maximum discrimination the resonator 11 should match the guide 10 in impedance at the frequency f . The auxiliary guides 12 and 13 adjoin the opposite wider sides 21 and 22 of the main guide 10 and are electromagnetically coupled thereto by the coupling orifices 23, 24, 25, and 26, 27, 28, respectively. These orifices are so spaced and the areas thereof are so chosen that the couplings between the main guide 10 and the auxiliary guides 12 and 13 are equal and are directionally selective; that is, left-to-right signal propagation in the

main guide 10 will induce left-to-right signal propagation in the auxiliary guides 12 and 13, but will not produce appreciable right-to-left signal propagation therein.

The right-hand ends of the auxiliary guides 12 and 13 are closed by the slidable short-circuiting pistons 30 and 31, respectively. These pistons are so positioned that the difference between the length of the electrical path from the input end 32 of the main guide 10 to one of the pistons 30 and the length of the electrical path from the input end 32 to the other piston 31 is approximately equal to an odd integral number of quarter wavelengths and, in addition, that each of these lengths differs from the length of the main guide 10 by approximately an odd integral number of eighth wavelengths, at the frequency f . Therefore, the distance S between the planes of the inner faces of the pistons 30 and 31 is made approximately equal to $n\lambda/4$, where λ is the wavelength within the guide and n is any odd integer. In Fig. 1, n is unity, and the length of the auxiliary guide 12 is longer than that of the auxiliary guide 13. Also, the distance D_1 between the plane of the inner face of the piston 31 and the plane 33 of the orifice 18 is made approximately equal to an odd integral number of eighth wavelengths and the distance D_2 between the plane 33 and the inner face of the piston 30 is made approximately equal to an odd number of eighth wavelengths. Therefore, D_1 is approximately equal to $m_1\lambda/8$ and D_2 is approximately equal to $m_2\lambda/8$, where m_1 and m_2 are odd integral numbers and may be either the same or different. In Fig. 1, m_1 and m_2 are each equal to unity.

The left-hand ends of the auxiliary guides 12 and 13 are terminated in devices for detecting and rectifying the microwave energy therein. As shown in Fig. 1, these devices are the crystal detectors 14 and 15, respectively, represented schematically. These crystals are connected in series-opposing relationship between the output terminals 16 and 17, and are paired and individually matched in impedance to the associated auxiliary guide at the operating frequency f .

In order to prevent the escape of microwave energy from the auxiliary guides 12 and 13 a quarter-wave choke is provided between each of the detectors 14, 15 and the associated output terminal. This comprises a cylindrical conductive sleeve 37 which surrounds the conductor 38. The sleeve 37 has a length approximately equal to $\lambda/4$, is open at the outer end, and at its inner end 39 is short-circuited and conductively connected to the conductor 38.

When the frequency discriminator is used in applications such as oscillator stabilization, where only comparatively slow drifts of frequency are to be corrected, the crystal detectors 14 and 15 can be replaced by the pair of thermistors 40 and 41, the equal resistances 46 and 47, and the battery 48, as shown in Fig. 3. Thermistors have the advantage that their impedance match can be maintained more easily over wider bands than is the case with crystals. Also, in some applications, the crystals 14 and 15 can advantageously be replaced by the pair of thermionic diodes 42 and 43, as shown in Fig. 4. The sources 44 and 45 supply the cathode current for the diodes 42 and 43, respectively.

An explanation of the operation of the frequency discriminator shown in Figs. 1 and 2 will now be given. When a microwave signal, hereafter called the incident signal, traveling from

left to right in the main guide 10, reaches the coupling orifices 23 to 28 it induces in the auxiliary guides 12 and 13 equal signals proportional to, and propagating in the same direction as, the incident signal. When these induced signals in the auxiliary guides 12 and 13 reach the right-hand ends thereof they are reflected by the short-circuiting pistons 30 and 31, reverse their direction of propagation, and travel to the left ends of the auxiliary guides where they aid in exciting the crystal detectors 14 and 15.

The portion of the incident signal in the main guide 10 which passes the orifices 23 to 28 continues traveling to the right until it reaches the orifice 18 of the cavity resonator 11, where it is partially reflected. The part which is reflected depends, both in magnitude and in phase, upon the deviation of the incident signal from the reference frequency f , and increases in magnitude as the deviation increases. This reflected signal in the main guide 10 propagates from right to left and, as it passes the orifices 23 to 28, induces in the auxiliary guides 12 and 13 equal signals proportional in magnitude to that of the reflected signal in the main guide 10.

There thus exist in each of the auxiliary guides 12 and 13 two components of signal, one induced by the incident signal in the main guide 10 and the other induced by the reflected signal in the main guide. When the incident signal is of frequency f there is a minimum reflection of it at the orifice 18 because the resonator 11 is resonant at this frequency and presents a substantially nonreactive impedance which preferably matches the characteristic impedance of the guide 10. Due to the positions of the pistons 30 and 31 with respect to each other and with respect to the plane 33 of the orifice 18, the two signal components in each of the auxiliary guides 12 and 13 are in quadrature, and their vector sums are equal. Therefore, the rectified voltages appearing across each of the detectors 14 and 15 are equal, and since these are connected series opposing the output voltage at the terminals 16 and 17 will be zero.

The reactive component of the impedance of the resonator 11, as viewed at the orifice 18, passes through zero at the frequency f and has a negative slope on each side thereof. Therefore, this component increases with the frequency deviation and is capacitive above f and inductive below f . This reactance, in turn, causes a phase shift in the reflected signal in the main guide 10 which increases with the frequency deviation and is leading below f and lagging above f . When this phase shift is lagging, the angle between the two signal components in the auxiliary guide 12 becomes acute and their vector sum is increased, while the angle between the signal components in the auxiliary guide 13 becomes obtuse and their vector sum is decreased. As a result, the detector 14 is more strongly excited than the detector 15 and, because of the series-opposing connection of the detectors, a net positive potential is obtained between the output terminals 16 and 17. This positive potential increases in magnitude as the frequency of the incident signal increases from f .

On the other hand, at frequencies of the incident signal below f , the leading phase shift produces an obtuse angle between the signal components in the auxiliary guide 12 and an acute angle between the signal components in the auxiliary guide 13. As a result, the detector 15 is more strongly excited than detector 14 and there

appears at the output terminals 16 and 17 a net negative potential which increases as the signal frequency decreases from f .

Fig. 5 shows a typical discrimination characteristic for the frequency discriminator of Figs. 1 and 2. The ratio of the rectified output voltage to the maximum voltage appearing at the terminals 16 and 17 is plotted against the percentage deviation of the input or incident signal from the nominal or reference frequency f . This characteristic applies to a discriminator in which the impedance of the cavity resonator 11 substantially matches the characteristic impedance of the main wave guide 10 at the frequency f , and the resonator 11 has a Q of 5000. The factor Q may be defined as the ratio of the energy stored to the energy dissipated per cycle. It is seen that at the frequency f , where the deviation is zero, the output voltage is also zero but increases negatively for the deviations below f , and positively for frequencies above f . Over the deviation range from -0.01 to $+0.01$ per cent the characteristic is quite steep and is substantially linear. The slope in this region, and therefore the sharpness of discrimination, may be increased by increasing the Q of the resonator 11.

Many modifications of the frequency discriminators herein disclosed will readily occur to persons skilled in the art. For example, in the structure shown in Figs. 1 and 2, either the piston 30 or the piston 31 may be moved either to the right or to the left by any small integral number of half wavelengths without substantially affecting the operation of the discriminator. Also, the orifice 18 may be moved either to the right or to the left by any small integral number of half wavelengths without substantially changing the performance. Furthermore, the orifice 18 may be moved either to the right or to the left by any small odd integral number of quarter wavelengths with only the result that the polarity of the output voltage at the terminals 16 and 17 will be reversed. Of course, the resonator 11 must be retuned to the frequency f when the orifice 18 is moved, and neither the orifice 18, the piston 30 nor the piston 31 can be moved so far to the left that it will interfere with the proper functioning of the right-hand coupling orifices 25 and 28.

What is claimed is:

1. A frequency discriminator comprising a main wave guide adapted at one end for the reception of electromagnetic waves of nominal frequency f , a cavity resonator resonant at approximately the frequency f and approximately matching said main guide in impedance at said frequency, means for electromagnetically coupling said resonator to the other end of said guide, two aperiodic auxiliary wave guides directionally coupled to opposite sides of said main guide, means for short-circuiting the ends of said auxiliary guides towards which said waves are directionally propagated, two detectors located, respectively, at the other ends of said auxiliary guides for deriving a unidirectional potential proportional to the high frequency power therein, each of said detecting means being approximately matched in impedance to the associated auxiliary guide, and means for connecting said detectors in series, the difference between the length of the electrical path from said one end of said main guide to the short-circuited end of one of said auxiliary guides and the length of the electrical path from said one end of said main guide to the short-circuited end of the

other of said auxiliary guides being approximately equal to an odd integral number of quarter wavelengths, and each of said lengths differing from the electrical length of said main guide by approximately an odd integral number of eighth wavelengths, at the frequency f .

2. A frequency discriminator in accordance with claim 1 in which said detectors are paired at the frequency f .

3. A frequency discriminator in accordance with claim 1 in which each of said detectors comprises a crystal.

4. A frequency discriminator in accordance with claim 1 in which each of said detectors comprises a thermistor.

5. A frequency discriminator in accordance with claim 1 in which each of said detectors comprises a thermionic diode.

6. A frequency discriminator in accordance with claim 1 which includes means for adjusting the lengths of said auxiliary wave guides.

7. A frequency discriminator in accordance with claim 1 which includes means for adjusting the resonant frequency of said resonator.

8. A frequency discriminator comprising a main wave guide adapted at one end for the reception of electromagnetic waves of a selected nominal frequency, a cavity resonator resonant at approximately said frequency and approximately matching said main guide in impedance at said frequency, an orifice coupling said resonator to the other end of said guide, two aperiodic auxiliary wave guides directionally coupled to opposite sides of said main guide, means for short-circuiting the end of one of said auxiliary guides towards which said waves are directionally propagated at a point $\lambda/8$ to one side of the plane of said orifice, means for short-circuiting the end of the other of said auxiliary guides towards which said waves are directionally propagated at a point $\lambda/8$ to the other side of said plane, two detectors located, respectively, at the other ends of said auxiliary guides, each of said detectors being approximately matched in impedance to the associated auxiliary guide, and means for combining the output voltage of said detectors in series-opposing relationship, the longitudinal axes of said wave guides being approximately parallel and λ being the wavelength within the auxiliary guide under consideration at approximately said frequency.

9. A frequency discriminator in accordance with claim 8 in which each of said detectors comprises a crystal.

10. A frequency discriminator in accordance with claim 8 in which each of said detectors comprises a thermistor.

11. A frequency discriminator in accordance with claim 8 in which each of said detectors comprises a thermionic diode.

12. A frequency discriminator in accordance with claim 8 in which said short-circuiting means are adjustable along said auxiliary guides.

13. A frequency discriminator in accordance with claim 8 which includes means for adjusting the resonant frequency of said resonator.

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