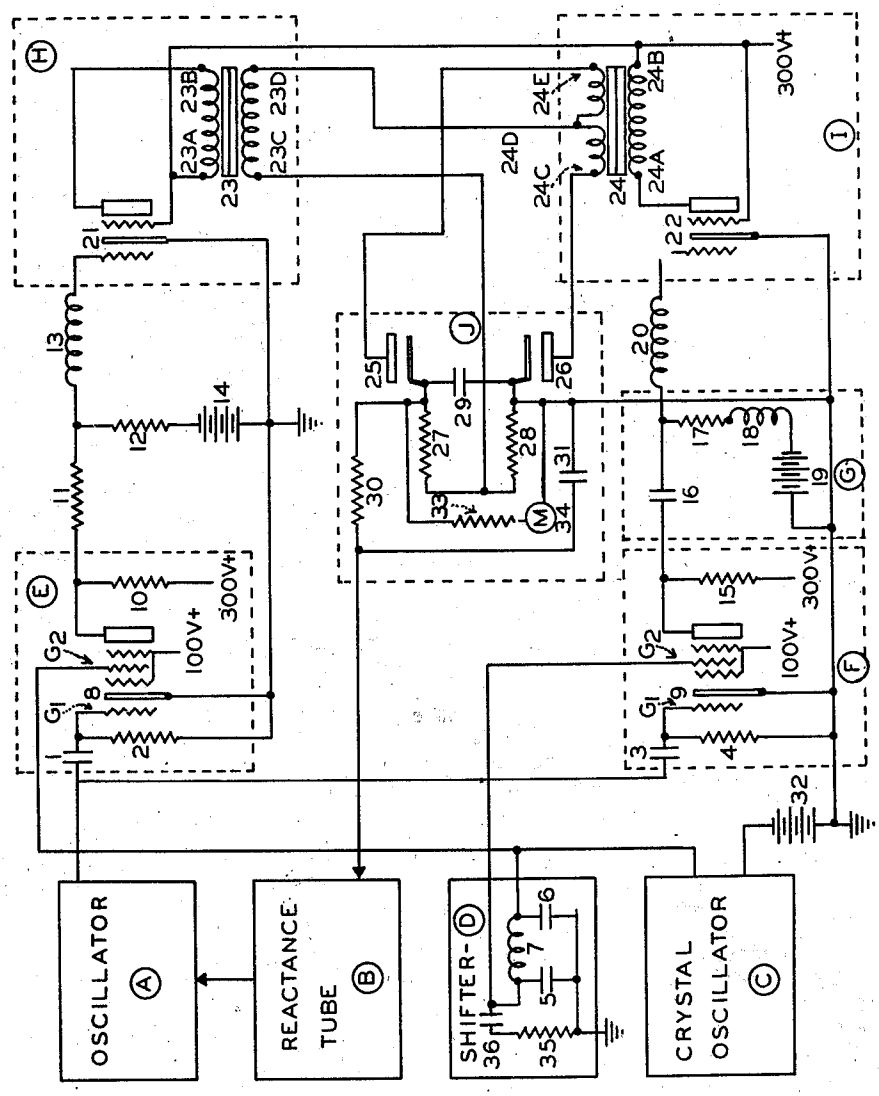
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RADIO APPARATUS

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RADIO APPARATUS

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This invention relates to electrical circuits generally. More particularly this invention relates to frequency stabilizing and adjusting systems and frequency deviation indicators.

An object of this invention is to provide a frequency discriminating device, the rectified output of which is a direct current voltage, whose polarity and amplitude is directly proportional to the frequency deviation and direction of deviation between an oscillator of fixed frequency and an oscillator, the frequency of which is to be controlled, or the deviation, from the fixed frequency, of which is to be indicated by a metering device.

Another object of this invention is to provide a discriminator-detector device, the balance frequency (frequency of zero direct current output) of which is determined solely by the fixed frequency oscillator, and is therefore not subject to variation due to temperature changes or circuit instabilities.

Other and further objects of this invention will be apparent to those skilled in the art to which it relates from the following specification and the claims.

In accordance with this invention I provide two beat frequency detectors for the purpose of deriving the beat frequency between two oscillators, the frequency of one of which is more or less fixed and the frequency of the other subject to variation, the magnitude of which it is desired to limit and/or indicate by metering device. In addition a phase shifting device is used to shift the phase of one of the oscillators before application to one of the beat detectors, this being for the purpose of displacing the phase of the two beat detector outputs by 90 degrees. A further phase shift is provided to one of the beat detector outputs which gives an additional shift of 90 degrees and renders the shifted beat output a direct function of the frequency. Under the above circumstances a phase turnover of 180 electrical degrees occurs between the derived beat supplies as the frequency deviation of the varying oscillator shifts from negative values through zero-beat to positive values. Two amplifiers are provided for amplifying the two beat supplies to the proper level and two transformers mix the two beats and apply the resulting voltages to a double diode detector, the purpose of which is to provide a direct current voltage proportional to the frequency deviation and direction of deviation of the frequency of the oscillator subject to variation from the frequency of the reference oscillator.

Further details of my invention will be apparent from the following specification and drawing in which, the sole figure illustrates an embodiment of my invention.

Oscillator A is a regenerative vacuum tube oscillator utilizing a tuned circuit as the frequency determining element. The reactance tube B forms a part of the frequency determining circuit of A and thereby permits the frequency of the oscillator A to be controlled by the bias voltage supplied to the grid of the reactance tube device B. This combination is conventional and has been described in various publications.

Oscillator A supplies a radio frequency voltage through condenser 1 to grid G_1 of vacuum tube 8. It also supplies, through condenser 3, grid G_1 of vacuum tube 9. Crystal oscillator C, which is a conventional device, utilizing a vacuum tube oscillator in which a quartz crystal forms the frequency determining element, supplies a radio frequency voltage to grid G_2 of tube 8. It also supplies the phase shifting network D which shifts the phase of the crystal frequency by exactly 90 electrical degrees and supplies the shifted output to grid G_2 of vacuum tube 9. Vacuum tubes 8 and 9 are mixer-detector devices, the purpose of which is to derive a beat frequency equal to the difference in frequency between oscillators A and C. For the purpose of illustration let it be assumed that the frequency of oscillator C is exactly 1000 kilocycles. Let it further be assumed that the frequency of oscillator A is near 1000 kilocycles, but is prone to vary above or below this frequency because of the effects of temperature variation and circuit instability. For example assume that the frequency of oscillator A becomes 1001 kilocycles. In this event, a beat frequency of 1000 cycles appears across resistor 10 in the plate circuit of detector E and across resistor 15 in the plate circuit of detector F.

The beats in the plate circuits of tubes 8 and 9 occur as a result of the falling in and out of step of the two radio frequency voltages when the phase of one of them is advancing at a greater rate than the other, which of course, is a result of a frequency difference. The phase displacement afforded by shifter D therefore causes a 90 degrees phase displacement between the two beat frequency sources at the plates of detectors E and F. If, now, the frequency of oscillator A becomes, for instance, 999 kilocycles, the phase relation between the beats will be reversed due to the fact that the phase of oscillator A is now continuously retarding with respect to that of oscillator C, whereas, when the frequency of oscillator A was 1001 kilocycles, its phase was continuously advancing with respect to that of oscillator C. If, for instance, the phase relation between the beat supplies from detectors E and F may be represented vectorially by the expression: $V_e = jV_f$, when the frequency of oscillator A is higher than 1000 kilocycles, then the expression indicating the phase relation between the beats when the frequency of oscillator A is lower

than 1000 kilocycles becomes: $V_e = -jV_f$. In these expressions, V designates voltage and sub letters *e* and *f* indicate respectively the outputs of detectors E and F. The phase reversal indicated occurs at zero-beat, since it is dependent upon whether the phase of oscillator A is advancing, or retarding with respect to that of oscillator C.

The purpose of network G is to provide an additional phase displacement of 90 degrees between the two beat frequency supplies and to provide an output, the amplitude of which, is proportional to the frequency. Network G is therefore interposed between the plate of detector tube 9 and the grid circuit of tube 22. Coil 20 has no appreciable reactance at the beat frequencies, but effectively chokes out radio frequency from the oscillators.

Connection is made from the plate of tube 8 through resistor 11 and choke 13 to the grid of tube 21. The purpose and characteristics of choke 13 are identical with that of choke coil 20. Resistor 12 returns resistor 11 to ground through bias battery 14. The combination 11, 12 and 14 provides the correct alternating voltage level and proper bias for tube 21.

The voltages at the grids of tubes 21 and 22 will as a result of the previously explained phase shifts be either in phase or out of phase depending upon whether the frequency of oscillator A is higher or lower than that of oscillator C.

Vacuum tubes 21 and 22 are conventional amplifier devices provided for amplifying the beat voltages delivered to their grids and applying their respective outputs to transformers 23 and 24, which, in turn, supply the balanced rectifier device J.

The secondaries of transformers 23 and 24 supply balanced rectifier J as follows: Connection is made from terminal 23*d* of transformer 23 to terminal 24*d* which is a center tap on the secondary of transformer 24. Terminal 24*c* connects to the plate of rectifier tube 25 and 24*e* connects to the plate of rectifier tube 26. The return is made from terminal 23*c* through resistors 27 and 28 to the respective cathodes of tubes 25 and 26. Rectifier 25 rectifies the series voltages supplied by the secondary of transformer 23 and half of the secondary of transformer 24, the output of which appears across resistor 27. Rectifier tube 26 is so connected that it rectifies the series voltages from the secondary of transformer 23 and the other half of the secondary of transformer 24. The output of this rectifier appears across resistor 28. The connections are so made that if the phases of the voltages from amplifiers H and I are such that the voltages in series with terminals 23*c* and 24*c* are in phase, then, the voltages in series with terminals 23*c* and 24*e* will be in phase opposition.

The output connection from the balanced rectifier J is made between the cathodes of tubes 25 and 26. With this connection the rectified voltage at the output will be zero if the voltages applied to the plates of tubes 25 and 26 equal. It will also be zero if one of the transformer voltages is zero. If the alternating voltages are unequal, a difference voltage will appear the polarity of which will depend upon which of the voltages is greater.

In considering the performance of the complete device it is apparent that if the frequency of oscillator A is equal to that of oscillator C, the beat outputs of detectors E and F will have zero frequency and since transformers 23 and 24 cannot pass direct current, the output of detector J will be zero. If the frequency of oscillator A deviates, a resulting beat frequency is applied to the balanced rectifier J from separate sources through transformers 23 and 24. The amplitude of the source from transformer 23 does not vary with the beat frequency, but the amplitude of the beat frequency delivered by transformer 24 is directly proportional to the frequency, therefore the voltage output of the detector J will depend upon the extent to which the voltage from the secondary of transformer 24 can unbalance the voltage applied to the two rectifier plates from the secondary of transformer 23. In other words, the unbalance, and hence the balanced detector output is directly proportional to the beat frequency and its polarity is dependent upon the phase relation of the beat sources, which reverses as the frequency difference goes through zero-beat.

The output of rectifier J is a pulsating direct current voltage and its pulsations are filtered out by condensers 29 and 31 in conjunction with resistor 30. The voltage across condenser 31 is therefore a pure direct current voltage whose polarity and amplitude are dependent directly upon the deviation and direction of deviation of the frequency of the oscillator A. This voltage is supplied to the grid of the reactance control tube B which directly and automatically limits the possible frequency deviation of the oscillator A.

Transformers 23 and 24 are high grade iron core devices capable of delivering constant amplitude response throughout a frequency band extending from 15 to 15,000 cycles. The transformers, as well as other components are selected to make the phase shift characteristics of amplifiers H and I identical.

Milliammeter 34 in conjunction with resistor 33 is calibrated to read the amount which the frequency of oscillator A deviates from that of C.

There remains to show that the phase shifter G can be made to properly shift the phase of any frequency in the band 0 to 15,000 cycles by 90 degrees. For this purpose an equivalent circuit will be assumed, in which the plate resistance of tube 9 and resistor 15 will be combined and called R_p. An equivalent driving voltage will be assumed to be in series with R_p and will be called E_g. The alternating voltage resulting across the combination of resistor 17 and inductor 18 in series, will be called E_r. The angular frequency in radians per second will be designated by ω, and the condenser 16, the resistor 17 and the inductor 18 will be indicated, in the analysis, as respectively C, R and L.

The vector resulting from the derivation of the ratio E_r/E_g yields the angle of phase shift. The equation for this is given by (1).

$$\frac{E_r}{E_g}=\frac{(R+j\omega L)}{(R+R_p)+j(\omega L-1/\omega C)} \qquad (1)$$

Rationalizing Equation 1 yields Equation 2, below.

$$\frac{E_r}{E_g}=\frac{R(R+R_p)+\omega L(\omega L-1/\omega C)}{(R+R_p)^2+(\omega L-1/\omega C)^2}+ j\frac{(R+R_p)\omega L-R(\omega L-1/\omega C)}{(R+R_p)^2+(\omega L-1/\omega C)^2}$$

If the numerator of the first term of Equation 2 could be equated to zero for all frequencies, the network G would shift the phase of any frequency passed through it by exactly 90 degrees.

This, of course, is not possible. However, suppose that the frequency band of importance extends only to 15,000 cycles, and that in this band, the components are selected so that $1/\omega C \gg \omega L$. In this case the numerator of the first term of Equation 2 will reduce to: $R(R+R_p)-L/C$. This expression does not vary with the frequency, and may therefore be equated to zero for frequencies within the band extending from zero to 15,000 cycles.

A further requirement is that E_r/E_g be a linear function. This means that the second term of Equation 2 must be directly proportional to the frequency. To illustrate that circuit components may be selected to sufficiently meet this requirement, we now consider the result of selecting values so that: $(R+R_p)^2 \ll (1/\omega C)^2$. Equation 2 then reduces to: $E_r/E_g=\omega CR$. This expression is perfectly linear. In practice, it has been found that the last above condition need not be stringently met in order to obtain satisfactory linearity.

In the circiut arrangement shown diode type rectifier tubes may be used to replace the mixer type tubes used in detectors E and F, and the network G may be placed in the plate circuit of detector E instead of the plate circuit of detector F.

While I have described this invention in detail in a preferred embodiment, it will be observed that modifications therein may be made without departing from the spirit and scope thereof and therefore I intend to be limited only as indicated by the scope of the following claims.

Having described my invention I claim:

1. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, amplifiers for amplifying the two separate beat frequency oscillations, a balanced rectifier, means for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be a positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, and means for controlling the frequency of said second source in accordance with the output of said rectifier.

2. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, a rectifier, means for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be a positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, and means for controlling the frequency of said second source in accordance with the output of said rectifier.

3. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, amplifiers for amplifying the two separate beat frequency oscillations, a balanced rectifier, a pair of transformers for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be a positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, and means for controlling the frequency of said second source in accordance with the output of said rectifier.

4. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices each of said detector devices deriving a heat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, a balanced rectifier, transformer means for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be a positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, and means for controlling the frequency of said second source in accordance with the output of said rectifier.

5. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices, each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting

the phase of one of the beat frequency oscillations by substantially 90 degrees, amplifiers for amplifying the two separate beat frequency oscillations, a balanced rectifier, means for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, the polarity of said voltage depending upon whether the frequency of the oscillation source subject to variation is higher or lower than that of the fixed source of oscillation, a variable reactance tube device for controlling the frequency of said variable source of oscillations, means for filtering and applying the output of said balanced rectifier to said variable reactance tube device for the purpose of exerting a controlling influence on the frequency of said second source of radio frequency oscillation.

6. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices, each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, a rectifier, means for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, the polarity of said voltage depending upon whether the frequency of the oscillation source subject to variation is higher or lower than that of the fixed source of oscillation, a variable reactance tube device for controlling the frequency of said variable source of oscillations, means for filtering and applying the output of said balanced rectifier to said variable reactance tube device for the purpose of exerting a controlling influence on the frequency of said second source of radio frequency oscillation.

7. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices, each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, amplifiers for amplifying the two separate beat frequency oscillations, a balanced rectifier, transformer means for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, the polarity of said voltage depending upon whether the frequency of the oscillation source subject to variation is higher or lower than that of the fixed source of oscillation, a variable reactance tube device for controlling the frequency of said variable source of oscillations, means for filtering and applying the output of said balanced rectifier to said variable reactance tube device for the purpose of exerting a controlling influence on the frequency of said second source of radio frequency oscillation.

8. In a frequency stabilizing and adjusting system the combination of, a source of radio frequency oscillations, the frequency of which is substantially fixed, a second source of radio frequency oscillations having a frequency subject to variation, the extent of which is to be controlled, two detector devices, each of said detector devices deriving a beat frequency between the frequencies of said sources of radio frequency oscillations, means for shifting the phase of one of said oscillation sources by substantially 90 degrees before application thereof to one of said detectors, a network for shifting the phase of one of the beat frequency oscillations by substantially 90 degrees, amplifiers for amplifying the two separate beat frequency oscillations, a balanced rectifier, a pair of transformers having the primaries thereof connected to said amplifiers and the secondaries connected to said rectifier for impressing said beat frequency oscillations on said rectifier in such a manner that the output of said rectifier will be zero if the frequency of the two sources of radio frequency oscillation are equal, and will be positive or negative voltage proportional to the frequency difference if the radio frequency oscillations have unequal frequency, the polarity of said voltage depending upon whether the frequency of the oscillation source subject to variation is higher or lower than that of the fixed source of oscillation, a variable reactance tube device for controlling the frequency of said variable source of oscillations, means for filtering and applying the output of said balanced rectifier to said variable reactance tube device for the purpose of exerting a controlling influence on the frequency of said second source of radio frequency oscillation.

9. The combination of two sources of radio frequency oscillations, the frequency of one of which is substantially constant and the frequency of the other subject to variation, the extent of which is to be controlled, two detector devices for deriving the beat frequency between said sources of oscillation, means for shifting the phase of one of said sources of radio frequency oscillations before application thereof to the corresponding beat detector, said beat frequency oscillations being displaced in phase by substantially 90 degrees, a phase shifter adapted to shift the phase of one of said beat frequency oscillations by approximately 90 degrees connected to the output of one of said beat detectors, a rectifier supplied by both of said beat frequency oscillations, means for varying the amplitude of one of said beat frequency oscillations so that the output of said rectifier provides a voltage which is a pulsating direct current voltage proportional to the frequency difference between the said sources of radio frequency oscillations and the polarity of which depends upon which of said sources of

radio frequency oscillation exceeds the other in frequency.

10. The combination of two sources of radio frequency oscillations, the frequency of one of which is substantially constant and the frequency of the other subject to variation, the extent of which is to be controlled, two detector devices for deriving the beat frequency between said sources of oscillation, means for shifting the phase of one of said sources of radio frequency oscillations before application thereof to the corresponding beat detector, said beat frequency oscillations being displaced in phase by substantially 90 degrees, a phase shifter adapted to shift the phase of one of said beat frequency oscillations by approximately 90 degrees connected to the output of one of said beat detectors, a rectifier supplied by both of said beat frequency oscillations, means for varying the amplitude of one of said beat frequency oscillations so that the output of said rectifier provides a voltage which is a pulsating direct current voltage proportional to the frequency difference between the said sources of radio frequency oscillations and the polarity of which depends upon which of said sources of radio frequency oscillation exceeds the other in frequency, and means for controlling the frequency of said variable source in accordance with said direct current voltage.

11. The combination of two sources of radio frequency oscillations, the frequency of one of which is substantially constant and the frequency of the other subject to variation, the extent of which is to be controlled, two detector devices for deriving the beat frequency between said sources of oscillation, means for shifting the phase of one of said sources of radio frequency oscillations before application thereof to the corresponding beat detector, said beat frequency oscillations being displaced in phase by substantially 90 degrees, a phase shifter adapted to shift the phase of one of said beat frequency oscillations by approximately 90 degrees connected to the output of one of said beat detectors, a rectifier supplied by both of said beat frequency oscillations, means for varying the amplitude of one of said frequency oscillations so that the output of said rectifier provides a voltage which is a pulsating direct current voltage proportional to the frequency difference between the said sources of radio frequency oscillations and the polarity of which depends upon which of said sources of radio frequency oscillations exceeds the other in frequency, means for filtering said pulsating direct current voltage, and means controlled by said filtered direct current voltage for controlling the frequency of said variable frequency source.

12. The combination of two sources of radio frequency oscillations, the frequency of one of which is substantially constant and the frequency of the other subject to variation, the extent of which is to be controlled, two detector devices for deriving the beat frequency between said sources of oscillation, means for shifting the phase of one of said sources of radio frequency oscillations before application thereof to the corresponding beat detector, said beat frequency oscillations being displaced in phase by substantially 90 degrees connected to the output of one of said beat detectors, a rectifier supplied by both of said beat frequency oscillations, means for varying the amplitude of one of said beat frequency oscillations so that the output of said rectifier provides a voltage which is a pulsating direct current voltage proportional to the frequency difference between the said sources of radio frequency oscillations and the polarity of which depends upon which of said sources of radio frequency oscillation exceeds the other in frequency, means for filtering said pulsating direct current voltage, and a variable reactance tube connected to said last means for controlling the frequency of said variable frequency oscillator in accordance with said filtered direct current voltage.

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