Oct. 12, 1937. J. W. CONKLIN 2,095,314

FREQUENCY MODULATION DETECTION

Filed March 23, 1934 2 Sheets-Sheet 1

Fig. 1

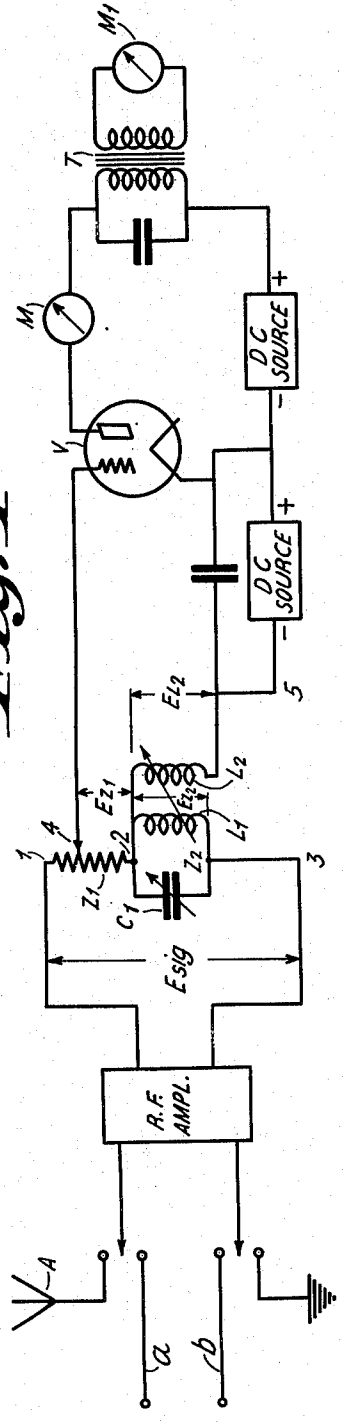
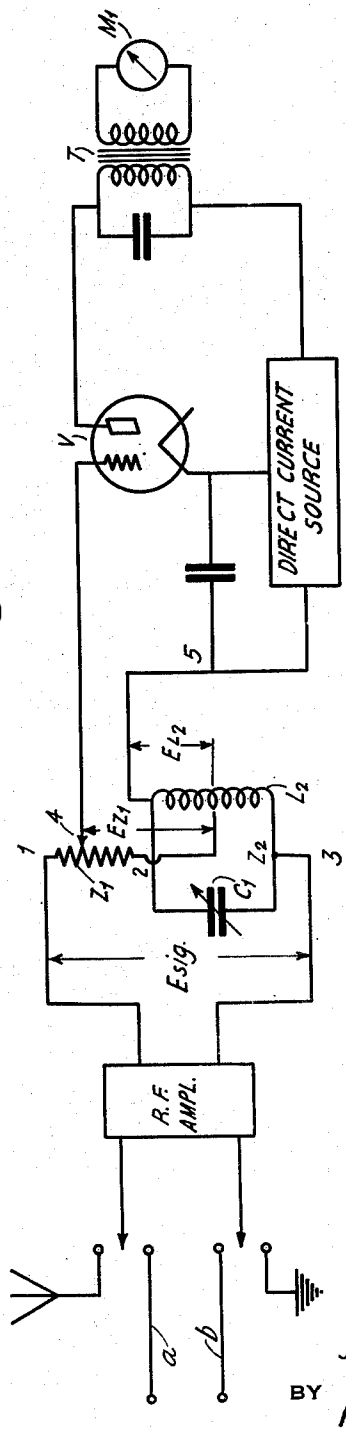


Fig. 2



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Filed March 23, 1934 2 Sheets-Sheet 2

Fig. 3

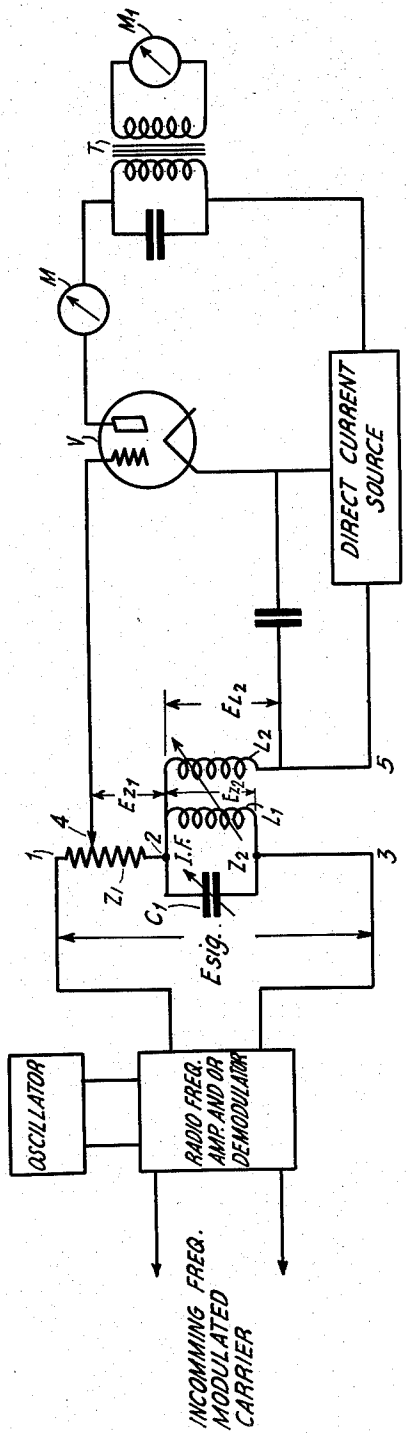
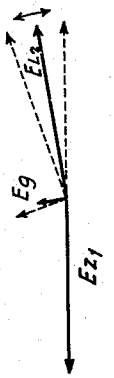


Fig. 4



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UNITED STATES PATENT OFFICE

2,095,314

FREQUENCY MODULATION DETECTION

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Application March 23, 1934, Serial No. 716,953

17 Claims. (Cl. 250—20)

This invention relates to a novel and simple method of and means for receiving and/or demodulating frequency modulated oscillations. The method and means of the present invention involves converting a frequency modulated wave into an equivalent amplitude modulated wave and demodulating the converted signal by a simplified means which, in a simplified manner, renders the signals. The demodulating means may take the form of an amplitude modulated wave demodulator. The particular features of the present invention include the novel and simple method and means for converting frequency modulations on a carrier wave to amplitude modulations. The converting means may comprise an impedance network having substantially constant impedance but rapidly varying phase angle over the range of frequency modulation employed, and an impedance network having substantially constant impedance and phase or having phase variations in the opposite sense or direction from the variations in the first mentioned network over the frequency range involved in modulation. The networks may be arranged and may be connected to any common source of frequency modulated oscillations and may include auxiliary circuits whereby the voltages or currents in the two networks are balanced against each other in such a manner as to produce a resultant voltage or current which will have amplitude modulations corresponding substantially to the original frequency modulations on the wave. The resultant of these voltages or currents may be applied to the control grid of a thermionic demodulating device.

In methods of and means for demodulating frequency modulated signals known heretofore, the circuits are complicated, employing a number of vacuum tubes and associated circuits and other delicate and expensive devices such as crystal filters. The circuits are generally quite cumbersome both in size and in operation and in some cases include refinements not necessary for the purposes at hand. The present invention furnishes an extremely simple method of and means for demodulating frequency modulated waves. The system is reasonably sensitive and is capable of being arranged within small physical dimensions and is well adapted to demodulating signals for certain purposes where linear reproduction is not imperative. For example, the method of and means for demodulating waves of the present invention may be used for monitoring purposes or for other measuring purposes as well as for receiving and demodulating messages. Any lack in sensitivity of the present system as compared with systems known heretofore more complicated in nature may be entirely overcome by increasing the amplification of the wave before it is applied to the converting system of my invention. This makes the demodulator of the present invention applicable to long distance communication and to general signalling purposes wherein frequency modulated waves are used and to all purposes where sensitivity and equality of the signal is not paramount.

The novel features of my invention have been pointed out with particularity in the claims at the end of the specification. The nature of my invention, the manner in which the method is carried out and circuit arrangements for carrying out said method will be understood by the following detailed description thereof and therefrom when read in connection with the drawings throughout which like reference characters indicate like parts insofar as possible and in which:

Figure 1 illustrates a demodulating circuit including the basic elements of my novel frequency converting system. Of course, this circuit may include any other elements necessary for the practical operation thereof;

Figures 2 and 3 illustrate modifications of the arrangement of Figure 1; while,

Figure 4 is a graph illustrating the manner in which the frequency modulations are converted, in accordance with the present invention.

Referring to the drawings in Figure 1, I have shown a converting circuit comprising, a resistance Z_1 having constant impedance and a constant phase angle of zero. The terminal 2 of Z_1 may be connected with an impedance Z_2 comprising a parallel tuned circuit which is preferably of the "low loss" type.

The characteristics of this parallel tuned circuit are that for a reasonable range about resonance the impedance thereof will be constant enough for the present purposes and the phase angle will vary substantially in proportion to the frequency involved in the frequency modulations on the carrier wave to be demodulated. The change of phase angle of the oscillations in this circuit will be proportional to the percentage change in the frequency modulations on the wave and to the "Q" (ratio of WL/R) of the circuit. The frequency modulated wave may be applied from any source such as for example an aerial A or lines *a* and *b* directly or by way of a radio frequency amplifier to the terminals 1 and 3. Lines *a* and *b* may be connected to any source of frequency modulated waves.

When the parallel circuit C_1 L_1 is tuned to resonance at the mean frequency of the carrier wave Z_2 will be equivalent to a resistance. Z_1 and Z_2 are selected to have the same order of absolute impedance, when Z_2 is operated near resonance. Thus the signal voltage will divide across Z_1 and Z_2. If the carrier wave is unmodulated the respective voltages EZ_1 and EZ_2 will be in phase. When the carrier wave is frequency modulated the respective voltages EZ_1 and EZ_2 will vary in relative phase with the phase of the voltage across Z_2 as the frequency of the wave changes in accordance with the signal. The voltage changes of varying phase appearing across Z_2 may be obtained from an inductance L_2 variably coupled as shown to Z_2. The voltages in L_2 will vary with, but in substantially opposite sense, to the voltages across Z_2. The variable coupling provides a means of adjusting the magnitude of the desired voltage. Preferably this circuit is operated near the resonance frequency of Z_2 and in order that the system may be adjustable to signal frequency Z_2 is as shown in Figure 1 provided with a variable capacity. Thus the voltages EZ_1 and EL_2 appearing across Z_1 and L_2 respectively may be adjusted to have substantially equal magnitude and any desired phase relation within certain limits. The algebraic sum of the voltages EZ_1 and EL_2 may be applied to the control grid and cathode of a thermionic tube V connected as shown. These voltages will produce a resultant potential on the control grid of V which varies in amplitude in accordance with the signal potentials which produce the frequency variations in the frequency modulated wave. The potential variations are repeated in V and appear in the output circuit thereof which includes a meter M. The signal modulations will also appear in a meter M_1 connected with the secondary winding of a transformer T, the primary winding of which is connected with the output electrodes of V.

In a modification the impedance Z_2 may be tuned to the intermediate frequency derived from a heterodyne receiver. In this case the circuit may be as indicated in Figure 3 in which the radio frequency amplifier and/or demodulator is energized by oscillations from a local source. These oscillations beat with the signal modulated wave to produce an intermediate frequency. The impedance Z_2 may be tuned to this intermediate frequency. In some cases this arrangement is preferable since the frequency of the intermediate frequency circuits need not be changed when the receiver is tuned to different signals. The circuit of Figure 3 may be otherwise similar to the circuit of Figure 1.

Under certain circumstances the receiver of Figure 1 may be further simplified as indicated in Figure 2. In this arrangement the impedance Z_1 is connected as shown to a point on the inductance L_1. The sum of the potentials of constant phase angle appearing across Z_1 and of the potentials of varying phase angle appearing across the upper portion of the inductance L_1 are applied to the control grids of tube V as in the prior modifications. The operation of this circuit is similar to the operation of the prior modifications and will be understood from the description of the operation of said modifications. This circuit eliminates the inductance L_2 of the arrangement of Figure 1.

In operation, the voltages E_s, and EL_2 in all cases are adjusted to have equal magnitude and displaced from anti-phase by the same phase displacement as would be caused by the peak frequency deviation to be used. If the signal voltages were adjusted to exact anti-phase a double frequency response would result. This may be accomplished by first adjusting to a null as evidenced by the detector plate current and then detuning to get the proper phase displacement. If a superheterodyne circuit was used, this adjustment could be obtained once and for all and the signal merely tuned for maximum response.

In Figure 4 the vector relations of the two voltages are illustrated, the dotted representations of EL_2 indicating the positions for modulation peaks. It may be seen that the resultant of these two voltages, which is applied to the grid of the detector tube has little phase shift, and varies between zero and a maximum equal to twice the unmodulated normal, a condition corresponding to 100% amplitude modulation. The audio-frequency envelope of the detector grid voltage will be substantially the same regardless of the normal displacement within limits for a given frequency modulation, only the resulting percentage amplitude modulation changing, provided the displacement shall always be sufficient to accommodate the peak deviations without passing through antiphase. Thus, from the standpoint of audio frequency output, the phase adjustment is not particularly critical.

Mathematically, as long as the angles are small:

$$Eg = 2EZ_1Q\left(K+\frac{\Delta f}{f}\right)$$

where K is proportional equivalent frequency displacement from antiphase

Δf is frequency deviation with modulation

f is signal frequency

In practice Q could be as high as 200 and $EZ_1 = Esig/2$ and to avoid distortion

$$\frac{2Q\Delta f}{f}$$

should not exceed 10° displacement.

This would represent a converted 100% modulated signal voltage equal to about 9% of the applied signal voltage for a frequency modulation of 0.045% which is a deviation frequency of 4500 cycles for a 10,000 k. c. carrier which represents quite a satisfactory order of conversion. The detection of the converted signal as an amplitude modulated wave is quite standardized and bears no relation to this invention.

In the above illustration I have selected the simplest practical circuit and other networks can be developed which may serve the same purpose. The circuit may also be expanded to function with a push-pull detector to balance amplitude modulation. Amplitude modulation could also be balanced by employing two circuits acting on a push-pull detector, one circuit responsive to frequency modulation as described and the other being responsive only to amplitude modulation, the two being balanced against each other in the push-pull detector to cancel noise and amplitude modulation.

My novel method of and means for demodulating signals is applicable to phase modulated signals as well as frequency modulated signals. When phase modulated signals are received on my novel circuits the signals derived in the output thereof are distorted due to the inherent difference between frequency and phase modulated signals. The distorted signals may be corrected by connecting a correcting network at any point

in the circuits in which the signal frequencies are flowing. This network may be so arranged that the amplitude of the signals in the output thereof is inversely proportional to the frequency of the signals impressed on the input thereof. The correction circuit may be as illustrated more in detail in Crosby's U. S. application No. 618,154 filed June 20, 1932. The correction circuits per se and the combination of a frequency modulation receiver and the correction circuit forms no part of the present invention and need not be described in detail here.

For many purposes the signals obtained by demodulating phase modulated oscillations on the frequency modulated oscillation demodulator of the present invention are entirely satisfactory for the purposes at hand. For example, for ordinary measuring works or for monitoring purposes the receiver of the present invention is perfectly satisfactory for the reception and demodulation of phase modulated waves.

Having thus described my invention and the operation thereof, what I claim is:

1. A device for converting frequency modulations on a carrier wave into corresponding potential variations comprising, a resistive impedance and a reactive impedance connected in series, said impedances being of substantially equal absolute impedance to said carrier wave, a circuit connected to the free terminals of said impedances for applying frequency modulated waves to said terminals of said series impedances, and means for tuning said reactive impedance to substantially resonance at the mean frequency of said carrier wave.

2. A device for converting frequency modulations on a carrier wave into corresponding potential variations comprising, a resistive impedance and a carrier wave resonate reactive impedance connected in series, a circuit in parallel with said impedances for applying frequency modulated waves to said series impedances to produce waves in said impedances which are relatively shifted in phase and a second circuit coupled to said impedances, said second circuit including means for reversing the phase of the waves in said reactive impedance whereby oscillations the amplitude of which is the algebraic sum of the potentials in both impedances are produced in said second circuit.

3. A device for converting frequency modulations on a carrier wave into corresponding amplitude variations comprising, a resistance, the impedance of which is constant for the various frequencies of said frequency modulated carrier wave, a reactive impedance connected with said resistance, the impedance of said reactive impedance being substantially constant with change in frequency of said carrier wave about a mean frequency in accordance with modulations, the phase angle of the voltages produced in said reactive impedance varying in proportion to the frequency of said carrier, means for applying frequency modulated waves to said impedances whereby voltages of phase equal to the phase of the applied carrier is set up in said resistance and voltages the phase angle of which varies in accordance with the variations in frequency of said carrier wave is set up in said reactive impedance, and circuit means connected with said impedances for deriving the algebraic sum of said voltages produced in said resistance and said reactance.

4. A frequency modulated wave demodulator comprising, an ohmic resistance, a parallel tuned circuit connected in series with said ohmic resistance, circuit means connected to points on said resistance and tuned circuit remote from their point of connection for applying the frequency modulated wave to said resistance and circuit, means for tuning said parallel circuit to substantially resonance at the mean frequency of the applied wave, and a thermionic tube having its input electrodes coupled to said impedances.

5. A circuit for converting frequency variations on a carrier wave into amplitude variations comprising, a pair of impedances in series and means for applying the wave to the terminals of said impedances, one of said impedances being resistive and of substantially constant impedance to the various frequencies of the applied wave and producing a voltage of a phase angle which does not change with changes in frequency of the wave, the other of said impedances being of substantially constant impedance to the various frequencies of the wave and being reactive thereby producing changes in the phase of the produced voltages which varies relative to the voltages of the applied wave, said reactive impedance being off resonance with respect to the carrier wave thereby reversing the sense of the potentials produced to displace the said potentials from antiphase by a phase displacement at least equal to the phase displacement that would be caused by the peak frequency deviation to be used, and circuit means for adding said potentials to produce a resultant, the amplitude of which is characteristic of the frequency modulations on said wave.

6. A circuit for converting frequency variations on a carrier wave into amplitude variations comprising, a radio frequency amplifier and a demodulator, a source of oscillations connected to said demodulator, a pair of impedances in series and means for applying intermediate frequency energy from said demodulator to the terminals of said impedances, one of said impedances being resistive thereby providing a substantially constant impedance to the intermediate frequency energy and producing in said intermediate frequency energy a phase angle which does not change with changes in frequency of the intermediate frequency energy, the other of said impedances being of substantially constant impedance to the intermediate frequency energy and being reactive thereby producing a voltage the phase of which varies with respect to the voltages of the frequency modulations on said intermediate frequency energies and means connected with said reactive impedance for displacing said voltage produced therein from anti-phase relation with respect to the voltages produced in said resistive impedance and for adding said potentials in said impedances to produce a resultant the amplitude of which is characteristic of the frequency modulations on said wave.

7. A circuit for converting frequency variations on a carrier wave into amplitude variations comprising, a pair of impedances connected in series a circuit connected to the free terminals of said impedances for applying the wave to the terminals of said impedances, one of said impedances being resistive and providing a constant impedance to the wave and a phase angle in the produced voltages which does not change with changes in frequency of the wave, the other of said impedances being of constant impedance to the wave and being reactive thereby producing a phase in the produced voltages therein which varies with respect to potentials in said wave, reactive means coupled to said reactive impedance

for reversing the phase of its produced voltage, and circuit means connected to said impedance and said reactive means for adding said potentials to produce a resultant, the amplitude of which is characteristic of the frequency modulations on said wave.

8. In means for converting frequency modulations on a carrier wave into amplitude modulations characteristic of the frequency modulations, a plurality of impedance elements connected together, means connected with said impedance elements for applying said frequency modulated wave to said impedance elements, one of said impedance elements offering a substantially constant impedance to said wave and producing a constant phase angle in the voltage set up therein by said applied wave with respect to the voltage of said applied wave, another of said impedances offering a substantially constant impedance to said applied wave and producing voltages the phase of which varies with respect to the voltages of the applied wave, and means connected with said impedance elements for combining the potentials so produced.

9. In means for converting frequency modulations on a carrier wave into amplitude modulations characteristic of the frequency modulations, a pair of impedance elements connected together, means connected with said impedance elements for applying said frequency modulated wave to said impedance elements, one of said impedance elements offering a substantially constant impedance to said applied wave and producing a constant phase angle in the voltage produced therein with respect to the voltage of said applied wave the other of said impedance elements offering a substantially constant impedance to the wave and producing voltages the phase angle of which is shifted with respect to the phase of the applied wave, means connected with said last named impedance element for reversing the phase of the last produced voltage, and means connected with said impedance elements and with said last named means for combining the voltage of reversed phase with the other produced voltage.

10. In means for converting frequency modulations on a carrier wave into amplitude modulations characteristic of the frequency modulations, a pair of impedance elements in series, means for applying said wave to the terminals of said series elements, one of said series elements being of constant impedance to the varying frequencies of the carrier wave so that the potentials produced therein are of constant phase angle with respect to the potentials of the applied carrier wave, the other of said impedance elements being of substantially constant impedance to the varying frequencies of said applied wave but producing potentials in said last named impedance element which vary in phase angle with respect to the phase angle of the potentials in said applied carrier wave, means connected with one of said elements for reversing the phase of one of the produced potentials, and means connected with said elements for combining the potentials of reversed phase with the other potentials algebraically.

11. A radio frequency receiver including a wave demodulator and a source of oscillations coupled thereto, an ohmic resistance, a parallel tuned circuit connected in series with said ohmic resistance, means connecting the output of said demodulator with the remaining terminals of said resistance and tuned circuit, means for tuning said parallel circuit to substantially resonance at an intermediate frequency, an electron discharge tube, and means for coupling the input electrodes of said tube to said resistance and said parallel tuned circuit, said coupling means including means for reversing the phase of the intermediate frequency potentials produced across said parallel tuned circuit.

12. The method of demodulating waves the frequency of which varies in accordance with signals which includes the steps of, producing voltages characteristic of the wave, the amplitude and phase of which voltages are constant with respect to the voltages of the wave to be demodulated, producing voltages, of a frequency equal to the frequency of the first produced voltages, the amplitudes of which are constant relative to the amplitude of the wave to be demodulated, and the phase of which latter voltages varies with respect to the phase of the voltages of the wave to be demodulated as the frequency thereof varies, and combining said produced voltages to obtain resultant voltages the amplitude of which varies as the frequency of the wave to be demodulated varies.

13. The method of demodulating waves the frequency of which varies in accordance with signals which includes the steps of, producing voltages, characteristic of the wave, the amplitude and phase of which are constant with respect to the amplitude and phase of the voltages of the wave to be demodulated, producing voltages of an amplitude substantially equal to the first produced voltage which amplitude is substantially constant relative to the amplitude of the voltages of the wave to be demodulated and the phase of which latter voltages varies with respect to the phase of the voltages of the wave to be demodulated in accordance with the variations in the frequency of the wave to be demodulated, and combining said produced voltages to obtain resultant variations the amplitude of which vary as the frequency of the wave to be demodulated varies.

14. In a system for demodulating a wave modulated in frequency in accordance with signals, an ohmic resistance, a tuned circuit connected in series with said ohmic resistance, the absolute impedance of said tuned circuit being substantially equal to the absolute impedance of said resistance for wave energy of a frequency substantially equal to the frequency to which said circuit is tuned, means connected with said series connected resistance and tuned circuit for applying thereto frequency modulated wave energy of a mean frequency substantially equal to the frequency to which said tuned circuit is tuned, and means for deriving a resultant of the voltages produced in said series resistance and tuned circuit.

15. In a device for converting frequency modulations of a carrier wave into corresponding potential variations, a resistive impedance and a reactive impedance connected in series, a circuit connecting the remote terminals of said impedances to a source of frequency modulated wave energy, means for tuning said reactive impedance to substantially resonance at the mean frequency of the wave energy of said source, and means responsive to potential variations connected in shunt to a portion of both of said impedances.

16. A radio receiver including a wave demodulator and a source of oscillations coupled thereto, an ohmic resistance, a parallel tuned circuit connected in series with said ohmic resistance, means connecting the output of said demodulator

with the remaining terminals of said resistance and tuned circuit, means for tuning said parallel circuit to substantially resonance at an intermediate frequency, an electron discharge tube and means for coupling the input electrodes of said tube in shunt to a portion of said resistance and said parallel tuned circuit.

17. In a system for demodulating wave energy modulated in frequency at signal frequency, an ohmic resistance, a parallel tuned circuit, a connection between one terminal of said ohmic resistance and a point on said parallel tuned circuit, means for applying frequency modulated wave energy to be demodulated between the other terminal of said ohmic resistance and a point on said parallel tuned circuit, said wave energy being substantially equal to the frequency to which said parallel tuned circuit is tuned, and a utilization circuit coupled between a point on said resistance and a point on said tuned circuit.

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