June 27, 1939. M. G. CROSBY 2,163,747

FREQUENCY MODULATION RECEIVER

Filed Oct. 30, 1937

Fig. 1

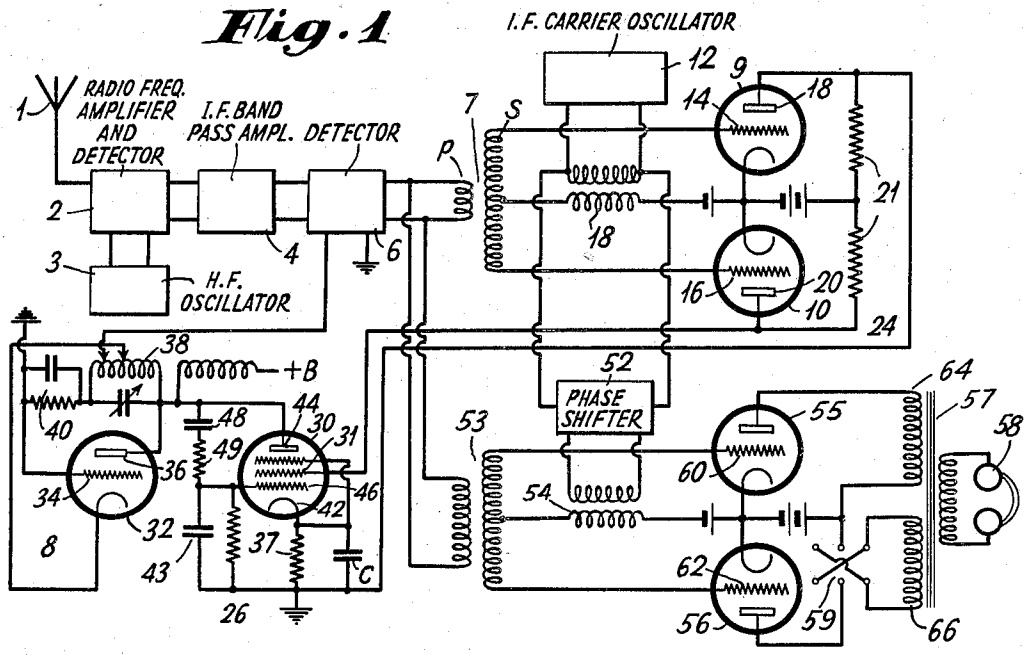
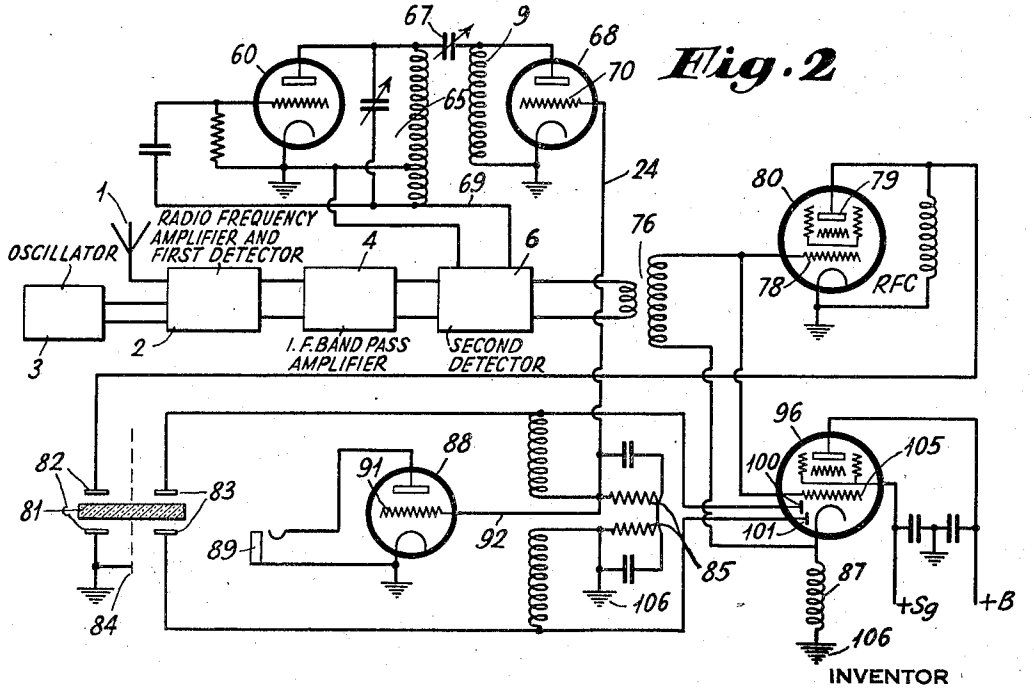


Fig. 2



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FREQUENCY MODULATION RECEIVER

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14 Claims. (Cl. 250—20)

This disclosure concerns a frequency modulation receiver of the type wherein a phase modulation receiver is employed and a correction is applied to convert the phase modulation output to a frequency modulation output. However, instead of applying the correction at the audio frequency output or at the intermediate frequency as has been done in the past, the correction is applied as a frequency modulation of a heterodyne oscillator at such a phase as to oppose or cancel the modulation on the incoming wave to the degree required to convert the output from a phase modulation output to a frequency modulation output.

In the prior art, frequency modulation has been received on a sloping filter receiver in which the frequency deviations are converted to amplitude deviations by the sloping filter. Conventional amplitude modulation detection methods are then employed to detect the resulting amplitude modulation. Crosby United States Patent #2,060,611 dated November 10, 1936; application #114,894 filed December 9, 1936, Patent #2,154,398, patented April 11, 1939; and Crosby application #114,778 filed May 26, 1937, Patent #2,138,341, patented November 29, 1938 describe this type of receiver.

Frequency modulation is also received on retard circuit receivers wherein the modulated wave is divided into two parts one of which is passed through a retard circuit and recombined with the unretarded wave. The resulting amplitude modulation is then detected by the ordinary methods. Crosby application #618,154 filed June 20, 1932; Patent #2,065,565 dated December 29, 1936; and Patent #2,087,429 dated July 20, 1937, describe such receivers.

A third method of receiving frequency modulation is by means of a corrected phase modulation receiver. Due to the inherent similarities between frequency and phase modulation, frequency modulation may be received on a phase modulation receiver, but the output will be distorted with respect to the amplitudes of the various modulation frequencies. The audio output will be inversely proportional to the modulation frequency so that the lower modulation frequencies will appear overmodulated and the higher frequencies undermodulated. To correct this distortion, an audio correct circuit may be inserted in the receiver output terminals which attenuates the output frequencies inversely proportional to the frequency. In other words the correction circuit would diminish the output of the lower modulation frequencies and increase that of the higher frequencies. In this way the distortion caused due to the fact that the frequency modulation was being received on a phase modulation receiver is compensated for.

The receiver of this disclosure employs a phase modulation receiver to receive frequency modulated waves, but instead of applying an audio correction, a form of correction is applied which effectively "unmodulates" the intermediate frequency of the receiver by the requisite amount to make the receiver output faithful to the true modulation applied at the frequency modulation transmitter. In order to accomplish this effect, part of the output of the phase modulation detector is utilized to frequency modulate an oscillator of a superheterodyne receiver. This modulation is applied to the said oscillator at such a phase as to modulate the resulting intermediate frequency of the receiver in such a direction that the modulation on the intermediate frequency is decreased. In general, the direction of modulation of the oscillator is the same as the modulation already present on the wave due to the frequency modulation at the transmitter. The phase modulation detector has an output when receiving frequency modulated waves wherein the low modulation frequencies are over accentuated (amplitudes inversely proportional to frequency). When these potentials having these characteristics are used to modulate the oscillations used for beating purposes, the lower frequency potentials have greater effect, being of relatively greater amplitude than the higher modulation frequencies. This, in effect, straightens out the demodulation characteristic of the receiver which without my novel method and means is adapted to phase modulation reception and with my method and means to frequency modulation reception. Consequently, the said frequency modulation of the intermediate frequency is effectively "unmodulated" into phase modulation so that the receiver is receptive to frequency modulation.

In describing my method and means for receiving frequency modulated waves, reference will be made to the attached drawing wherein both figures each show receivers including the elements essential to operation in accordance with the principle outlined above.

The circuit of Figure 1 shows a specific embodiment wherein a phase modulation receiver of the synchronized local oscillator type is utilized. Units 1, 2, 3, and 4 make up a conventional superheterodyne type of receiver. The intermediate

frequency energy from amplifier 4 is fed to a second detector 6 connected with a second local oscillator 8 and from the output of the second detector 6 to differential detectors 9 and 10 via transformer 7, the primary P of which is coupled to 6 and the secondary S of which is coupled to the grids 14 and 16 of tubes 9 and 10. Intermediate frequency energy from oscillator 12 is also fed to the grids 14 and 16 of these differential detectors via common leg transformer 18. In operation, the frequency of 3 and 8 and 12 are such that the mean frequency at the output of 6 is equal to the mean frequency of 12. In other words the output of 6 is synchronized with the oscillations produced by 12. The differential detector output energy supplied from the anodes 13 and 20 which appears across resistors 21 operates through circuit 24 to frequency modulate the oscillator 8. This differential detector energy varies in accordance with the phase deviations between the carrier oscillator 12 and the output of second detector 6. The operation of this type of differential detector is more completely described in Crosby Patent #2,065,565 dated December 29, 1936. In brief, these detectors produce a detected voltage which has one polarity when the phase between the frequency modulated intermediate frequency energy and the oscillations from the carrier oscillator 12 deviates in one direction, and a voltage of opposite polarity when this phase deviates in the other direction. Consequently, by applying this detected voltage to the grid of a modulator tube, say in 26, which modulates the frequency of the high oscillator 8, a frequency correction may be applied to the said oscillator which will bring the intermediate frequency at the output of 6 back into synchronism with the oscillations from oscillator 12. The oscillator 8 and the modulator 26 may be of any type. For example, modulators of the reactance tube type such as shown in my United States applications #165,056 filed September 22, 1937 and #167,344 filed October 5, 1937, Patent #2,156,374, patented May 2, 1939 and Patent #2,156,375, patented May 2, 1939, respectively, may be used with any oscillator such as for example an oscillator as shown in said application.

In ordinary automatic tuning or frequency control practice, a time constant circuit is inserted in the leads 24 to the modulator 26 of the high oscillator 8. This is to prevent the signal variations due to the applied modulation from varying the frequency of the high frequency oscillator and to allow only the slow and more gradual drifts from synchronism to operate the control. However, in the present receiver this time constant circuit is eliminated and the signal modulations in the output resistors 21 of detectors 9 and 10 is allowed to act through the modulator 26 to modulate the high frequency oscillator. This step is that one which enables this type of receiver to receive frequency modulation. The frequency modulation which normally comes in at the intermediate frequency is automatically corrected to phase modulation in a manner similar to that in which an automatic volume control with a fast time constant removes amplitude modulation. The normal output of the phase modulation detectors would be very strong in low modulation frequencies and weak in the highs due to the fact that frequency modulation was being received on a phase modulation detector. When this output is fed back to the high frequency oscillator to "unmodulate" it, the depth of modulation for the lower modulation frequencies of the intermediate frequency modulated wave is reduced to a value which makes the modulation phase modulation.

The potentials appearing in resistors 21 are supplied by way of circuit 24 to a controlling grid 31 and cathode 42 of a tube 30 in the modulator. The tube 30 is a reactance tube and controls in a manner which will now be described the frequency of the oscillations produced by the oscillator 8. The oscillator 8 is of the grounded grid type and includes a tube 32 having its grid 34 and anode 36 coupled in a frequency stabilizing and regenerative circuit 38 as shown. A point on the circuit 38 is coupled to the detector in 6, this circuit being completed by way of ground. The grid end of circuit 38 is also grounded for radio frequency by connecting one end of the grid leak and condenser arrangement 40 to ground. The reactance tube 30 has its anode 44 coupled to its grid 46 by phase shifting condenser 48 and resistance 49. The grid 46 is connected to the cathode 42 by way of bias resistor 37 and condenser 43. The anode 44 is coupled to the high potential end of 38 while the cathode 42 is grounded by by-pass condenser C. The value of resistance 49 is high as compared to the reactance of condenser 43 for the frequency produced in 38 so that the current through this circuit is largely resistive and is in phase with the voltage. However, the voltage drop through 43 leads the current by substantially 90° and a phase quadrature relation between the radio frequency potentials on anode 44 and grid 46 necessary for the reactive effect is obtained. The tube reactance, that is, the reactance tube 30, shunts the circuit 38 and consequently the reactance tube controls to some extent, the frequency of oscillations produced by 32 and 38. This reactive effect which may be considered inductive or capacitive is in turn controlled by the potentials supplied from 24 to the grid 31 of tube 30. The potential supplied to 31 varies in accordance with the potentials in 21 which in turn are characteristic of frequency modulations on the wave energy as converted by a phase modulated wave demodulator. These potentials, accordingly, act through reactance tube 30 to unmodulate the oscillations produced in tube 32 and circuit 38. Since the plate 44 is connected to the plate 36 and the grid 46 is excited by voltages displaced in phase relative to the voltages in circuit 38 the plate current in tube 30 is likewise out of phase with the voltage in 38 and the control tube 30 looks like a reactance to the circuit 38.

Similar arrangements have been shown in my United States application #124,967 filed February 10, 1937, Patent #2,065,565 dated December 29, 1936, Patent #2,085,008 dated June 29, 1937, application #136,578 filed August 13, 1937, application #209,919 filed May 25, 1938, application #167,344 filed October 5, 1937, Patent #2,156,375, patented May 2, 1939.

The above "unmodulating" circuit converts the intermediate frequency of the receiver from frequency modulation to phase modulation. Hence, the phase modulation detectors 55 and 56 will receive the modulation without distortion. Oscillations from 12 are supplied by phase shifter 52 to 54 in phase on the grids 60 and 62. Signal modulated waves are supplied from the output of 6 in phase opposition to the grids 60 and 62 from 53. The anodes of 55 and 56 are connected to primaries 64 and 66 of transformer 57. Phase adjuster 52 enables the reception of either amplitude or frequency modulation. Since the phase

detectors 9 and 10 would be insensitive to applied amplitude modulation, there would be no "unmodulating" effect due to amplitude modulation and the detectors 55 and 56 would only function as automatic frequency control detectors. Then carrier exalted amplitude modulation reception could be effected by either adjusting in 52 the carrier from 12 at 90° with the intermediate frequency energy from 6 and throwing switch 59 to the parallel position, or by adjusting the carrier to 0° in one detector and 180° in the other with switch 59 in the push-pull connection. The output of detectors 55 and 56, combined in transformer secondary 57, is made available for utilization in phones or other utilization device 58.

The receiver of Figure 2 employs a phase modulation receiver of the carrier filter type. By this is meant that the synchronized oscillator 12 of Figure 1 has been dispensed with and the modulated wave carrier isolated and used in place of the locally produced synchronous oscillations. Units 1, 2, 3, 4, comprise a heterodyne receiver including a bandpass intermediate frequency amplifier 4 which is tuned to pass the frequency modulated wave energy of lower frequency. The oscillator tube 60 and circuit 65 comprising a variable condenser and inductance connected as shown, the oscillator 60 and line 69 with the detector 6, constitute a superheterodyne receiver. Tube 68 is the frequency modulator tube for the oscillator 60. This tube varies the effective capacity produced by condenser 67 when a variation of the voltage of grid 70 varies the plate resistance of the tube 68. The output of the second detector 6 is fed via transformer 76 to the grid 78 of coupling tube 80 and from the anode 79 of 80 to the input electrodes 82 of a four electrode crystal filter. 81 is the crystal. Shield 84 shields the crystal input electrodes 82 from the crystal output electrodes 83 so that capacitive coupling is eliminated. The output electrodes 83 of the crystal filter feed energy from which all modulations have been removed or stripped to the anodes 100 and 101 of the duplex-diode-pentode tube 96 in a push-pull manner much the same as transformer 7 of Figure 1 operates to feed unfiltered energy to the grids 14 and 16 of the triodes 9 and 10, instead of diode detectors as in Figure 2. The unfiltered energy is fed to the diode differential detector by feeding it to the grid 105 of the pentode part of tube 96 so that it appears on cathode choke 87. By feeding the unfiltered energy in the cathode circuit in this manner, the same result as that of the "common leg" transformer 18 of Figure 1, is accomplished. The diode detector energy is taken from resistors 85 connected in shunt to 100 and 102 and grounded at 106 and fed via line 24 to the grid 70 of tube 68 to control its output reactance which shunts the frequency determining circuit 65 of 60 and "unmodulates" the oscillator 60. Since there is an inherent phase shift of 90° in this type of crystal filter, there is no need for a phase shifter in this circuit because the phase quadrature relation between the energy direct from 76 and the energy from 76 passed by the crystal is inherently obtained in the crystal. The detected audio output is taken from resistor 85 and fed via line 92 to the grid 91 of coupling tube 88 where it is made available for utilization at jack 89.

While it will be obvious that an unlimited selection of frequencies may be used in the various oscillators and for the received modulated wave and that I contemplate the use of all appropriate frequencies, I have found that it is satisfactory to use oscillators at 3 of such a frequency that the output of 2 and 4 is of about 460 kc. The modulated oscillators 28 and 60 may then operate at say, 560 kc. with an output from 6 of 100 kc.

It is understood that the above described embodiments omit all details which would be common practice in the art of frequency and phase modulation reception. For instance, an amplitude limiter could be inserted in both circuits following the intermediate frequency amplifier. Also any type of phase modulation receiver, such as those of Crosby's United States Patent #2,114,335 dated April 19, 1938; Patent #2,064,106 dated December 15, 1936; Patent #2,112,881 dated April 5, 1938; application #124,967 filed February 10, 1937; and Patent #2,076,175 dated April 6, 1937, could be made to operate as frequency modulation receivers in the manner described in this disclosure.

By applying an audio or intermediate frequency correction, such as are described in Crosby United States application #618,154 filed June 20, 1932, and application #124,967 filed February 10, 1937 respectively, the receivers of this disclosure may be corrected so that they will receive phase modulation. For instance, an audio circuit, which amplifies the output frequencies inversely proportional to frequency, could be inserted in the output leads of either receivers of this disclosure, or any other employing the ideas herein disclosed, so as to make the receiver receive phase modulation. This appears to be a rather round-about way of receiving phase modulation—that is, "unmodulating" a phase modulation receiver to make it receive frequency modulation and then applying a correction circuit to make it receive phase modulation again. However, there are advantages in this process. One advantage is in the fact that automatic frequency control is enhanced. For instance in the case of the synchronized oscillator receiver of Figure 1, the audio frequency control circuit must be very faithful or an off-synchronism condition will cause an annoying audio heterodyne in the receiver output. By allowing the audio frequency control circuit to be "fast" in the manner of this "unmodulated-corrected" receiver, the audio frequency control has a better control capability.

The principle of operation here is equally applicable to systems for modulating an oscillator of a frequency modulated wave demodulator when the latter is to be used for phase modulated waves to unmodulate the said waves in such a manner that the output of the frequency modulated wave demodulator will be a correct representation of the signals used at the transmitter to modulate the wave. Normally when phase modulated waves are received on a frequency modulated wave receiver the resulting potentials vary in amplitude directly as the frequency of the modulating potentials vary. Thus, potentials are then fed back to the oscillator to modulate the same in a sense to cause the output potentials of the receiver to be truly representative of the modulating potentials used at the transmitter. In the claims the term "length modulation" has been used to cover both systems.

I claim:

1. In a wavelength modulated wave demodulating system in combination, a detector having electrodes including an output electrode, an alternating current circuit connected with certain

of said electrodes, an impedance connected with certain of said electrodes, means for impressing wavelength modulated wave energy on said alternating current circuit, the characteristic of said detector being such that the potentials on said output electrode vary in amplitude nonlinearly as the frequency of the modulations on the wave energy impressed on said alternating current circuit varies, and means for unmodulating said wave energy in accordance with said potentials.

2. In a frequency modulated wave demodulating system in combination, a detector having electrodes including an output electrode, an alternating current circuit connecting certain ones of said electrodes in an input circuit, an impedance connected with electrodes of said detector, means for impressing frequency modulated wave energy on said input circuit, the characteristic of said detector being such that the potentials on said output electrode vary in amplitude inversely as the frequency of the modulations on the wave energy impressed on said alternating current circuit varies, and means for unmodulating said wave energy in accordance with said potentials.

3. In a frequency modulated wave demodulating system in combination, a detector having input and output electrodes and having an alternating current circuit connected to its input electrodes and an impedance connected to its output electrodes, means for impressing frequency modulated wave energy on said alternating current circuit, the characteristic of said detector being such that the potentials across the impedance in the output thereof vary in amplitude inversely as the frequency of the modulations on the wave energy impresed on said alternating current circuit varies, and means for unmodulating said wave energy in accordance with said potentials.

4. Means for adapting a phase modulated wave receiver of the heterodyne type including a local oscillator coupled with a detector and a phase modulated wave demodulator coupled to the detector and responsive to the difference frequency, to the reception of frequency modulation comprising, means for impressing frequency modulated wave energy on said detector and frequency modulated wave energy of the difference frequency on said demodulator, and means for modulating the frequency of the local oscillator in accordance with potentials from the output of said phase modulated wave demodulator.

5. Means for adapting a phase modulated wave receiver of the heterodyne type including a local oscillator coupled with a detector responsive to frequency modulated wave energy and a phase modulated wave demodulator having an input coupled to the detector and responsive to the difference frequency and an output including an impedance, to the reception of the frequency modulated wave energy comprising, means for impressing frequency modulated wave energy on said detector, and means coupling said impedance to said oscillator to modulate the frequency of the same in accordance with the potentials produced in the output of said phase modulated wave demodulator and in a direction similar to the direction of frequency modulations on said waves.

6. Means for adapting a phase modulated wave receiver of the heterodyne type including a local oscillator coupled with a detector excited by frequency modulated wave energy and a phase modulated wave demodulator coupled to the said detector and responsive to the difference frequency, to undistorted reception of frequency modulated wave energy comprising an impedance connected with the output of said phase modulated wave demodulator, and a control circuit connecting said impedance to said local oscillator to control the frequency thereof in accordance with the potentials in the output of said demodulator and in a direction to unmodulate the frequency modulations on said wave energy.

7. Means for adapting a phase modulated receiver of the heterodyne type including a local oscillator coupled with a detector responsive to frequency modulated wave energy and a phase modulated wave demodulator having an input coupled to the detector and responsive to the difference frequency and an output including an impedance to the reception of the frequency modulated wave energy comprising, means including a reactance tube having control electrodes connected to said impedance and electrodes coupled to said oscillator to modulate the frequency of said oscillator in accordance with the potentials produced in the output of said phase modulated wave demodulator and in a direction similar to the direction of frequency modulations on said waves.

8. In a system for demodulating frequency modulated wave energy, in combination, a first detector with means for impressing frequency modulated wave energy thereon, a local oscillator coupled with said detector for producing with said frequency modulated wave energy a beat frequency, a second detector having an alternating current input circuit coupled to the output of said first detector and having an output circuit including an impedance, said second detector being excited by wave energy of beat frequency, the character of said second detector being such that the potentials in the output circuit thereof vary in amplitude inversely as the frequency of the modulations on the beat frequency impressed on the input circuit thereof, and means coupling the output of said second detector to said local oscillator to modulate the frequency of the same in a sense to unmodulate the frequency modulations on said wave energy of beat frequency.

9. In a system for demodulating frequency modulated wave energy in combination, a first detector with means for impressing frequency modulated wave energy thereon, a local oscillator coupled with said detector for producing with said frequency modulated wave energy a beat frequency, a second detector having an alternating current input circuit coupled to the output of said first detector and to a source of oscillations of a frequency substantially equal to the mean frequency of said beat frequency, said second detector having an output circuit including an impedance, said second detector being excited by frequency modulated wave energy of beat frequency and wave energy of the mean beat frequency, the character of said second detector being such that the potentials in the output circuit thereof vary in amplitude inversely as the frequency of the modulations on the beat frequency impressed on the input circuit thereof, and means coupling the output of said second detector to said local oscillator to modulate the frequency of the same in a sense to unmodulate the frequency modulations on said wave energy of beat frequency.

10. A system as recited in claim 9 wherein said source of oscillations comprises an oscillator

substantially synchronized with said mean beat frequency.

11. A system as recited in claim 9 wherein said source of oscillations comprises a crystal filter having an input fed by energy from the output of said first detector and an output coupled to said second detector.

12. In a system for demodulating frequency modulated wave energy in combination, a first detector with means for impressing frequency modulated wave energy thereon, said first detector having an output, a local oscillator coupled with said first detector for producing with said frequency modulated wave energy a beat frequency, a second detector having an alternating current input circuit coupled to the output of said first detector, and a second alternating circuit input including a highly selective filter coupled to the output of said first detector, said second detector having an output circuit including an impedance, said second detector being excited by wave energy of beat frequency and wave energy of said beat frequency as passed by said filter, the character of said second detector being such that the potentials in the output thereof vary in ampltiude inversely as the frequency of the modulations on the beat frequency impressed on the input thereof varies, and means coupling the output of said second detector to said local oscillator to modulate the frequency of the same in a sense to unmodulate the frequency modulations on said wave energy of beat frequency.

13. A system as recited in claim 12 wherein said filter shifts the phase of the energy passed thereby substantially 90°.

14. The method of demodulating alternating current, the frequency of which has been modulated in accordance with signals, including the steps of, beating said frequency modulated alternating current with oscillations, of a mean frequency substantially equal to the mean frequency of the said frequency modulated alternating current, in phase displaced relation, deriving from said beating action voltages which vary in amplitude inversely as the frequency of the signals used to frequency modulate said alternating current vary, and modulating the frequency of said oscillations used in said beating action in a sense to tend to make the derived voltages vary linearly in accordance with the frequency of the signals used for modulating the frequency of said alternating current.

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