June 13, 1944. M. G. CROSBY 2,351,192

FREQUENCY MODULATION RECEIVER

Filed March 13, 1942 2 Sheets-Sheet 1

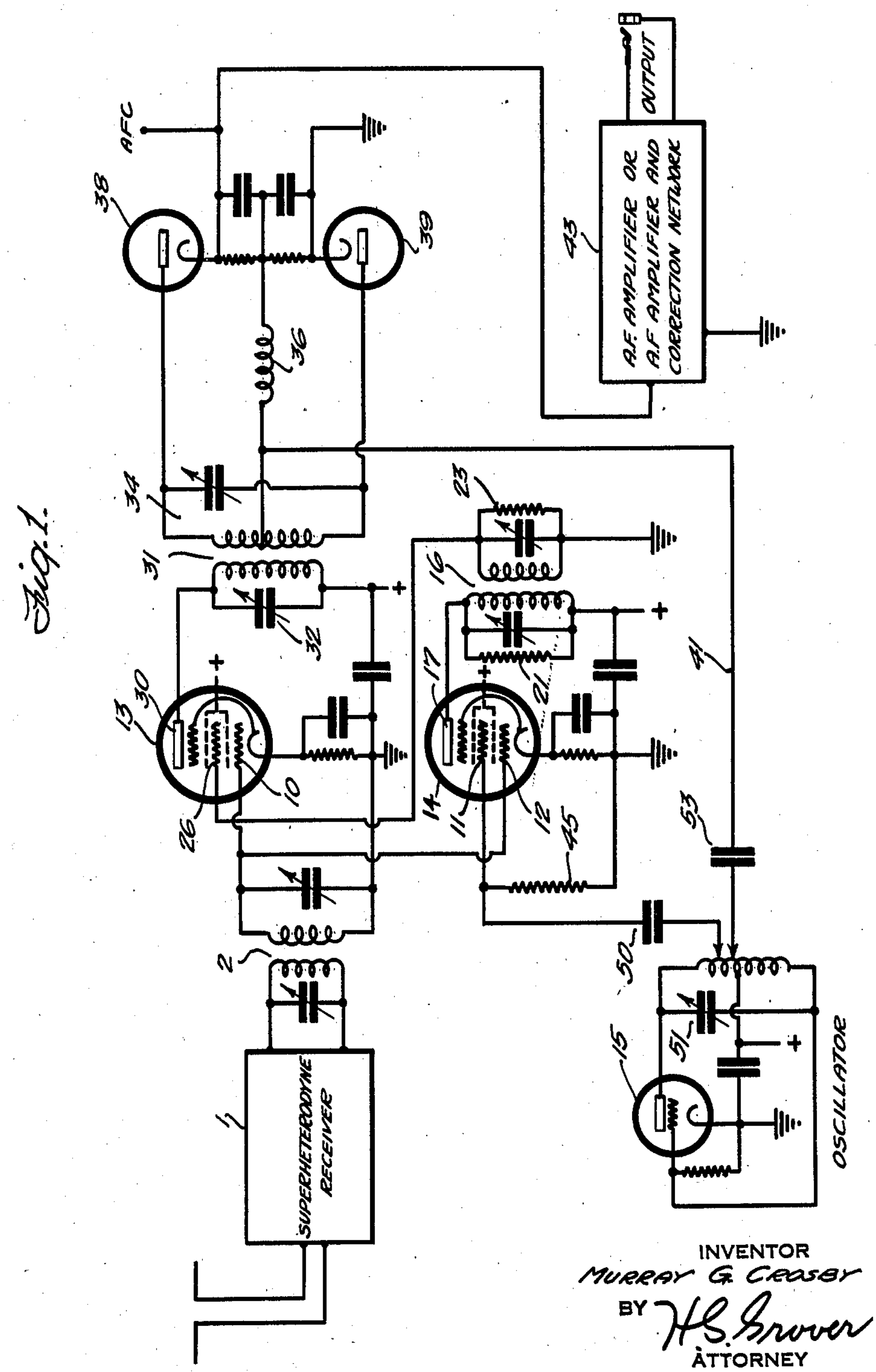

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Fig. 2a.

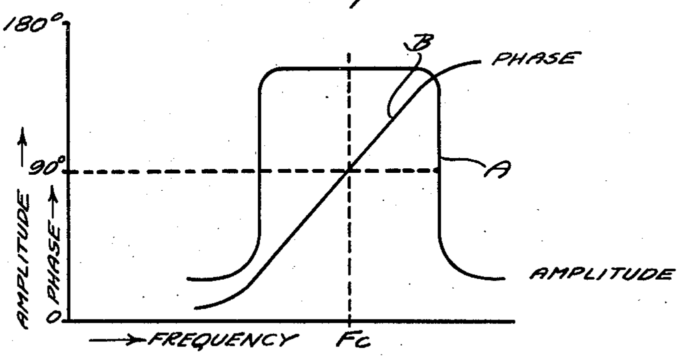


Fig. 2b.

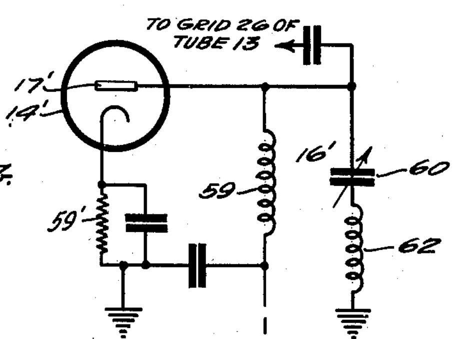
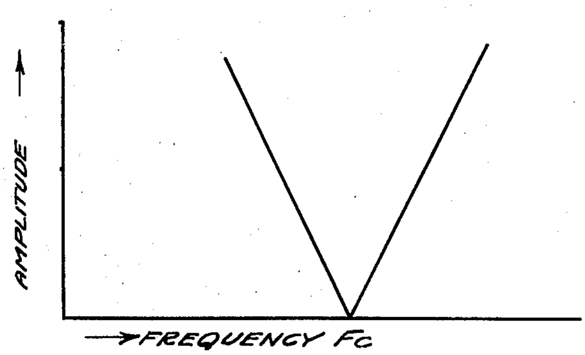


Fig. 2c.



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FREQUENCY MODULATION RECEIVER

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Application March 13, 1942, Serial No. 434,509

5 Claims. (Cl. 250—20)

This application concerns a frequency modulation receiver in which the incoming signal is heterodyned to another frequency and passed through a retard circuit to superimpose a variable phase shift with frequency upon the heterodyned wave. This wave is heterodyned again with the original signal in a manner that removes the frequency variations and leaves the phase variations that were superimposed. These phase variations are then detected to receive the original frequency modulation signal.

Another method of using this principle is also described which, instead of making use of the variable-phase-shift-with-frequency principle of Crosby U. S. Patent 2,229,640, dated January 28, 1941, makes use of the principles described in my U. S. Patent 2,060,611, dated November 10, 1936. In this latter system a carrier-rejecting circuit is substituted for the retard circuit.

In describing my invention more in detail reference will be made to the attached drawings wherein:

Fig. 1 illustrates the essential components of a frequency modulation receiver arranged in accordance with my invention;

Fig. 2*a* shows the characteristics of the phase retarding circuit 16 of Fig. 1;

Fig. 2*b* illustrates a modified form of circuit for deriving from the frequency deviations on the wave energy corresponding phase deviations on the wave energy;

Fig. 2*c* illustrates the characteristics of the circuit of Fig. 2*b*.

Fig. 1 shows a specific embodiment of the receiving system. Intermediate frequency output from a superheterodyne receiver 1 is applied through tuned transformer 2 to the grids 10 and 12 of respective converter tubes 13 and 14. The grid 11 of converter tube 14 is fed by local oscillator 15 with the result that in mixer tube 14 the incoming signal is heterodyned down to an intermediate frequency. Transformer 16, whose primary circuit is coupled to anode 17 of tube 14, is tuned to this intermediate frequency, and acts as a retard circuit to apply a variable phase shift with frequency to the frequency modulated intermediate frequency wave. This transformer 16 has a phase and amplitude characteristic which is shown in Fig. 2*a*. It is adjusted and damped by resistances 21 and 23 to produce a band-pass action, this being indicated by curve A of Fig. 2*a*. The phase characteristic for this adjustment is such that for the carrier in the mid-frequency position, the output phase is 90 degrees. As the frequency is modulated to either side of the carrier frequency, the phase is varied towards 180 or zero degrees.

This phase-frequency modulated wave is fed to the grid 26 of converter tube 13 which heterodynes the incoming signal of intermediate frequency fed to grid 10 with the phase-frequency modulated wave fed to grid 26. The output of converter tube 14 is the difference between a constant frequency wave (supplied by oscillator 15) and the frequency modulated wave supplied to grid 12 of tube 14 so that the output at transformer 16 is frequency modulated to the same extent to which the wave supplied to grid 12 is modulated. However, the output of converter tube 13 is the difference between the frequency modulated incoming wave on grid 10 and the frequency modulated output from converter tube 14 on grid 26 so that the difference is constant in frequency. This choice of heterodyne frequencies causes the resulting wave in the output of converter tube 13 to have the same frequency as oscillator 15. The output frequency from tube 13 has the phase modulation component imparted by the retard circuit but does not have the frequency variations of the original frequency modulated signal. This output is fed from plate 30 to tuned circuit 32, coupled to tuned circuit 34. The phase variations may then be detected by means of the phase detector consisting of transformer 31, choke 36, and diodes 38 and 39. The phase modulated energy from tube 13 is fed to the push-pull secondary of the input transformer 31 and the unmodulated carrier from oscillator 15 is fed by lead 41 to the common leg of this input circuit. These two waves are adjusted to be 90 degrees apart for the unmodulated condition with the carrier tuned to the middle of the retard circuit 16. Since transformer 16 imparts a 90 degree shift and transformer 31 imparts another 90 degree shift, further phase adjustment is necessary to produce the proper 90 degree relation between the phase modulated energy fed to tuned circuit 34 and the stripped carrier or oscillations fed in phase by lead 41 to the diodes 38 and 39. This may be accomplished by means of the adjustment of the size of coupling condenser 50 and resistor 45, or by variation of inductance 36 and coupling condenser 53, or by a combination of both. If desired, a further phase adjusting means may be inserted in either the lead in which 50 is inserted or the lead in which 53 is inserted.

The principle of operation of the type of phase detection which is used here is more completely described in my U. S. Patent 2,081,577, dated May 25, 1937. Any other type of phase modulation receiver may be used such as that of my U. S. Patent 2,114,335, dated April 19, 1938, or I may use the method described in my U. S. Patent 2,229,640 in which a frequency modulation receiver is converted into a phase modulation receiver by means of an audio correction network at the receiver output terminals. With these last mentioned receivers, the presence of the unmodulated carrier is not necessary so that the phase modulation detector is connected directly to the output of the converter stage, including tube **13**, and the lead **41** is omitted. The output of diode rectifiers **38** and **39** is now corrected as well as amplified in a stage or stages **43**.

Since my receiver may be used for detecting phase or frequency modulated waves and waves having the characteristics of both, the words phase and frequency modulation as used herein are to mean the various types of modulation wherein the instantaneous frequency of wave energy is varied as a function of modulating potentials. The generic expression "angle modulated" is employed to include these two types of modulation.

As an example of the operation of the circuit of Fig. 1, let it be assumed that the intermediate frequency fed to transformer **2** is 5 megacycles and that the frequency of oscillator **15** is 2 megacycles. The intermediate frequency appearing in retard circuit **16** will then be 3 megacycles and will be frequency modulated the same number of cycles as the original incoming signal. This 3 megacycle wave will have the phase variations imparted to it by retard circuit **16** so that the phase of the output will be proportional to the wave frequency at the input. The 3 megacycle wave is then heterodyned in tube **13** with the original 5 megacycle intermediate frequency to produce a 2 megacycle output which has the phase variations imparted by the retard circuit, but the frequency variations have been removed since the heterodyning frequency used in converter **13** had the same frequency variations as the output of **16** so that the difference frequency is constant. It will be apparent upon investigation that converter tube **13** must deliver the difference frequency, as distinguished from the sum of the frequencies in **2** and **16**, to its output circuit **31**. This insures that the heterodyne conversion removes the frequency modulation component of the wave from **16**. Converter tube **14** may deliver to transformer **16** the sum or difference frequency between the frequencies fed from transformer **2** and oscillator **15**.

Although a transformer with a band-pass characteristic is shown for the retard circuit **16** in Fig. 1, any type of band-pass or low-pass filter network may be used. Likewise a simple tuned circuit may be used at **16**. The main requirement is that the output phase vary with the frequency of the input.

Fig. 2*b* shows a circuit which may be substituted in place of the tuned transformer **16** of Fig. 1. This circuit comprises a plate supply choke **59**, and in parallel therewith a condenser **60** and inductance **62** which are series tuned to the carrier frequency. The choke **59** is connected at its upper end to anode **17′** of diode **14′**. The lower end of choke **59** returns to the grounded end of the diode cathode resistor **59′**. This type of circuit produces an amplitude-frequency characteristic as shown in Fig. 2*c*, since in the presence of carrier frequency output from tube **14** the series tuned circuit is of low impedance and its impedance increases as the carrier frequency deviates. The phase characteristic of this type of circuit is such that the polarity is reversed on either side of the carrier frequency; in other words, as the carrier goes through the frequency F_c, there is a 180 degree phase shift. With this type of characteristic, the combination with the unmodulated carrier in the phase modulation detector is such that the output of converter **13** subtracts from the unmodulated carrier from **15** on one side of the carrier frequency, F_c, and adds to the unmodulated carrier on the other side of F_c. This causes amplitude modulations with envelopes 180 degrees out of phase to be fed to the two diodes **38** and **39**. Further description of this type of phase detection is contained in my U. S. Patent 2,060,611.

Another way of looking at the operation of the circuit with the network of Fig. 2*b* replacing **16** is to consider the output of converter **13** as consisting of carrier-eliminated amplitude modulation. With the circuit **16** of Fig. 1 replaced by the circuit **16′** of Fig. 2*b* it can be seen that the output of converter **13** is carrier-eliminated amplitude modulation when it is realized that the output of the network is zero at carrier frequency and only allows an output to be produced when the frequency is modulated. The frequency variations are then removed in the heterodyning process effected by converter tube **13** so that the resulting output from mixer tube **13** is amplitude modulation sidebands with carrier removed. When these sidebands are re-combined in the circuits **34** with the carrier from oscillator **15**, the amplitude modulation is ready for detection. With this type of reception, the phase relation between the sidebands from mixer stage **13** and the carrier from oscillator **15** is adjusted so that amplitude modulations will be produced at the inputs of diodes **38** and **39**, which have their envelopes 180 degrees out of phase. This phase relation may be obtained by means of reactances **50** and **51**, or **53** and **36**.

What is claimed is:

1. In an angle modulated wave receiver, a wave frequency converter having an input and an output, a source of oscillations coupled to said input, connections for impressing angle modulated wave energy on said input, said energy having predominantly the characteristics of frequency modulation, a circuit which converts said angle modulations into corresponding phase deviations coupled to said output, a second wave frequency converter excited by said angle modulated wave energy and by wave energy passed by said circuit coupled to the output of said first converter, and a phase modulated wave demodulator coupled to said second wave frequency converter.

2. In receiver apparatus for converting wave length modulated wave energy having predominantly the characteristics of frequency modulation into wave length modulated wave energy having predominantly the characteristics of phase modulation and detecting said phase modulations, circuits for heterodyning said first mentioned wave energy with wave energy of substantially constant frequency, connections for passing the energy resulting from said heterodyning process through a circuit the electrical length of which varies with variations in frequency of the passed wave energy thereby to superimpose thereon modulation having the characteristics of phase modulated wave energy, a frequency converter for mixing said last named wave energy with said first mentioned wave energy, means for deriving wave energy having

predominantly the characteristics of phase modulated energy from said last mixing process, and a phase modulation demodulator responsive to said last named wave energy.

3. In a frequency modulated wave demodulator, a source of wave energy modulated in frequency in accordance with signals, a source of wave energy substantially constant frequency, a rectifier coupled to both of said sources for heterodyning wave energy from both of said sources to derive wave energy of a difference frequency, a circuit the electrical length of which varies with variations in frequency of the energy passed thereby, coupled to said rectifier, a second rectifier coupled to said last named circuit and to said first named source for heterodyning the wave energy passed by said circuit with frequency modulated wave energy from said first source to derive the difference frequency, and a phase modulated wave demodulator coupled to said second rectifier.

4. In a frequency modulated carrier wave receiver, a frequency converter having an input circuit and an output circuit, a source of local oscillations of high frequency coupled to said input circuit, a source of frequency modulated wave energy, connections for impressing said modulated wave energy on said input circuit, a retard circuit which converts frequency modulations into corresponding phase deviations coupled to said output circuit, a second frequency converter, means connected to the converter for exciting the latter by said modulated wave energy, additional means to excite the second converter by wave energy passed by said retard circuit, and a phase modulation detector circuit coupled to said second frequency converter.

5. In a receiver for converting modulated wave energy having predominantly the characteristics of frequency modulation into modulated wave energy having predominantly the characteristics of phase modulation, a source of said first named modulated wave energy, means for heterodyning said first modulated wave energy with wave energy of substantially constant frequency, connections for passing the modulated wave energy resulting from said heterodyning process through a retard circuit the electrical length of which varies with variations in frequency of the passed wave energy thereby to superimpose thereon modulation having the characteristics of phase modulated wave energy, a frequency converter for mixing said last named phase modulated wave energy with said first modulated wave energy, means for deriving modulated wave energy having predominantly the characteristics of phase modulated energy from said conversion process, and a phase modulation demodulator responsive to said last named phase modulated wave energy.

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