May 26, 1942. E. PETERSON 2,284,444

DEMODULATION CIRCUITS

Filed Aug. 27, 1940

FIG. 1

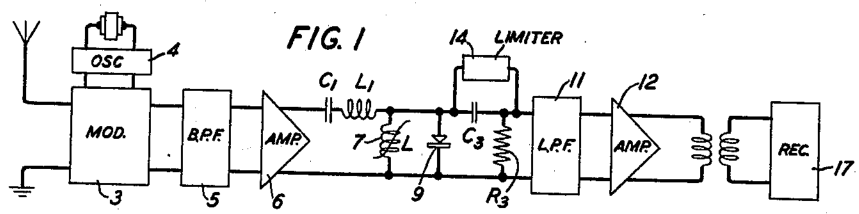


FIG. 3

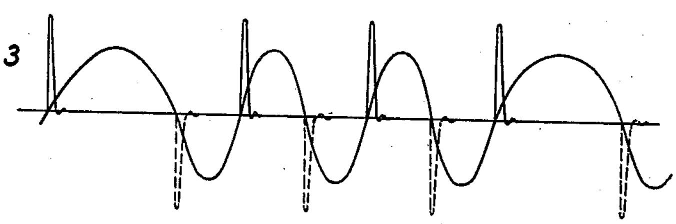


FIG. 2

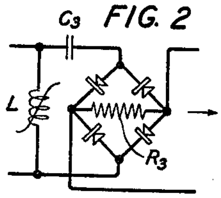


FIG. 4

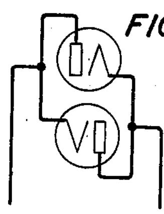


FIG. 5

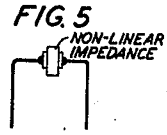
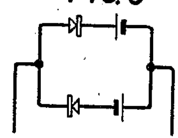


FIG. 6



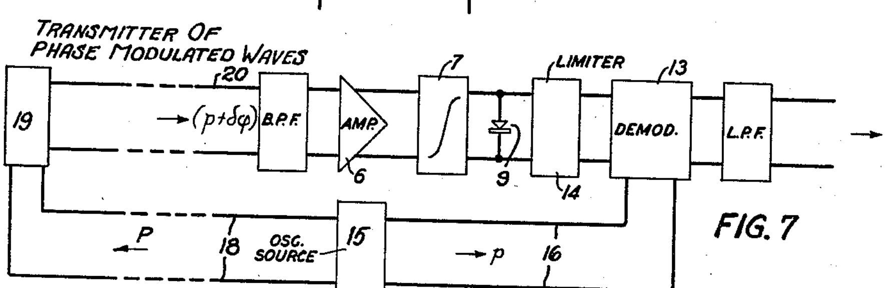


FIG. 7

FIG. 10

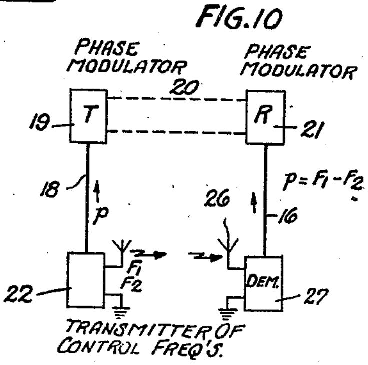


FIG. 8

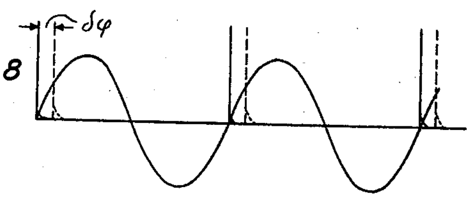
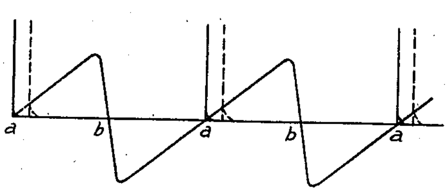


FIG. 9



INVENTOR
E. PETERSON
BY H. A. Burgess
ATTORNEY

Patented May 26, 1942

2,284,444

UNITED STATES PATENT OFFICE

2,284,444

DEMODULATION CIRCUIT

Eugene Peterson, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application August 27, 1940, Serial No. 354,351

9 Claims. (Cl. 250—20)

This invention relates to detection or demodulation of wave-length modulated waves, that is, frequency modulated or phase modulated waves, in high frequency signals and more particularly to circuit arrangements in which use is made of the properties of saturated core inductances of the type described in patent to Wrathall 2,117,752, May 17, 1938.

The purpose of the invention is to provide a means for securing a frequency indication or a phase indication and to this end I provide means whereby pulses are generated, the frequency of which is determined solely by the momentary frequency for frequency modulated waves, or the time displacements of which from normal or no signal condition is proportional to the momentary phase displacement in phase modulating waves. In order at the same time to render the received signal dependent solely on frequency or on phase modulation, use is made of amplitude limiting devices all in a manner hereinafter described.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which:

Fig. 1 is a diagram of a circuit adapted for demodulation or detection of a frequency modulated wave;

Fig. 2 discloses a modification of a part of the circuit of Fig. 1;

Fig. 3 shows curves for explaining the principles involved in the circuit of Fig. 1;

Figs. 4 to 6 are modifications of a detail of Fig. 1;

Fig. 7 shows a circuit adapted for detection or demodulation of a phase modulated wave;

Figs. 8 and 9 are curves for explaining the principles involved in the circuit of Fig. 6; and

Fig. 10 illustrates the generation of control waves and transmission thereof to a transmitting and a receiving station.

Referring more particularly to Fig. 1, there is shown an incoming circuit for a received frequency modulated wave, this incoming circuit being an antenna system, as shown, or an appropriate line circuit. The incoming wave may be impressed directly on a harmonic generator coil 7 or it may be first impressed on a modulator circuit 3 to which is also connected an oscillator 4 of controlled frequency, the frequency being so chosen that the output of the modulator will contain an intermediate carrier of frequency $p/2\pi$ with modulation side-bands extending over the same frequency swing as on the initially received wave. A band-pass filter 5 is connected to the modulator to pass this intermediate frequency and its side-bands, and the output of the band-pass filter is then impressed on a circuit containing the non-linear magnetic coil 7. This circuit is of the type described in the patent to Wrathall referred to above and possesses the property of generating sharp impulses of very short duration with one pulse for each positive loop and one in the reverse direction for each negative loop of the impressed wave. This is illustrated in Fig. 3 which shows schematically a short section of a frequency modulated wave. The generated impulses, also shown in this figure, occur very nearly at the time when the current wave in the coil is passing through its zero value. It is apparent that were one to integrate the effect of all of these pulses the result would be substantially zero. In accordance with one form of my invention, however, I connect across the coil 7 a rectifier element 9 which suppresses the impulses of the one sign and the integrated value of the remainder will be represented by a low frequency current in a translating device 17, the amplitude of the current being proportional to the number of pulses generated per unit of time and thus proportional to the momentary frequency of the original incoming wave. In another form of my invention I use both pulses by the full wave rectifier of Fig. 2. Obviously the output voltage across the resistance R_3 will contain high frequency components. These may be filtered out so far as the translating device 17 is concerned by a low-pass filter 11. Appropriate amplifiers, such as 6 and 12, may be inserted as desired.

In a frequency modulated wave it is desirable that there shall be no amplitude modulation present. Due to various imperfections, however, in the circuit or in the transmitting medium, variations in amplitude may enter. These effects largely disappear in using coil 7 but not entirely so, for it is found that the amplitude of the peaks generated by the coil is substantially proportional to the four-tenths power of the input.

In order to more fully eliminate the corresponding disturbances I find it desirable in some instances to associate with the circuit some amplitude limiting device such as that shown at 14. While such a limiting device may be introduced at any of various points in the circuit, I have shown it as bridged across the condenser C_3. In this case the limiting device may take on a variety of forms such as shown in Figs. 4 to 6. For example, in Fig. 4 the limiting device is shown as two diode rectifiers which will substantially prevent the voltage across condenser C_3 from rising above a specified value. In Fig. 5 the limiting device is shown as a thyrite resistor, and in Fig. 6 it is shown as two oppositely directed copper-oxide rectifiers connected in parallel and biased by suitable voltages so that they serve as virtually open circuits until the voltage over C_3 rises above a specified value.

In one mode of operation of magnetic harmonic generators the condenser C_3 is made very large and R_3 is made so large that it is virtually an open circuit, in which case practically no voltage is built up across the condenser and practically no current flows through R_3 so that voltage across R_3 is substantially the same as that across the non-linear coil L. This arrangement, which may be spoken of as open circuit operation, is found particularly advantageous if the circuit into which the coil works has a high input impedance. For the suppression of the pulses of one sign, if such suppression is used, the rectifier may be placed in series with R_3 or in parallel. In either case I find that the limiter for the purposes described above is not required, for if the instantaneous amplitude of the signal increases, due to such causes as noise, the magnetizing force in the coil rises more rapidly giving a higher reactance voltage but it sweeps over the range of high inductance of the coil in a shorter time, that is, the height of the generated peak is somewhat greater but its duration is less so that the area under the peak loop is substantially independent of the amplitude of the signal. It is these areas which are integrated in the translating device. Another way to express this is to note that under these conditions the average current through R_3 will be the same no matter what the incoming wave amplitude may be so long as it is above a certain minimum value. Thus under these circumstances the non-linear coil and its associated output current functions as a unitary self-limiting detecting device for a frequency modulated wave. In all cases and especially the one in which the rectifier is placed in series with R_3 it is desirable that the rectifier shall be a linear one or that it shall be operated in that part for which it is substantially linear.

My circuit arrangement for detection or demodulation of a phase modulated wave is illustrated in Fig. 7. Here again the incoming phase modulated wave received over line **20** from distant transmitter **19** is impressed on a harmonic generator **7** bridged by a rectifier element **9**, which latter suppresses impulses of one sign. In Fig. 8 the impulses are shown in full lines and as equally spaced, corresponding to the generation of the impulses when the incoming wave is not signal modulated. If, on the other hand, the incoming wave is phase modulated, then the timing of the impulses will be altered forward or backward in accordance with the phase of the modulated wave as shown by the dotted impulses.

It is apparent that the mere integration of these new pulses will not in itself give rise in a translating device to any appreciable signal current. In the circuit arrangement, however, I impress the pulses on a modulating element **13** on which there is also impressed a carrier frequency $p/2\pi$ from a source **15**. This carrier frequency must be precisely that of the incoming carrier frequency and is shown by the sinusoidal curve of Fig. 8. The phase of this locally introduced carrier frequency as applied to the demodulator **13** is so adjusted that the pulses from an unmodulated arriving wave occur at the time when the locally generated wave as applied to demodulator **13** is passing through its zero value. Under these conditions the modulation effects, which are proportional to the instantaneous cross-product of the two inputs, are substantially equal to zero. If, however, the pulses are displaced in time due to phase modulation, then the demodulation cross-product term is proportional to the instantaneous value of the locally introduced carrier, and thus the amplitude of the resultant low frequency wave is proportional to the momentary phase modulation of the incoming wave. In order to provide the precise agreement between the incoming carrier frequency and that produced at the receiver some of the wave from source **15** may be supplied over line **18** to the distant transmitter **19** to serve as the transmitting carrier wave from station **19**.

These facts may be readily shown by the following analysis:

Let the incoming wave be represented by

$$i=A\cos(pt+\delta\phi)$$

in which $\delta\phi$ is the phase displacement at any instant and for a phase modulated wave is given by

$$\delta\phi=KQ\cos qt$$

In this expression q is the varying frequency of the original signal, Q is the amplitude of this signal and K is a suitable proportionality factor to convert KQ into angular measurement and is the maximum phase shift for the phase modulated wave. When the incoming wave is impressed on the non-linear coil **7**, the output of the coil is made up of a series of terms represented by

$$\sum_1^n b_n \cos n(pt+\delta\phi)$$

This along with the locally introduced carrier is impressed on the demodulating element so that its input becomes

$$[\Sigma b_n \cos n(pt+\delta\phi)+C\sin pt]$$

In the output of the demodulator the terms of interest are primarily the cross-product terms

$$[\Sigma b_n \cos n(pt+\delta\phi)]\sin pt$$

Of these, all the alternating current cross-product terms are of carrier frequencies with their side-bands or harmonics thereof except the one corresponding to $n=1$. This term is the one low frequency term and appears as

$$\frac{b_1}{2}\sin(KQ\cos qt)$$

Furthermore, if the phase displacement is relatively small, that is, if $KQ\cos qt$ is small, this then becomes

$$\frac{b_1}{2}\left(KQ\cos qt-\frac{K^3Q^3}{24}\cos 3qt+\ \ldots\ \right)$$

showing that the low frequency output is substantially linear with respect to the original modulating wave, thus giving a good reproduction thereof.

The case thus treated is a special one but it may be generalized. If, for example, the locally introduced carrier is some harmonic of the frequency $p/2\pi$, such as the kth harmonic, then the input on the modulator will be given by

$$[\Sigma b_n \cos n(pt+\delta\phi)]\sin k\,pt$$

The only cross-product term which yields signal frequency will be that for which n is equal to k and this term appears as

$$\frac{b_k}{2}\sin(kKQ\cos qt)$$

A double advantage now becomes apparent. The first of these is the fact that the number of pulses per unit time will be increased by the factor k, thus increasing the strength of signal. The second is that the factor corresponding to the depth of modulation, or frequency swing, has been increased from KQ to kKQ, that is, has been increased by the factor k, representing a further increase in signal strength.

It should be apparent from inspection of Fig. 7 that the range of phase modulation over which the final output is substantially linear with respect to the original signal is that over which the instantaneous value of the locally introduced carrier frequency is substantially linear, that is, in the neighborhood of the cross-over points in the curve of Fig. 8. As sine θ departs from linearity, the distortion increases. It is possible, however, to increase very materially the range of linearity by altering the form of the locally introduced carrier frequency. This is illustrated in Fig. 9, which makes use of certain disclosures in copending application of Manley-Wrathall Serial No. 354,372, filed August 27, 1940, and consists in introducing in place of a sinusoidal carrier wave, a saw-toothed wave, as shown in Fig. 9. Any suitable method for obtaining such a saw-toothed wave from a sine wave is satisfactory, such as a relaxation circuit, and while in general it will not be physically possible to duplicate the ideal curve, any step towards this will permit an extension of the amount of phase modulation without appreciable departure from linear output. It should be noted that there would normally have been an impulse corresponding to the points b in Fig. 9, as well as the points a, but any disturbances due to these are eliminated by the rectifier element across the non-linear coil 7 whereby all pulses of one sign are suppressed.

It will be found from the above analysis that the best condition under which a cross-product term of signal frequency is obtained is when the locally introduced carrier frequency is 90 degrees out of phase with the incoming carrier frequency. Thus, since the incoming carrier frequency in the expressions above has been represented by a cosine function, the locally introduced term must be represented by a sine function. This brings out the necessity, as has already been referred to above, of properly phasing the local carrier frequency with respect to the incoming carrier frequency. The importance is also apparent of maintaining the locally generated frequency precisely in step with the incoming carrier frequency. In case my circuits are being used in connection with an extensive wire system, then it is evident that the carrier frequency to be locally introduced may be derived from a source of standard frequency which supplies this standard frequency to the transmitting station also. If such derivation of the locally introduced carrier is not feasible, then it may be obtained by radio transmission from some suitable station of two frequencies, the difference of which is equal to the desired carrier and is obtained by suitable demodulation circuits.

This is illustrated in Fig. 10 in which the transmitting station 19 at line 20 may be as in Fig. 7, leading in this case to a receiving station 21 which may contain apparatus similar to that at 7, 9, 14 and 13 of Fig. 7. A carrier wave of frequency p is supplied to station 19 over path 18 from a suitable source as in Fig. 7. For the purpose of supplying a local carrier wave to station 21 of proper frequency and properly phased with respect to the incoming carrier frequency, radio transmitter 22 is provided. This sends out two frequencies F_1 and F_2 whose difference frequency is equal to the frequency p. The two frequencies F_1 and F_2 are received in radio receiver 26, demodulated at 27 and the difference frequency p is supplied over path 16 to the receiving station 21.

What is claimed is:

1. In a receiving system for wave-length modulated waves, a demodulation circuit comprising a saturable core magnetic harmonic generator adapted to produce sharp positive and negative pulses, means for impressing thereon wave-length modulated waves of sufficient amplitude to cause saturation of the core of said harmonic generator for a part of each cycle to generate alternate positive and negative pulses timed in accordance with the received wave, means for suppressing pulses of the one sign whereby pulses of one sign remain variably spaced on a time axis in accordance with the wave-length modulation of the received waves, and translating means for producing low frequency output current varying in amplitude in accordance with the variable spacing of said pulses on the time axis.

2. In a demodulation circuit for phase modulated waves, a magnetic harmonic generator excited by received phase modulated waves for generation of positive and negative pulses, means for suppressing pulses of one sign, a demodulation element in the circuit on which the remaining pulses are impressed, and a source of unmodulated carrier frequency associated with the demodulating element, the output of the demodulator for each pulse being substantially proportional to its phase displacement with respect to its own carrier frequency.

3. In a demodulation circuit for phase modulated waves, a magnetic harmonic generator excited by received phase modulated waves for generation of positive and negative pulses, means for suppressing pulses of one sign, a demodulation element in the circuit on which the remaining pulses are impressed, a source of unmodulated carrier frequency associated with the demodulating element and so phased that there is substantially no demodulation product from pulses due to unmodulated waves but for other pulses the demodulation product is substantially proportional to their phase displacements.

4. The combination of claim 2, characterized by this, that the source of locally introduced unmodulated carrier frequency yields a saw-toothed wave whereby the demodulation output is linear with respect to phase displacement over a wider range.

5. The combination of claim 2, characterized in this that the locally introduced unmodulated carrier frequency is the kth harmonic of the incoming signal carrier frequency.

6. In the demodulation of a received phase modulated wave of the carrier frequency p, the method of demodulation which consists in impressing the received phase modulated wave on a peak producing device yielding harmonics of the incoming wave, suppressing all peaks in one direction, impressing the remainder on a demodulating element, impressing also on the de-

modulating element a locally introduced carrier frequency which is the kth harmonic of the signal carrier frequency, and deriving from the output of the demodulator the signal wave.

7. The combination of claim 6 further characterized in this that the method includes so shaping the locally introduced carrier frequency that it is saw-toothed in form whereby the region of linear demodulation is extended.

8. In a receiving system for waves the frequency of which has been modulated in accordance with signals, a demodulation circuit comprising a magnetic harmonic generator acting as a unitary self-limiting pulse generator, the generator including a non-linear, saturating core magnetic coil on which the received frequency modulated wave is impressed, a load circuit shunting the non-linear coil comprising a large capacitance and a large resistance in series and means to derive the signal from the generated pulses.

9. In a receiving system for waves the frequency of which has been modulated in accordance with signals, a demodulation circuit comprising a magnetic harmonic generator acting as a unitary self-limiting pulse generator, the generator including a non-linear, saturating core magnetic coil on which the received frequency modulated wave is impressed and a load circuit shunting the non-linear coil comprising a large capacitance, a large resistance in series and means for rectifying the currents flowing in the load circuit and means to derive the signal from the generated pulses.

EUGENE PETERSON.